Development and Evaluation of Optimal Blended E-learning and Simulation Educational Program for Procedural Training

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ABSTRACT

Knowledge and skill requirements during surgical training increase as surgical techniques and ethical considerations of patients' safety advance. Duty hour restrictions and the high-stakes nature of surgery challenge surgical educators to develop efficient and effective training programs. Education technology has been introduced into surgical training programs to address these issues. However, there is little published information about how to design a teaching program incorporating e-learning and evaluate the learning experience. This thesis aimed to identify current applications and unmet needs of education technology in general thoracic surgery and how to optimize the learning experience.

The literature review revealed a lack of high-level evidence regarding e-learning: there are few randomized controlled trials, and a variety of study designs and education technologies in general thoracic surgery. There is no standard assessment to evaluate the learning experience. The use of multimedia and interactivity in e-learning are perceived well by learners, possibly because these features improve cognitive load and usability. We hypothesized that designing a training program using an instructional design framework incorporating established learning principles, theories of cognitive load and usability would result in an optimized learning experience. We then developed a blended learning program for surgical residents combining a novel e-learning module and in-person simulation for chest tube insertion.

In a pilot study in advance of simulation, 13 first-year surgical residents were randomized: 7 received the e-learning module + reading materials (e-learning group); 6 received only reading materials (controls). Pre-and post-tests evaluated knowledge; skill was assessed during simulation using a Global Rating Scale by blinded assessors. Cognitive load and usability were assessed using rating scales.

We found significant improvements in knowledge from baseline in the e-learning group ($p=0.047$) but not controls ($p=0.50$). All residents in the e-learning group reached skill proficiency vs 60% controls ($p=0.07$). All domains of usability were rated high by all residents in the e-learning group. We observed a lower extrinsic and greater germane cognitive load ($p=0.04$, 0.03, respectively) in the e-learning group.

This thesis work fills important gaps identified by our review. The pilot study demonstrated that a blended learning program, combining e-learning with simulation, improved the learning experience, knowledge, and technical skill. Principles of instructional design, theories of cognitive load and usability were incorporated throughout the research. This thesis highlights a new teaching strategy in surgical education.

RÉSUMÉ

Les exigences en matière de connaissances et de compétences au cours de la formation en chirurgie augmentent à mesure que les techniques chirurgicales et les considérations éthiques sur la sécurité des patients progressent. De plus, en raison des restrictions liées aux heures de service et de la nature des enjeux de la chirurgie, il est difficile pour les formateurs en chirurgie de développer des programmes de formation efficaces. Certaines technologies ont été intégrées aux programmes de formation afin de pallier ces problèmes. Dans cette thèse, nous avons cherché à identifier les applications actuelles et les besoins non satisfaits en termes de technologie d'enseignement appliquée à la chirurgie thoracique générale, puis nous avons exploré différentes façons d’optimiser l'expérience d'apprentissage dans le cadre d’une étude pilote.

L’analyse des documents existants a révélé un manque de preuves probantes dans le domaine de l'apprentissage en ligne, il n’y a eu que peu d'essais contrôlés aléatoires, mais une grande variété de conceptions d'études et de technologies éducatives appliquées à la chirurgie thoracique générale. L'utilisation du multimédia et de l'interactivité dans l'apprentissage en ligne est bien perçue par les apprenants, peut-être parce que ces caractéristiques améliorent la charge cognitive et l’ergonomie. Nous avons émis l'hypothèse qu'un programme de formation reposant sur un cadre de conception pédagogique intégrant des principes d'apprentissage établis, des théories de charge cognitive et d’ergonomie optimiserait l'expérience d'apprentissage. Nous avons ensuite élaboré un programme d'apprentissage mixte pour les résidents en chirurgie, combinant un nouveau module d'apprentissage en ligne et une simulation en personne de l'insertion d'un drain thoracique.

Dans le cadre d'un essai pilote aléatoire et contrôlé, les participants se sont vus attribuer soit le module en ligne et des documents de lecture (groupe en ligne), soit les documents de lecture

uniquement (groupe témoin), avant une simulation pratique d'insertion de tube thoracique. Les connaissances ont été évaluées par des tests antérieurs et postérieurs avec des questions à choix multiples, et les compétences à l'aide d'une échelle d'évaluation globale par des évaluateurs en aveugle lors de la simulation. L'ergonomie et la charge cognitive ont été évaluées à l'aide d'échelles d'évaluation. Treize résidents en chirurgie de première année inscrits à la Fondation chirurgicale de l'Université McGill ont accepté de participer à cette étude. Un résident du groupe témoin n'a pas terminé l'étude et a été exclu. Les données de sept résidents du groupe en ligne et de cinq résidents du groupe témoin ont été analysées.

Nous avons constaté une amélioration significative des connaissances par rapport au niveau de base dans le groupe en ligne (p=0,047), mais pas dans le groupe témoin (p=0,50). Tous les résidents du groupe en ligne ont réussi à maîtriser les compétences, contre 60 % des membres du groupe témoin (p=0,07). Tous les résidents du groupe en ligne ont donné une note élevée à l'ensemble des domaines d'ergonomie. Nous avons observé une charge cognitive extrinsèque plus faible et une charge cognitive pertinente plus importante (respectivement p=0.04 et 0.03) au sein du groupe en ligne.

Cette thèse vient combler des lacunes quant à la documentation sur la formation chirurgicale identifiées par notre analyse. L'étude pilote a démontré qu'un programme mixte, combinant un module en ligne et une simulation en personne, a permis d'améliorer l'expérience d'apprentissage, les connaissances et les compétences techniques. Les principes de conception pédagogique, les théories de charge cognitive et d'ergonomie ont été intégrés tout au long de la recherche. Cette thèse met en évidence une stratégie d'enseignement nécessaire dans le domaine de la formation chirurgicale qui, grâce à sa flexibilité, pourrait contribuer à alléger les contraintes de temps des stagiaires.

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CONTRIBUTION OF AUTHORS

Dr. Junko Tokuno, the candidate, contributed to all aspects of the thesis, including the literature review, design of the trial protocol, development of the e-learning module, data acquisition, statistical analysis, results interpretation, and manuscript writing. The candidate had full access to all the data and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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CHAPTER 1. INTRODUCTION

1.1 Introduction

The advancement of surgical procedures in the last three decades, such as minimally invasive surgery, brought tremendous positive impact on clinical outcomes [1-3], while also increasing the amount of skills and knowledge surgical trainees must master. Simultaneously, due to the growing concern of patient safety and duty hour limitations, training opportunities in clinical environments have been restricted [4, 5]. To address these issues, reconsideration of educational interventions became necessary and simulation training was introduced and became widespread [6-8].

Despite these advances, it can be challenging to motivate surgical trainees to engage in traditional simulation training programs, while they are occupied with clinical duties. In addition, it is not always easy for trainees to reach and exceed the thresholds of proficiency of knowledge and technical skills with only one-time simulation training. For example, high complication rates of chest tube insertion among residents who received simulation training have been reported [9].

A variety of education technologies, or digital education, have been used in surgical simulation training including online platforms, such as e-learning, enabled remote, asynchronous and/or repeatable learning [10, 11]. This delivery method provides flexibility of learning and is expected to improve the learning experience of trainees, potentially leading to efficient self-directed learning. For procedural training, blended learning, in which an e-learning module is provided as preparation for in-person simulation training, can be an alternative teaching strategy to improve trainees' proficiency and learning experience. This new learning experience may involve challenges in human-computer interactions and a risk of increasing cognitive load [12, 13] given it requires learners to learn how to use the education technology (e-learning), as well as the original learning tasks.

In this thesis work, our aim was to evaluate the use of this delivery method by developing a blended learning program combining an e-learning module and in-person simulation training for procedural training of chest tube insertion.

1.2 Thesis Objectives

The specific objectives of this thesis were:

(1) to identify the current applications and unmet needs of digital education, searching published articles in general thoracic surgery, a representative field of surgery characterized by high-stakes procedures. We hypothesized that online digital education delivered as part a blended learning program, prior to in-person simulation training would be especially effective for teaching complex procedural tasks.

(2) to develop an e-learning module for procedural training using a framework of instructional design and to provide the module within a blended learning program, with hands-on simulation training to optimize the learning experience.

(3) to evaluate the learning experience using variables of usability and cognitive load, as well as knowledge and skill.

1.3 Thesis Organization

Chapter 2 contains the first manuscript, “Digital Education in General Thoracic Surgery: A Narrative Review” [14] to describe the current application and unmet needs of digital education in general thoracic surgery, which provides rationale for the pilot study.

Chapter 3 contains the second manuscript, “Cognitive Load in Surgical Education”, which describes the importance and evaluation of management of cognitive load during learning experiences, how the assessment has been measured, and how the theory of cognitive load has been implemented in surgical education.

Chapter 4 contains the third manuscript, “Blending E-learning and Simulation Educational Program for Procedural Training: A Pilot Study of Design and Assessment.” This manuscript demonstrates that a blended learning program which combines an e-learning module and in-person simulation improved learning experience, as well as surgical residents’ proficiency. In addition, the description of how instructional design principles, cognitive load theory, and concepts of usability were incorporated into the work.

Chapter 5 provides an overall discussion and conclusions of this thesis work. Chapter 6 contains references, and Chapter 7 contains several appendices. Terms and definitions used in this thesis are shown in appendices.

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CHAPTER 2. CURRENT APPLICATION OF DIGITAL EDUCATION IN GENERAL THORACIC SURGERY

2.1 Preamble

In surgical education, digital education,-delivered by e-learning or virtual reality (VR) simulators have been commonly used in surgical education. However, high-level evidence is still lacking with regard to the effectiveness of digital education for procedural training. To evaluate blended learning for procedural training, we first conducted a literature review of digital education in general thoracic surgery, in which mastery of high-level skills is required. Our goal was to summarize published e-learning programs in general thoracic surgery and identify unmet needs. This literature review would be valuable to guide further development of digital education in this field.

2.2. Manuscript #1. Digital Education in General Thoracic Surgery: A Narrative Review

Running head: Digital Education in General Thoracic Surgery

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Abstract

Background: Since advanced technologies were introduced into surgical education, a variety of new programs have been developed. However, a comprehensive review of digital education in general thoracic surgery has not been performed. The aim of this narrative review was to identify the current applications of digital education in general thoracic surgery.

Methods: A literature search was performed using keywords related to general thoracic surgery and digital education, including e-learning and virtual simulation, up to September 2021. Studies published in English investigating the effect of digital education in general thoracic surgery were included.

Results: Thirteen studies met the criteria. The settings were in undergraduate (n= 6) and postgraduate education (residency) (n= 5), and mixed audience with other disciplines (n= 2). Theoretical knowledge (n= 5), technical skills (n= 4), and both knowledge and technical skills (n= 4) were the stated educational objectives for the studies. The didactic materials were transferred to hardware, software, or online platforms and delivered with multimedia materials. Technical skills training for bronchoscopy and chest tube insertion (n= 5) were offered using virtual reality and computer-based simulations. Subjective evaluation was done in 10 studies. Although, after the digital education training, there was observed improvement in knowledge or skills in 8 studies, studies were not designed to test for superiority compared to controls through randomized controlled studies.

Conclusions: This review summarizes the current applications of digital education in general thoracic surgery and helps establish the needs for future studies in this field.

Abbreviations:

VATS: video-assisted thoracoscopic surgery

VR: virtual reality

RCT: randomized controlled trial

BSTAT: Bronchoscopy Skill and Task assessment Tool

EBUS: endobronchial ultrasound

RATS: robot-assisted thoracic surgery

3D-CT: three-dimensional computed tomography

TSDA: Thoracic Surgery Directors Association

Introduction

Within the last 3 decades, development of advanced surgical techniques, such as video-assisted thoracoscopic surgery (VATS) and robotic surgery have improved perioperative and long-term outcomes of patients [2, 3]. During the same era, there has been increased public awareness about medical errors and patients' safety in response to the introduction of new procedures into clinical practice [6-9]. As a result of the rapid evolution surgical techniques, trainees are required to learn an increased amount of knowledge and skills during their training. These needs must be accommodated as duty hours have become restricted [4, 5]. Pulmonary surgery requires a high level of skill; a small technical error may lead to life-threatening complications; thus surgical trainees seek to achieve mastery during their training. In this context, surgical educators are challenged to develop efficient and effective educational interventions and provide evidence of their value.

An attraction of online education over the traditional passive training system, is its ability to engage the learner through its interactive nature and its accessibility, at a time and place convenient to the learner. These formats make it easy to link other educational resources, or references to the literature, providing a basis for evidence-based learning. It also allows the educator to imbed self-assessment tests in the module to provide feedback to the learner of their progress. These educational methods have been introduced in different fields of medical education with the aim of maximizing opportunities for learning [15-17], however, the current offerings in general thoracic surgery and unmet needs have not yet been reviewed. In this manuscript, we review studies related to the applications of digital education in general thoracic surgery and identify unmet needs to be addressed.

Methods

To identify relevant literature for this review, the authors searched the MEDLINE, EMBASE, and Scopus databases for English language publications from January 2000 to September 2021. Search criteria included peer-reviewed journal articles that reported empirical research. Search terms included "thoracic surgery", "cardiothoracic surgery", "undergraduate", "postgraduate" and "continuing education", "e-learning", "online/web-/internet/computer/screen/app-based curriculum or program", and "virtual-reality (VR) simulations" (MEDLINE search strategy is shown in Supplemental material A). Scope of content was limited to knowledge and procedures related to general thoracic surgery. Follow-up studies were included if the training effect was explored, but they were considered as one study. Studies that evaluated digital education for other expertise or disciplines rather than general thoracic surgery, studies that did not investigate training effect (e.g., validation studies), and studies that were not written in English were excluded.

Results

In total, 1820 articles were identified using the predefined search criteria; 681 were excluded because of duplication, and 998 articles were excluded after title and abstract screening. Further evaluation of the full text excluded 141 articles. Finally, a total of 16 articles of 13 unique studies met the criteria for analysis (Figure 1), including three follow-ups of 2 studies [11, 18, 19]. Overview of studies included for the review is shown in Table 1.

Curriculum and Style

Study participants were undergraduate (n= 6 studies), surgery residency (n= 5), multidisciplinary (medical students, residents, and military medical service [n= 1]), fully-trained and trainees in thoracic surgery and respirology (n= 1). A variety of terms were used to describe digital education:

e-learning, online, and mobile learning module [20-22], internet hybrid and web-based curriculum [20-22, 23-25], instructional video [26], app-based serious gaming [27], simulation (-based) training [28, 29], computer (-based) simulation, system [30, 31], and mobile telesimulation unit [32]. Covered content included chest tube insertion (n= 5), bronchoscopy (n= 4), general knowledge (n= 2), chest trauma (n= 2), and VATS lobectomy (n= 1). Didactic contents were delivered with multimedia (e.g., illustrations, animations, and videos) (n= 8) and with serious games (n= 1). Technical skill simulators were found in 4 studies for bronchoscopy training, including general navigation skill (n= 1), endobronchial ultrasound (EBUS) (n= 1), chest tube insertion (n= 1), and VATS lobectomy (n= 1).

Study Design

We identified seven randomized controlled trials (RCT) [11, 23, 26-29, 32]. Comparisons were performed between digital education and controls: traditional lecture (n= 2), in-person instruction (n= 1), task trainer (n= 1), animal model training (n= 1), and comparison between education technology and controls without instruction (n= 1) and comparison between serious gaming of relevant procedure and a different procedure (n= 1) were also included. Another controlled study investigated the effect of animation video instruction on skill performance of chest tube insertion, but randomization was not mentioned [22]. Other studies compared outcomes at baseline and after training (n= 6) in a single cohort. A retrospective study (n= 1) was included. The majority were single center studies (n= 11).

Proficiency Assessment and Outcome

A total of seven studies described the method of knowledge assessment: multiple-choice questions (n= 2), written test (n= 1), combination of multiple-choice questions and written test (n=1), scores on in-training examination (n= 1), and oral test (n= 1). In one study, knowledge was calculated from score of Bronchoscopy Skill and Task assessment Tool (BSTAT), with knowledge and skill domains, a validated assessment tool for bronchoscopy navigation [30, 33]. Besides BSTAT, there was no validated assessment tool used to measure performance. With respect to knowledge assessment, 5 of 6 studies with pre-intervention and post-intervention testing showed significant improvement after the intervention [11, 19, 20, 24, 26, 29, 31]. In contrast, three other RCTs found that digital education did not show significant knowledge improvement compared to controls [18, 23, 25, 26].

Skill assessment was done by assessors via direct observation (n= 2) or video (n= 3), and by built-in simulator metrics. Bronchoscopic procedural skills were assessed using validated tools, BSTAT and EBUS Efficiency Performance Score [28, 34] for bronchoscopy navigation skills and for EBUS skills, respectively. In 2 studies, baseline skill assessment was done using bronchoscopy simulators with significant improvement after training [28, 30]. A RCT revealed that computer-based EBUS training significantly improved lymph node identification vs animal model training [30]. RCTs for chest tube insertion showed that remote training was as effective as in-person instruction for knowledge, skill acquisition, and retention [32], and that peer-reviewed video instruction was as effective as a didactic lecture [17]. In a study of VATS lobectomy training, with skill assessment using a validated scoring system [29, 35], residents trained with VR simulation required longer time to complete a VATS lobectomy in a porcine model compared to residents trained with a task trainer, but no significant difference was observed in number of errors or bleeding [29].

Subjective Evaluation of Learning Experience

In 11 studies, learners' subjective assessment of their digital education was examined using Likert scale (n= 5), descriptive analysis (n= 3), or in a mixed fashion (n= 3). Items used for evaluation were usefulness (n= 5), confidence (n= 3), satisfaction (n= 3), benefit (n= 2), suggestions for improvement (n= 2), reality (n= 1), degree of standardization (n= 1), and favored content (n= 1). Survey questions and measurement tools differed by studies; there were no validated or standardized surveys used for perception analysis.

Satisfaction after training was evaluated to be high in 3 studies [18, 23, 28, 32]. Confidence improved in three studies after training with digital education [18, 23, 26, 28], while only one RCT proved significant improvement over control group [18, 23].

Training Intensity and Cost

Two studies monitored how long trainees spent training [11, 19, 20, 24]. One study found negative correlation between time spent with e-learning and knowledge improvement [20], while frequent access to web-based curriculum resulted in improvement of scores on in-training examination [11, 19, 24].

In 4 studies, the costs of training were reported: computer-based EBUS simulator cost more than $100,000 U.S. [28], an app-based serious gaming was free [37], CD-ROM and internet hybrid curriculum cost $340,000 U.S. [18, 24]. The cost of telecommunication unit used for remote training of chest tube insertion was described as "low cost [32]."

Comment

In this literature review, we identified that new teaching strategies have been implemented into undergraduate and postgraduate training covering different topics and skills related to general thoracic surgery. The number of RCTs and subjects in some studies were limited. Greater number of RCTs and study participants would be helpful to increase the statistical impact to generalize and to provide high level evidence for the effectiveness of digital education.

Multimedia-rich content was one of the major features of didactic materials in digital education. This form of educational content is thought to mitigate cognitive load [36, 37], possibly resulting in higher subjective evaluation of the learning experience. Additionally, the evolution of educational technology during these 2 decades should be considered. The platforms delivering didactic content started as CD-ROMs [18, 24] and computer-based simulation [20] in the 2000s and evolved into the latest software and online-based modules, where internet plays an essential role [11, 29, 21, 22, 24-27]. Newer platforms have advantages of flexibility to be easily updated, distributed, and accessed. Other attractions of digital didactic content were interactivity and immediate feedback. Now that built-in metrics are available for assessment and feedback in virtual simulators [28], and remote training has been proven to be feasible and effective for technical skill training [32], these technological advancements have the promise to lead to efficient and convenient self-directed learning. In addition, as a result of their interactivity and ease of access, education technology has the potential to improve the quality and efficiency of communication, such as by an app-based feedback process [38].

There were few studies that used validated assessment tools for both knowledge and technical skills. To prove the benefit of any novel educational program, rigorous assessment of its impact is necessary to provide a level of evidence for its effect. Subjective data have some value in assessing new educational interventions. Although there was too much heterogeneity and too little validity evidence for these measures to draw any general conclusions, subjective data are useful to evaluate the user experience as we design and implement training programs.

In this search, we identified only 1 study about VR simulator training for VATS lobectomy, although it is one of the most frequently performed procedures in general thoracic surgery. In this paper, there was no proven benefit of VR over a traditional task trainer [29]. However, the authors have subsequently developed and provided validity evidence for a new VR simulator for VATS lobectomy [39, 40]. Further studies on the effect of training using this newly developed simulator are expected.

In our search, the cost of training varied according to the technology [18, 24, 27, 32]. The effect of training on knowledge and skills, time-efficiency, user preferences, and consideration of ethical issues (e.g., on-the-job training [7, 8] training with an animal model [28]), should be taken into account when implementing digital education. Although this review did not find any definite relationship between time spent and proficiency improvement, it is an important consideration in the context of work-hour restrictions for surgical trainees.

There are limitations to this literature review. We only searched published training programs, and studies investigated training effect. There are other applications of digital technology being used. For example, robot-assisted thoracic surgery (RATS) simulators have been developed, and training curricula for residents are being designed [41, 42]. In minimally invasive approaches, such as VATS or RATS, three-dimensional computed tomography (3D-CT) reconstruction is frequently performed for surgical planning by configuring major structures, such as pulmonary arteries and veins, into concise images for lung resection [43-45]. Now that VATS and RATS are essential skills to master in general thoracic surgery, the training effect of developed simulators and screen based programs, and the value of 3D imaging should be evaluated.

Further, associations-led resources should not be ignored (a list is shown in Supplemental material B). The Thoracic Surgery Directors Association (TSDA) offers a supplemental curriculum based on the Accreditation Council for Graduate Medical Education milestones, which first started with internet and CD-ROM hybrid educational platforms [17, 23], and now also offers more resources, such as videos and online presentations [46]. Under the guidance of TSDA, the Thoracic Surgery Residents Association has published a mobile application for test preparation and is organizing social media, such as Facebook or Twitter, to provide resources and opportunities for trainees [47, 48]. The Association of Young Thoracic and Cardiovascular Surgeons and the French Society of Thoracic and Cardiovascular surgery provide training courses and a logbook to track clinical and academic history, with the guidance of senior surgeons [49]. CTSNet [50] is a comprehensive online platform for educational information directed at the international community of surgeons directed by the Society of Thoracic Surgeons, the American Association for Thoracic Surgery, and the European Association for Cardio-thoracic Surgery. The goal of these association-led resources is to impact both trainees' proficiency and their career development.

Conclusions

This review provides an overview of the current applications of digital education in thoracic surgery, identifies gaps and suggests future material for study.

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Table 1. Identified studies.

Authors/Year	Participants/Setting	Platform/Content/Methods	Main results	Comments
Smolle et al. (2007) [20]	Medical students (n= 41) Single center	-Computer-based simulation for chest trauma. -Knowledge was assessed by pre- and post-tests with multiple-choice questions.	-Knowledge improved after training by 14.3%. -Overall positive evaluation was given by the majority (82.9%) of the students.	-Without control -Skill assessment was not included.
Davis et al. (2012) [31]	Residents (n= 15)	-Computer-based trauma training system for thoracic trauma and abdominal trauma. -Knowledge was assessed by pre- and post-tests with multiple-choice questions and written test.	-Knowledge about thoracic trauma significantly improved after training (56 to 90, $p< 0.001$). -87% of participants answered they would use the module for future training, 93% highly evaluated the descriptions of anatomy, and 100% answered the description of procedure was clear.	-Without control -Subjective analysis includes perceptions on both topic of thoracic and abdominal trauma. -Skill assessment was not included.
Gold et al. (2004) [23]	Residents just before their thoracic surgery training (n= 138) Multi center	-CD-ROM and internet hybrid curriculum. including 75 didactic segments in thoracic surgery. -Comparison of the use of the module and ITE score.	-There was no significant difference in ITE score between intervention group and control group. -Positive correlation between the use of the module and ITE score. -Intervention group stated significantly positive perceptions than control group (3.4 vs 2.9).	-RCT -Control group received only outline of the curriculum. -Skill assessment was not included.

Gold et al. (2005) [18]	Residents just before their thoracic surgery training (n= 138) Multi center	-The same content as study by Gold in 2004. -Long-term follow-up of utilization. -Three-year follow-up.	-Use of modules varied with the subject matter. Thoracic anatomy, adult cardiac diagnostic studies, thoracic physiology and cardiopulmonary bypass were highly used segments.	-Long-term follow-up of the utilization -Knowledge assessment referred to the previous study. -Skill assessment was not included.
Antonoff et al. (2014) [24]	Residents (n= 19) Multi center	-Internet-based using Moodle format. Four courses: Pulmonary physiology; Tracheal anatomy; tracheobronchial disorder; and tracheobronchial surgery. -Time spent and quiz data were tracked. -Subjective evaluation was included.	-Senior trainees spent less time and passed quiz with fewer attempts. -Residents evaluated the module: easy to navigate (100%), courses are overall beneficial in learning (100%).	-Pilot study -Without control -Skill assessment was not included.
Antonoff et al. (2016) [11]	Residents (n= 187) Multi center	-The same content as study by Antonoff in 2014. -Utilization and 2-year sequential ITE scores were compared.	-There was no significant difference in scores of ITE by utilization. -High-volume users' ITE score tended to improve greater than the scores of low-volume users (+18.2% vs +13.0%, p= 0.199).	-Without control -Subjective evaluation was done in the previous study (Antonoff, 2014). -Skill assessment was not included.
Luc et al. (2018) [19]	Residents (n= 256)	-The same content as study by Antonoff in 2014. -Relationship between the frequency of login to the curriculum and ITE scores were analyzed.	-Significant improvement in ITE scores was not observed among the residents who increased the frequency of study immediately before ITE.	-Without control -Subjective evaluation was done in the previous study (Antonoff, 2014).

			-Highest scoring trainees used the curriculum significantly more often than medium-range scorers ($p = 0.039$).	-Skill assessment was not included.
Sterse Mata, et al. (2012) [25]	Medical students (n= 16) Single center	-Web-based bronchoscopy curriculum and control group with traditional lecture. -Knowledge assessment after the intervention by multiple-choice questions. -Subjective evaluation was included.	-There was no significant difference in knowledge between the two groups. -Learners evaluated the web-based curriculum positively because of the multimedia components and the possibility of going back and forth, but also pointed too much text. -Learners in control group cited the importance of teacher.	-RCT -Without baseline assessment -Assessment tool was not validated.
Stather et al. (2012) [28]	Trained physicians in respirology and thoracic surgery, trainees in respirology and thoracic surgery (n= 12) Single center	-EBUS training with computer simulation or wet-lab (animal model) simulation following lecture. -Skill performance was evaluated using a validated built-in metrics of the simulator and a validated tool, EBUS efficiency Performance Score. -Subjective evaluation was included.	-Computer simulation showed significantly better skill of identifying lymph nodes than wet-lab simulation ($p = 0.002$). -Wet-lab simulation increased learner confidence. -100% participants responded wet-lab and computer simulation are complementary learning opportunities.	-RCT -Before and after the training, essential knowledge for the procedure was tested (results are not shown).
Gopal et al. (2018) [30]	Medical students (n= 47) Single center	-Bronchoscopy simulation training. -Basic bronchoscopy navigation skill and anatomy knowledge were assessed before and after intervention by one thoracic surgeon via direct observation.	-After the training, total BSTAT score significantly improved (from 12.3 to 48.0 ($p < 0.0001$)). -Anatomy knowledge (from 0.1 to 31.1 ($p < 0.0001$)), and navigation skills significantly	-Without control -BSTAT was validated, but this study used a truncated version.

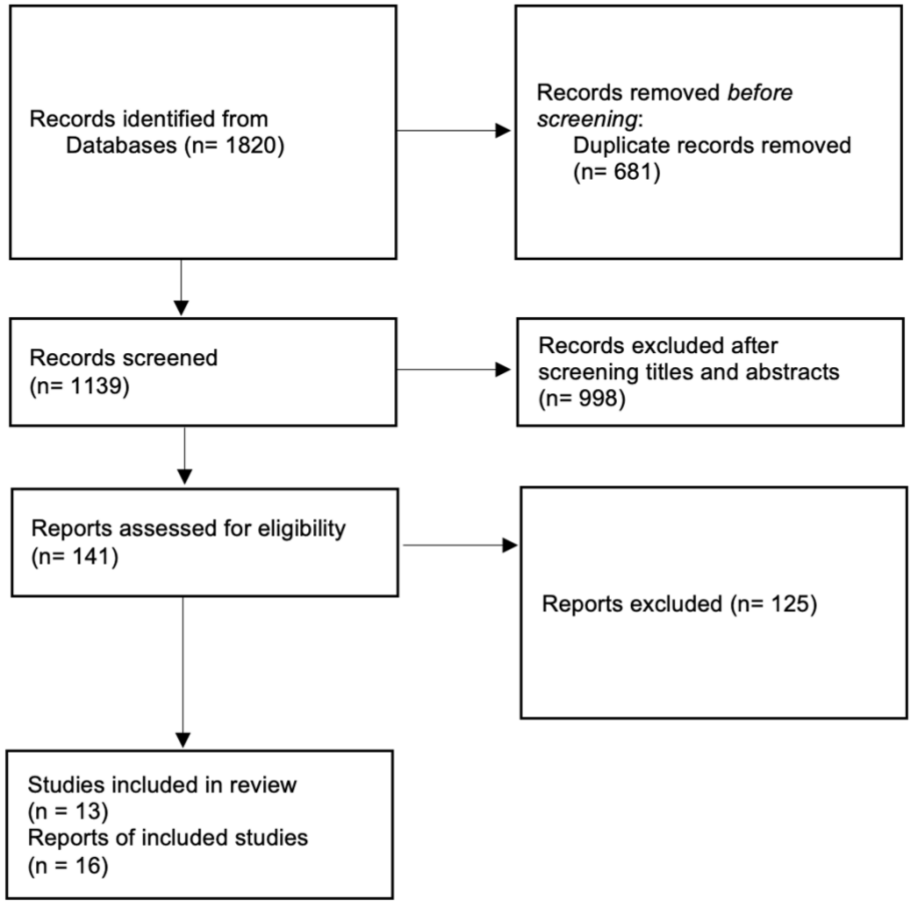
		-A validated assessment tool, BSTAT was used for skill and knowledge assessment. -Subjective evaluation was included.	improved (from 12.1 to 17.4 ($p < 0.0001$)). -More than 90% participants responded the simulation training was useful.	
Davis et al. (2012) [22]	Residents (n= 44) Medical students (n= 42) US Army Forward Surgical Team members (n= 42) Single center	-Mobile learning module with animation, video and narration about knowledge and skills for chest tube insertion. -Available on mobile device. -Skill performance was assessed using task simulator using a checklist by direct observation of two assessors.	-Intervention group scored better than control group (11.1 vs 7.17, $p < 0.001$).	-Controlled study but random allocation was not clearly described. -Control group did not receive any instruction. -Assessment tool was not validated. -Knowledge and subjective evaluation were not included.
Saun et al. (2017) [26]	Medical students (n= 30) Single center	-16-minute peer-reviewed video about chest tube insertion was selected as a standardized online video. -Control group received a 17-minute recorded lecture. -Skill performance was assessed using a checklist. -Knowledge examined orally in pre- and post-tests during the skill test, -Subjective evaluation was included.	-There was no difference in skill performance ($p = 0.09$) between the groups. -Online video group showed better knowledge scores in post-assessment ($p < 0.001$). -No statistical difference in confidence improvement.	-RCT -Assessment tools for skills and knowledge were not validated.

Haubruck et al. (2018) [27]	Medical students (n= 116) Single center	-App-based serious game designed to cover every step of chest tube insertion following a didactic lecture. -Control group received the same lecture, then experienced serious game for thoracentesis. -Skill performance of chest tube insertion was assessed on porcine cadaveric model using modified OSATS. -Subjective evaluation was included.	-Intervention group performed over control group (38.0 vs 30.5, $p < 0.001$). -Intervention group showed significantly better economy of time and motion ($p = 0.004$), less help needed ($p < 0.001$), and more confidence in handling of instruments ($p < 0.001$). -Participants evaluated the benefits and reality of simulation of serious game positively than traditional learning methods ($p < 0.001$).	-RCT -Control group received content for a different procedure. -Knowledge assessment was not included.
Jewer et al. (2019) [32]	Medical students (n= 69) Single center	-Chest tube insertion training using telesimulation unit. -Comparison of three conditions: control group with no instruction, comparison groups with in-person hands-on instruction, and intervention group with remote instruction. -Skill performance was assessed on a simulator using modified OSATS, and pre-and post-tests for knowledge were assessed by brief written test. -Subjective evaluation was included.	-Intervention group performed better than control group ($p < 0.001$), and comparison group performed better than control group ($p < 0.001$). -There was no significant difference in knowledge test scores between the groups ($p = 0.13$). -There was no significant difference in satisfaction between intervention and comparison groups.	-RCT -Assessment tool for knowledge was not validated. -Comparison of pre-intervention and post-intervention knowledge in each group was not reported.
Okusanya et al. (2020) [21]	Residents (n= 23) Single center	-Online module about bedside procedures: endotracheal intubation, arterial line insertion, central venous line insertion,	-Participants' perception on standardization of the procedure of chest tube insertion significantly improved (from 4.1	-Without control -Results of skill assessment are not shown.

		pigtail tube thoracotomy, thoracentesis and nasogastric tube placement were assigned followed by hands-on training. -Skill was assessed by instructors to evaluate if a trainee is competent. -Knowledge was examined by pre- and post-test. -Subjective evaluation was included.	to 4.6 (p= 0.03)), while confidence did not improve.	-Procedure specific knowledge results are not available (only total score is shown).
Jensen, et al. (2014) [29]	Residents (n= 24)	-The aim of this study was to Investigate post-training VATS lobectomy performance on porcine model. -Intervention group trained with a VR simulator designed for nephrectomy -Control group trained with traditional task trainer. -Performance was assessed by a validated scoring system.	-Control group finished lobectomy significantly faster than intervention group (26.6 vs 32.7 minutes, p= 0.032). -No difference was observed in bleeding, anatomical and non-anatomical errors.	-RCT -Simulator was not designed for VATS lobectomy. -Knowledge and subjective evaluation were not included.

ITE, in-training examination; RCT, randomized controlled trial.

Figure 1. Flow diagram for the study.



Supplemental material A. MEDLINE search strategy.

1. Thoracic Surgery/
2. mediastinoscopy/ or pulmonary surgical procedures/ or bronchoscopy/ or lung transplantation/ or pneumonectomy/ or sternotomy/ or thoracoplasty/ or thoracoscopy/ or thoracic surgery, video-assisted/ or thoracostomy/ or thoracotomy/ or thymectomy/ or tracheostomy/ or tracheotomy/
3. Thoracic Surgical Procedures/
4. thoracic surg*.mp.
5. thoracoscop*.mp.
6. thorcacotomy.mp.
7. bronchoscop.mp.
8. 1 or 2 or 3 or 4 or 5 or 6 or 7
9. augmented reality/ or virtual reality/
10. computer-Assisted Instruction/
11. e learn*.mp.
12. ((web or screen or internet or computer or hybrid or virtual or remote or digital) adj2 (learn* or instruct* or teach* or curricul* or train* or program* or module* or workshop* or educat*)).mp.
13. virtual reality.mp.
14. augmented reality.mp.
15. 9 or 10 or 11 or 12 or 13 or 14 or 15
16. 8 and 15

Supplemental material B. Representative association-led resources.

Association	**Audience**	**Digital content/Resources**
TSDA	Residents, resident training program directors and coordinators	Supplemental video and audio materials for Thoracic Surgery Curriculum
TSRA	Residents, medical students	Mobile application for test preparation Distribution of educational information and opportunity on social media
AJCTCV SFCTCV	Trainees in France	E-learning with self-evaluation tests Aid of career development with milestones, logbook to record surgical experience and publications
STS AATS EACTS	Worldwide cardiothoracic surgeons and health professionals	"CTSNet" Video, text and audio-based content Event calendar Profile page for individual surgeons, networking Job opportunity board

TSDA, Thoracic Surgery Directors Association; TSRA, Thoracic Surgery Residents Association; AJCTCV, Association of the Yong Thoracic and Cardiovascular surgeons; SFCTCV, French Society of Thoracic and Cardiovascular surgery; STS, Society of Thoracic Surgeons, AATS, American Association for Thoracic Surgery; EACTS, European Association of Cardio-thoracic Surgery.

CHAPTER 3. COGNITIVE LOAD IN SURGICAL EDUCATION

3.1 Preamble

Due to the advancement of procedures from traditional open surgery to thoracoscopic surgery or robotic surgery, the amount of learning tasks and the complexity of skills and knowledge required have increased. In addition to the busy clinical duty, overwhelming tasks may induce burnout or impairment of performance for learners.

In the field of education, cognitive load theory has been developed as a theoretical framework of the cognitive architecture; the theory posits that our working memory and information processing is limited, which implicates that a cognitive load exceeding the individual learner's cognitive capacities leads to a cognitive overload. Therefore, it is important to optimize learning experiences and to manage cognitive load of these experiences. Indeed, our preliminary search in the surgical education field revealed that complexity of tasks and cognitive load are correlated, and higher cognitive load was associated with impaired laparoscopic performance. Also, one of the major features of digital education, such as e-learning is the incorporation of multimedia content, which has a close relationship with cognitive load theory. Multimedia learning allows learners to receive information via visual and audio channels, which promotes information processing in limited working memory.

Based on the literature review titled "Digital Education in General Thoracic Surgery" [14] we identified unmet needs of digital education in general thoracic surgery. One of the gaps identified was a lack of a standardized approach to evaluate the learning experience. Based on these findings, we evaluated cognitive load in our pilot study. In this chapter, we explore how cognitive load can be assessed and the present knowledge for its use in surgical education.

3.2 Manuscript #2. Cognitive Load in Surgical Education

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ACGME Competency: Practice based learning and environment

Abbreviations

VR: virtual reality

AR: augmented reality

MIS: minimally invasive surgery

SMEQ: the Subjective Mental Effort Questionnaire

SRME: the Subjective Rating of Mental Effort

NASA-TLX: the National Aeronautics and Space Administration Task Load Index

HRV: heart rate variability

fNIR: near-infrared spectroscopy

EEG: electroencephalography

3D: three-dimensional

2D: two-dimensional

UHF-VR: ultra-high-fidelity virtual reality

Introduction

Simulation plays a critical role in surgical training by providing an effective and experiential learning opportunity protecting patient safety [6]. Currently, training programs using various kinds of simulation have become common in undergraduate, postgraduate, and continuing education, supported by evidence of the effectiveness of simulation training [7, 8, 51]. These simulations range from low-fidelity (e.g., training using part-task trainers) to high-fidelity (e.g., mannequins and virtual reality (VR) or augmented reality (AR), or even computer-based simulations that focus on knowledge and decision making [52]. Further, the introduction of truly novel surgical approaches, as seen in minimally invasive (MIS), and endovascular approaches, has taught us that learning these challenging techniques is mentally demanding [53]. Because this escalation of demands can lead to frustration and burnout [54], it is important to monitor the mental workload of learners with different educational approaches.

Cognitive load theory provides a theoretical framework of the cognitive architecture [55, 56]. The main premise of this theory is that our working memory and information processing capacity are limited, which implies that a cognitive demand exceeding the individual learner's cognitive capacities leads to cognitive overload. In this theory, three different types of cognitive load are considered: the intrinsic load derived from the learning task itself (inherent to the complexity of the task), the extraneous load caused by the way the learning task is presented or the learning situation (poor teaching and instructions, and distractions in learning environment), and the germane load of the learning process and the retention (mental schema formation for the actual learning). The theory proposes that cognitive overload could be detrimental to learning; therefore, the design of teaching strategies should consider how to manage the cognitive load [55-57].

The cognitive load theory is important to understand, and management of cognitive load should be considered to design and deliver optimal training programs in surgical education. A systematic review has been previously published about measurement tools of surgeons' intraoperative cognitive load, which focused on the technical aspects of assessment [58]. In the present article, we will briefly summarize the present knowledge of cognitive load in surgical education, e.g., differences among modalities and procedures, and training designed based on cognitive load theory, and provide an outline about how this knowledge may help improve design of future training programs.

Terminology

Different terms to describe cognitive load were found: Cognitive Load, Cognitive Workload, Cognitive Cost, Cognitive Demand, Cognitive Effort, Cognitive Engagement, Mental Workload, Mental Strain, and Mental Effort. These terms have been often used interchangeably.

Assessment Tools

A variety of measurements have been used for cognitive load. Some studies used multiple assessment tools. Both subjective and objective evaluations are included. Self-report techniques generally use rating scales involving one or multiple dimensions.

The Subjective Mental Effort Questionnaire (SMEQ) [59-62] and subjective rating of mental effort (SRME), or Paas scale [63-65], are two independent single-item questionnaires. Both have been used to assess mental effort. NASA-TLX, one of the most widely used measurements of subjective workload, provides an overall index of mental workload as well as the relative contributions of six subscales: mental demands, physical demands, temporal task demands, effort, frustration, and perceived performance [61, 62, 66-80]. Leppink provided validity evidence for a questionnaire composed of 10 items for the three types of cognitive load (intrinsic, extraneous, and germane) [81-83]. These instruments were originally developed and test for validity in the fields of engineering, psychology, education, and industry, then introduced into the medical and surgical fields. The surgical task load index (SURG-TLX) was developed and assessed as a surgery-specific measurement of cognitive load and referred to as NASA-TLX. This is composed of six subscales: mental demands, physical demands, temporal demands, task complexity, situational stress, and distractions [84, 85]. Naismith, et al. assessed the relationships between the NASA-TLX, the Paas scale, and the Leppink scale, and found that the two former questionnaires can be used interchangeably for assessment of intrinsic cognitive load, but they did not predict extraneous or germane cognitive load, as measured by the Leppink scale [86]. Sewell, et al. suggest that studying different types of cognitive load would provide richer understanding when undertaking instructional design [87].

Objective measures of cognitive load include physiological parameters and secondary task analyses. Some of the physiological parameters reflect the activity of the sympathetic nervous system caused by cognitive load, such as heart rate variability (HRV) [70, 80], skin conductance or skin resistance [88, 89], heat flux [90], pupil dilation [78], and blink rate [80, 92]. Gaze entropy and velocity can also be used to objectively measure cognitive load [68, 71, 76]. Near-Infrared spectroscopy (fNIR) and electroencephalography (EEG) are used to monitor brain metabolism, a reflection of cognitive load [70, 71]. Secondary task analysis is another common technique to assess cognitive overload. In this technique, a secondary task or distraction such as a visual or auditory challenges used while evaluating the operator's ability to perform a task. In this case the reaction time (the duration between stimulus onset and the subject's response to it) are taken as a relevant performance measure. The secondary tasks provide an alternative measure of mental workload by occupying spare attentional capacity [64, 80, 92-96].

There are some drawbacks of each approach that have been discussed. Regarding self-reported measurements, the response can be biased because of their subjective nature, and they cannot measure cognitive load in real time [62, 65, 71, 80]. In contrast, although objective measures can provide real-time measures of cognitive load during the task, devices, or equipment to monitor the physiological parameters may cause surgeons' discomfort [89], and audio or visual stimuli for secondary task analysis can substantially cause distraction from the primary task [77, 80, 95]. Given these features of individual assessment tools, Zakeri used multiple instruments, such as HRV, blink rate, reaction time and NASA-TLX to better assess cognitive load during laparoscopic surgery in a simulation environment and demonstrated the correlations between "traditional measurements (NASA-TLX and reaction time)" and physiological parameters [80]. Similarly, the correlations between a subjective measure, such as NASA-TLX, and objective measurements including fNIR, pupil size, and gaze dynamics have been reported [68, 70, 71, 77]. It is important to choose a suitable assessment tool according to the objectives of the analysis and environment.

Cognitive Load of Surgical Procedures

Studies have evaluated cognitive load to rate the difficulties of surgical procedure and to compare the level of difficulty between procedures. As an example, Hu, et al. showed that higher NASA-TLX scores were reported by trainees as the level of difficulty of laparoscopic procedure increased [78]. Yurko, et al. showed that high cognitive load was associated with impaired laparoscopic performance [67]. In contrast, Schuetz, et al., observed that intraoperative distractions resulted in fewer intraoperative errors, and postulated that higher cognitive load stimulated enhanced mental alertness and concentration during the procedure [88]. Cognitive load was compared during laparoscopic surgery and robotic surgery; robotic surgery was found to require either similar or lower cognitive load [60, 72]. In contrast, Berguer, et al. found that robotic surgery was associated with slower technique and higher errors compared to laparoscopic surgery [89]. Ergonomic factors should be considered when comparing laparoscopic and robotic surgery. Fatigue in upper limbs during laparoscopic surgery may have a negative impact on performance [97]. Since NASA-TLX includes physical demands besides cognitive workload, the overall score may be affected by ergonomic issues. Hubert, et al. evaluated NASA-TLX during laparoscopic and robotic surgeries and found significant differences in only physical demands (lower in robotic surgery), and greater muscle fatigue in laparoscopic surgery, as measured by electromyography [98]. In addition to ergonomics, the three-dimensional (3D) view in robotic surgery can influence the perceived cognitive load, whereas laparoscopic surgery is more often performed using monocular or two-dimensional (2D) imaging. A study by Inama, et al. demonstrated similar scores of NASA-TLX overall and all its subscales comparing 2D and 3D views for laparoscopic surgery, while greater fatigue and difficulty in focusing and concentration were reported with surgery with 3D view [99].

Regardless of surgical procedure, evidence seems to demonstrate that training, especially when reinforced by repetition results in decreased cognitive load and improved skill performance [76, 78, 95, 96]. Likewise, experienced surgeons tended to report lower cognitive load than novices, suggesting that experience and task familiarity lead to desired cognitive load [62, 64, 70].

Cognitive Load of Training Modalities

The relationship between high-fidelity simulation training and cognitive load is still controversial. A randomized controlled study provided evidence that an AR simulator was associated with lower temporal demands and effort, measured by NASA-TLX, compared to hands-on training for robotic-assisted surgery [74]. In another study, Andersen, et al. compared training using a VR simulator vs cadaveric training for mastoidectomy [93]. They demonstrated lower cognitive load, measured by reaction time with secondary task analysis, in the VR group. In contrast, other studies that compared VR with physical task trainer simulators for laparoscopic surgery, and others that compared VR simulation training with a live porcine model showed no difference in cognitive load [76, 79]. In another study, Andersen and colleagues, compared training with ultra-high fidelity (UHF) VR simulation, or immersive VR simulation, which provides increased graphical realism, with conventional screen-based VR simulation training. They found that a higher cognitive load (measured by secondary-task reaction time) and impaired performance in the UHF-VR group [92, 96]. The authors recommend that novices first should train with a lower level of complexity in the learning environment, and higher fidelity training should be implemented later for advanced training.

Consideration of Cognitive Load in Instructional Design

In the context of medical education, Mayer suggests that cognitive load theory should be integrated into medical instruction by reducing extraneous processing, managing essential processing, and fostering generative processing [56]. Segmenting large pieces of information into smaller segments will allow learners to advance at their own pace. In support of this theory, a study comparing cognitive load and learning effect (technical skill) between segmented and continuous video-based learning found lower self-reported extraneous cognitive load when the segmented video was used. Moreover, when comparing subjects who spent the same amount of time (1 and 2 hours), those who studied with segmented video demonstrated fewer errors in their technical skill assessment than subjects with the continuous video [82]. Mayer also proposed that extraneous cognitive load be reduced by avoiding irrelevant material [56]. However, in another study, irrelevant context to learning task did not influence learning negatively [83]. The authors interpreted that the learners should be able to focus on the task at hand and avoid engagement with the content that was irrelevant to the learning task. However, the authors also consider that the participants' expertise level may have influenced the result; generalization of this result may be challenging.

Gardner, et al., reported that seductive but irrelevant visual and audio details, embedded in an instructional video of laparoscopic procedures, increased cognitive load and impacted negatively on skill performance [69]. With these findings, it is essential to consider the content and delivery of instruction materials, especially when teaching a naïve audience.

Future Perspectives

As above, cognitive load theory has been implemented in several ways for surgical training. Still, we believe the consideration of cognitive load theory should be more widespread for the best practice of surgical education. Previously published studies have shown that the effectiveness of high-fidelity simulators is unproven and may depend on the learners' prior knowledge and skills. When planning the use of simulators for technical training and digital modules for theoretical knowledge, the concept of human-computer interaction must be considered. As long as we use digital interfaces for surgical education, trainees must be comfortable using the system before they can effectively and efficiently learn the actual knowledge and skills. Since the complexity of interfaces is anticipated to increase cognitive load, the teaching modality should be designed to be highly usable to result in successful learning. Although human-computer interaction and usability are sometimes presented interchangeably with cognitive load in education and engineering, they are actually distinct but interrelated concepts [100]. Given that cognitive load is impacted by surgeons' experience, expertise, and task complexity, the concept of cognitive load should be consideration in competency-based training. The quality of training will be better when analysis of cognitive load is incorporated in designing optimal training curricula, so appropriate tasks are given to the trainees based on their competency level. Also, data from cognitive load measurements can be used to following trainees' learning curve. In this context, differentiation between the three types of cognitive load may be useful to identify leaners' gaps (experience or competency: intrinsic cognitive load) and gaps in learning tasks (the way of presentation or instruction, or complexity: extraneous cognitive load). Finally, since higher cognitive load is associated with poorer skill performance and task load is correlated with higher risk of burnout [54], measuring and managing cognitive load will be helpful to predict overload leading to safer clinical practice and avoidance of burnout among surgeons.

Conclusions

In conclusion, assessment of cognitive load in surgery has the potential to be applied in many areas to provide better training curricula, working environment, and safer clinical practice. In planning surgical education, educators should understand cognitive load theory and know how to measure cognitive load. These concepts can then be integrated when delivering an optimized content, when assigning tasks with appropriate amount of cognitive load to the leaners.

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CHAPTER 4. BLENDING E-LEARNING AND SIMULATION EDUCATIONAL PROGRAM FOR PROCEDURAL TRAINING

4.1 Preamble

Chest tube insertion is one of basic surgical procedures to treat pleural diseases. Surgical trainees are supposed to master this procedure during training period. However, high complication rates have been reported even after residents experience traditional simulation training. An alternative teaching strategy is necessary, and we sought to implement one form of digital education, blended learning, to address this issue. One of the advantages of blended learning is the delivery method such that there are two components which include asynchronous learning and synchronous learning in one learning experience This provides an advantage to learners as it provides flexibility as to when they will access the learning material at a time that is convenient for them. They can learn essential theoretical knowledge using online materials, usually an e-learning module, as preparation for the synchronous component. Although the effectiveness of blended learning has been reported in medical education [101, 102], the evidence for procedural training has not been studied well. Since McGill University offers in-person hands-on simulation training to first-year surgical residents, we hypothesized that a blended learning program composed of an e-learning module and simulation would be helpful to improve proficiency and to optimize learning experience. A study suggested that the asynchronous part is important for the learning outcomes and learners' satisfaction in blended learning [103].

We then identified some gaps for implementation of an educational program with e-learning as follows: clinical medical educators face some barriers because most clinicians have not been trained formally as educators. It should be noted that the instructional design principles provide theoretical framework to address this issue; therefore, in this study, we decided to employ the ADDIE framework, which is commonly used for the instructional design in that it provides procedural guidance to creating education programs.

Through the literature review, “Digital Education in General Thoracic Surgery” [14], we found the evaluation of learning experience has not been conducted by standardized measurement tools. In the work in “Cognitive Load in Surgical Education”, we identified the importance of the management of cognitive load, considering the nature of digital technology of human-computer interaction, and the need of evaluation of usability as well.

In this study, we aimed to 1) develop an e-learning module incorporating the ADDIE framework of instructional design, 2) provide the e-learning module for chest tube insertion as a component of blended learning program with hands-on simulation training for junior surgical residents, 3) investigate if the newly created blended learning would improve knowledge and technical skill, and 4) investigate learning experience, cognitive load, and usability, with the blended learning.

4.2 Manuscript #3. Blending E-learning and Simulation Educational Program for Procedural Training: A Pilot Study of Design and Assessment

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Brief title: Optimization of procedural training with blended learning

Abstract

Background: The complication rate of chest tube insertion has been reported to be high even after standard simulation training. Blended learning combining e-learning and in-person simulation can be an alternative educational strategy. We developed an interactive e-learning module with multimedia content to teach chest tube insertion in preparation for surgical residents' simulation training. Our aim was to evaluate usability and cognitive load in addition to knowledge and technical skill improvement.

Study Design: The ADDIE framework of instructional design was used to create the interactive e-learning module with multimedia materials. In advance of in-person simulation, 13 first-year surgical residents were randomized into two groups: 7 received the e-learning module and reading materials (e-learning group); 6 received only the reading materials (controls). Knowledge was evaluated by pre-and post-tests; skill was assessed using a Global Rating Scale by blinded assessors during the simulation. Cognitive load and usability were evaluated using rating scales.

Results: Post-intervention, the e-learning group showed a significant improvement from baseline in knowledge ($p = 0.047$), while controls did not ($p = 0.500$). For technical skill, 100% of residents in the e-learning group reached a predetermined proficiency level vs 60% of controls ($p = 0.07$). Usability was rated high by all e-learning residents. We observed a lower extrinsic and greater germane cognitive load ($p = 0.04$, 0.03, respectively) in the e-learning group.

Conclusion: In this pilot study, the new e-learning module improved proficiency of learners, with excellent usability and desired cognitive load. This teaching program was effective and well received by the learners.

Keywords: e-learning; blended learning; online learning, instructional design principles; chest tube insertion; usability; cognitive load; simulation

Abbreviations:

ATLS: Advanced Trauma Life Support

ADDIE: Analysis, Design, Development, Implementation, and Evaluation

ISO: International Organization for Standardization

CONSORT: Consolidated Standards of Reporting Trials

OSATS: Objective Structured Assessment of Technical Skills

COVID: Coronavirus disease

Introduction

Chest tube insertion is a fundamental technique for management of chest trauma and pleural diseases, and surgical trainees must master the procedure. Simulation training has been often provided to surgical trainees, in courses such as Advanced Trauma Life Support (ATLS), but a high complication rate is reported among trainees, even after simulation training, due to its high-stakes nature as a life-saving procedure [9]. To address this unmet educational need, an alternative teaching strategy should be considered.

Blended learning has the advantage of combining asynchronous and synchronous learning. The asynchronous component is usually carried out with e-learning, a form of electronic and internet-based teaching, which allows trainees flexible self-directed learning. Trainees can prepare for the synchronous component with an e-learning module. Although the effectiveness of blended learning for medical education has been reported [16, 104], the evidence for procedural training has not been well studied. One study demonstrated that asynchronous component significantly affected trainees' knowledge improvement and satisfaction, suggesting the design of e-learning would be important in the delivery of a blended learning program [105]. However, because few faculty members have been formally trained to create and to use e-learning, there has been a great deal of variability in quality and e-learning has not met learning needs [22]. The principles of usability and cognitive load should be considered when developing an educational program with technology. Usability is the concept that describes how it is easy to use a system in terms of human-computer interaction. Poorly designed products or inappropriate use of technology can lead to poor learners' satisfaction and high dropout rates [106-108]. Effectively incorporating features of active learning in education technology, such as multimedia and interactive elements [109], has been shown to improve learning outcomes and learning experience by mitigating cognitive load and enhancing usability [12, 55, 56, 110, 111].

Instructional design is the creation of learning experiences and educational materials based on established learning principles [112-115]. The ADDIE framework, one of the most representative instructional design approaches [113, 116], has been applied to develop e-learning modules for healthcare professionals, and has been shown to improve knowledge and learner satisfaction [116-118]. “ADDIE” is an acronym for Analysis, Design, Development, Implementation, and Evaluation, and describes fundamental steps to create educational materials. In each phase, the learner-centered education is considered: learners are allowed to learn autonomously, and to associate the learning with their experience and current problems [116].

In this pilot study, we sought to provide a blended learning program for chest tube insertion to junior surgery residents combining a new e-learning module based on the principles of instructional design and standard in-person simulation training. We hypothesized that the e-learning module would be effective in producing proficiency levels of knowledge and skills in surgical residents. Further, we hypothesized that the e-learning module would lead to optimal usability and cognitive load.

Methods

Experimental Design

This was a blinded randomized controlled study, conducted at the Steinberg Centre for Simulation and Interactive Learning, McGill University (Montreal, Canada). This study was approved by McGill University internal review board (A09-E48-21A). Participating residents and assessors were asked to provide signed consent. Incentive was given to resident participants when they completed all administered activities in this study: a raffle, where one of the participants would win a 200-dollar gift card.

It is compulsory for first-year surgical foundation residents, from all surgical disciplines at McGill University, to participate in a hands-on simulation training program covering essential skills for surgeons independent of specialty. Although this program includes instruction for several basic surgical procedures, including suturing, anastomosis, and chest tube insertion, etc., only chest tube insertion was addressed in this study. Study participants were allocated randomly on 1:1 ratio into two groups: e-learning and controls. The block randomization method was done by one of the investigators, who was not involved with residents training. Participants were asked to take a pre-test to assess baseline knowledge and complete a survey to provide demographics (age, gender, handedness, prior clinical exposure to chest tube insertion, prior simulation training including ATLS course). One week before the hands-on simulation, the e-learning module and a list of reading materials (textbook chapters) [119-121] were provided to the e-learning group; the same reading materials, without the e-learning module, were given to the control group. During hands-on training, participants in both groups received instruction from an experienced instructor, who was blinded to group allocation, then were assessed on their performance by two blinded evaluators. Immediately after the skill assessment, all participants were asked to take a post-test to evaluate their knowledge, to complete surveys for usability and cognitive load, and to provide other feedback related to their educational experience. The e-learning module, the list of reading materials, tests and surveys were provided through the McGill University online learning management system, myCourses. All participants were familiar with its use. The Consolidated Standards of Reporting Trials (CONSORT) diagram is shown in Figure 1.

Instructional Design and Content Development

The design of the study followed the ADDIE framework, under the guidance of an expert in instructional design for e-learning and education technology. In the phase of Analysis, educational needs were defined by a panel of experienced surgeons with the goals of improving skill of chest tube insertion and the theoretical knowledge relevant to the procedure. As content, we included four subunits: indications and contraindications, preparation, procedure, and complications. The ATLS course guidelines was selected as the basis for the content because McGill University's Department of Surgery has been offering ATLS courses regularly and the instructions in ATLS course were familiar to study participants. In the Design phase, specific, measurable, achievable, relevant, and time-bound learning objectives [122] were to: 1) explain the indications/contraindications for chest tube insertion, 2) prepare the appropriate equipment for the procedure, 3) demonstrate the procedure in the simulation environment, 4) identify potential complications of the procedure. Details how to assess the learning outcomes were then considered and are shown in *Assessment.* In the next phase of Development, didactic content of subunits was developed to achieve learner-centered learning through interactions between the module and learners. In contrast to traditional lectures, it was designed to encourage learners to obtain didactic information by activities such as clicking or hovering over graphics, and quizzes were included at the end of each subunit as a knowledge check. Multimedia materials, graphics and animations were included to illustrate physiopathology of conditions for which chest tubes are indicated, necessary equipment, etc., and a narrated video was created to show step-by-step instructions. Each subunit was designed to be completed within three to six-minutes to allow leaners to learn at their own pace (segmentation) [56], and they could access the module as many times as they wanted during the period prior to the simulation event. The phases of

Implementation and Evaluation were the main body of this study to facilitate the teaching program and evaluate learning outcomes. Details are provided in *Experimental Design* and *Assessment.*

Assessment

To assess theoretical knowledge about the procedure, experts in surgery and education created two tests (pre- and post-tests) comprised of 15-item multiple-choice questions. Questions in the pre- and post-tests were different, but the content area and level of difficulty were designed to be the same.

Skill performance was assessed by two experienced surgeons who were not involved with formal evaluation of residents and who were blinded to the study group. A Modified Objective Structured Assessment of Technical Skills (OSATS), which was validated in previous studies [123], was used to assess skills. It consists of a Global Rating Scale of 10-items, where 1 represents the poorest level of performance and 5 is considered best performance; the items evaluate the location of incision, subcutaneous dissection, intercostal dissection, instrument handling during dissection, digital exploration of pleural cavity, handling of drainage tube, insertion of drainage tube, estimation of the intracorporeal drain length, economy of time and movement, and degree of assistance or coaching. In this study, in addition to these items, we added one additional item related to fixation of the tube to the skin. In total, eleven steps of the procedure were evaluated (Appendix A). The mean of scores from two assessors were reported and a total score of 44 or more out of 55 ($\geq$ 80%) was required for proficiency.

After the simulation, the learners were surveyed again. In this evaluation, participants were asked to rate their confidence, usability of the module, cognitive load, and other perceptions. Post-intervention confidence level was assessed in the same manner as in the pre-survey. A questionnaire for usability was developed referring to the International Organization for Standardization (ISO) 9241-11 guideline and a previous article [124-126, and Anish Arora, personal communication]. The questionnaire was composed of six questions to cover three domains of usability: effectiveness, efficiency, and satisfaction, each assessed using a 5-point Likert scale, where 1 represents “strongly disagree” and 5 “strongly agree.” Cognitive load was evaluated using a 10-item questionnaire based on a 0-10 Likert scale, where 0 represents “not at all the case” and 10 is considered “completely the case” [82, 127]. The questionnaire was comprised of three items for intrinsic, three items for extraneous, and four items for germane cognitive load. Although intrinsic cognitive load is generally expected to be unchanged by instruction, teaching materials with smaller extrinsic cognitive load, and greater germane cognitive load are considered optimal for learning [115-118]. The mean scores for each type of cognitive load were calculated and compared between groups. At the end of the post-survey, participants were asked to provide their perceptions of the provided materials, and suggestions for improvement through open-ended questions.

Statistics

Quantitative data analysis was used to examine scores from knowledge tests, technical skills, and Likert scales. Numerical data are reported as median and range. Between-group comparisons of the scores for knowledge, skills, and survey questions were performed using non-parametric tests (Wilcoxon test), and scores at baseline and after intervention within subjects were compared using Wilcoxon signed rank test. Categorical data were evaluated using Pearson’s chi square test. Inter-rater reliability was assessed by intraclass correlation coefficient using Microsoft Excel 2016

(Microsoft, Corp, Redmond, WA), and other data were statistically evaluated using JMP Pro 15 (SAS Institute, Inc, Cary, NC) and p values for comparisons are reported. Qualitative analysis was used to explore residents' attitudes towards the teaching materials.

Results

Of a total of 36 first-year surgery foundation residents considered eligible, 13 residents consented to participate. Seven residents were randomized to the e-learning group and six to the control group. One resident in the control group dropped out from the study because of a clinical emergency. The other 12 residents completed the pre-test, pre-survey and prepared with the e-learning and/or reading materials before the hands-on simulation; all participants completed the simulation training and post-intervention evaluations. Demographics of the participants were similar between the two groups, except for age and gender ($p = 0.046$, 0.038, respectively). All residents had previously taken an ATLS course, and ten had some prior clinical experience with the procedure (either performance of the procedure on a real patient or observation) (Table 1).

Theoretical Knowledge

Overall, all participants showed significant improvement from pre-test to post-test ($p = 0.008$). The median score for the pre-test in the e-learning group was 12 (range: 8-15, 95% CI: 9.5-13.6) and 13 (range: 10-13, 95% CI: 10.7-14.1) in controls; there was no significant difference in baseline knowledge ($p = 0.31$). The median score in post-test was 14 (range: 11-15, 95% CI: 12.1-14.7) in the e-learning group and 13 (range: 12-14, 95% CI: 12.2-14.2) in controls, and there was no significant difference in post-intervention knowledge ($p = 0.48$). When the scores in two tests were compared, the e-learning group showed a slight but significant improvement ($p = 0.047$), while the control group did not ($p = 0.500$) (Figure 2, Table 2).

Technical Skill

The median score for technical skill performance was 50 (range: 47-52.5, 95% CI: 47.8-52.3) in the e-learning group vs 46.5 (range: 36.5-50,95% CI: 13.2-61.4) in controls (p= 0.06) (Table 2). Importantly, all residents (100%) in the e-learning group reached a proficient performance level in the technical skill assessment, whereas only three of five (60%) control residents reached proficiency (Figure 3). Inter-rater reliability was fair at 0.38.

Usability

All subjects (100%) in the e-learning group responded positively (agree or strongly agree) to questions in all domains of usability, whereas one to two subjects (20-40%) in control group evaluated neutrally or negatively. However, statistically, there was no significant difference in any questions between the two groups (Table 3, and Figure 4).

Cognitive Load

Three types of cognitive load: intrinsic, extraneous, and germane cognitive load were assessed. The median scores were 1.9 (range: 0-4.25, 95% CI: 0.1-3.6), 0.4 (range: 0-1, 95% CI: 0-0.8), 9.2 (range: 6.5-10, 95% CI: 7.8-10.5), respectively in the e-learning group and 3.4 (range: 1-7.8, 95% CI: 0.1-6.6), 2.1 (range: 0.7-5.7, 95% CI: -0.5-4.7), 6.5 (range: 4-9.8, 95% CI: 2.9-10.1), respectively in the control group. A significant difference was observed between study groups in extraneous cognitive load and germane cognitive load (p= 0.04, 0.03, respectively), whereas there was no significant difference in intrinsic cognitive load (p= 0.37) (Table 4, and Figure 5).

Attitudes and Feedback

Residents also provided free-text comments in the post-intervention survey. In the e-learning group, five residents (71%) liked multimedia materials, and students suggested voice-over for the didactic content and immediate quizzes on spot as ways to improve the module. In the control group, three residents (60%) in control group found the ATLS manual interesting because they are familiar with the material, and the graphics were of good quality. Students suggested more videos, interactive content, and reduction of the load would improve the educational experience.

Discussion

Since high complication rates for chest tube insertion have been seen even after simulation exposure, repeated training of the procedure has been recommended to reduce complications [9]. In the present study, using an instructional design framework, we created a new e-learning module to optimally prepare for in-person hands-on simulation training, for junior surgical residents as part of a blended learning delivery mode, with the goal of optimizing the learning experience. We then examined the logistics and feasibility of implementing this teaching program. In this blended learning program, the newly developed e-learning module, compared to standard reading materials, was likely to contribute to improvement of residents' knowledge and skill with optimized learning experience.

In the field of surgical education, primary interests of research are usually acquisition of knowledge acquisition, technical skills, or non-technical skills [22]. It is understandable because the primary aims of surgical education are to provide safer clinical practice for future patients. However, it is sometimes challenging to encourage surgical trainees to engage in training programs, while they are occupied with clinical duties. Surgical training requires residents to acquire a large amount of knowledge and procedural expertise. This is in the context of providing clinical service that is highly demanding. For this reason, learning interventions that optimize cognitive load and that have high usability are attractive to engage the learner and retain the learning. According to cognitive load theory, the information of instruction is obtained separately via visual and audio channels and processed in working memory to construct and store the schema of instruction. However, because of the limited capacity of working memory, the theory emphasizes that factors not contributing to retention should be eliminated [12, 55, 56, 111]. Also, the theory posits that instruction using multimedia is helpful for information processing by stimulating two different sensory channels. It is reported that high cognitive load may negatively influence performance in medical and surgical simulation training [68, 128]. In this study, data revealed consistent intrinsic cognitive load between the two groups but smaller extraneous cognitive in the e-learning group. The result of intrinsic cognitive load reflects the participants' homogeneous backgrounds and similar baseline attitudes towards the procedure. We also assume that extraneous cognitive load was reduced by multimedia and interactive presentations of the e-learning module as best practice of established principles of instructional design, helping the information processing. Consequently, the mitigated extraneous cognitive load induced the greater germane cognitive load resulting in improvement in knowledge, and technical skill as a result of the efficient self-directed learning. It also should be noted that multimedia and interactive content, which were main features of the e-learning module, were favored among residents in e-learning group and requested by residents in control group as can be seen from the open-text comments.

In addition, in a usability questionnaire, all participants in the e-learning group evaluated the module to be high, while the evaluation in control group varied widely. However, the usability survey in the present study did not show any statistical difference between two groups. Possible explanation of the results is that the control group received the reading assignment via the same learning managing system as the one e-learning group used. In terms of human-computer interaction, using the same platform for both groups may have impacted the residents' perception of usability. Likewise, the concept of instructional design has been partly applied by selecting reading materials to allow all residents to achieve the same learning objectives as those of the e-learning module. These similarities may have minimized the differences in perceptions on usability between the groups.

As some residents in both groups already showed excellent scores at baseline, there may been a ceiling effect limiting the opportunity to demonstrate differences between groups. However, the results suggest that blended learning with the e-learning module is likely to improve theoretical knowledge and technical skills of trainees to exceed thresholds that are difficult to reach with only one of simulation training experience. Since we consider the control group also experienced the delivery of blended learning combining asynchronous learning with reading materials and synchronous simulation, we assume the learning in asynchronous component of the blended learning affected the results. The durability of the learning effects and the translation of learning to clinical performance would be important to study in the future.

This pilot study provides important new knowledge about design and assessment, and feedback regarding logistical challenges. However, there are some limitations in this preliminary study. It was not powered sufficiently to show small but significant differences. Although a sample size of 30 participants (or greater) was expected based on recommendations for pilot trial design [129], actual sample size became smaller due to the poor recruitment and constraints imposed due to the coronavirus disease (COVID)-19 pandemic. The low inter-rater reliability also affected the ability to discriminate differences in technical performance. This could have been improved by better training of the raters using pre-recorded videos of performances to align ratings. Moreover, in this study, we did not assess the baseline skill performance for logistical reasons. Because this study was conducted as a pilot trial to investigate the feasibility of the newly developed e-learning module, we did not intervene during the hands-on simulation for ethical reasons in the pilot study. The coaching during the simulation was given by an experienced instructor, blinded to learners' study group. As a result, there may have been some inconsistency between the degree of specific coaching during performance of the simulated chest tube insertion. Although the usability questionnaire was generated from ISO 9241-11 standards and evidence in the literature, the data collection to assess validity and reliability of the questionnaire used to assess usability is ongoing.

The ADDIE framework for instructional design proved very useful for designing this module, but ADDIE is not a one-time methodology but ideally an iterative process, in which the module is revised after implementation and evaluation. Informed by our findings in the pilot and recognizing the limitations of the study this e-learning module will be refined and improved.

Conclusions

We developed an e-learning module for chest tube insertion using a framework of instructional design as a preparation for hands-on simulation training, where the module was highly interactive and characterized by high quality multimedia. In this blended learning, residents who prepared with this e-learning module showed improvement significantly in knowledge and reached or exceeded proficiency level of skill performance. The module also showed optimal cognitive load and its usability was highly rated by all residents. Lessons learned from this pilot study will form the basis for provision of a high-quality procedural training, and the principles from this study can be used to inform development of future programs with education technology in surgery.

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Table 2. Demographics of study participants.

Variables	**E-learning group**	**Control group**	**p value**
Age, Median (Min-Max)	26 (24-29)	28 (28-30)	0.046
Gender (Male/Female)	3/4	5/0	0.038
Dominant hand, (Right/Left/Ambidextrous)	6/1	4/0/1	0.35
Prior experience of ATLS			1.00
-Taken the course	7	5	
-Never	0	0	
Prior clinical experience of chest tube insertion			0.28
-Performed on a real patient	3	3	
-Observed	4	1	
-Never	0	1	
Specialty program			0.37
-General Surgery	4	2	
-Cardiac Surgery	1	0	
-Neurosurgery	0	1	
-Orthopaedics	0	1	
-Urology	1	0	
-Otolaryngology	1	0	
-Obstetrics and gynecology	0	1	

Table 3. Scores in knowledge tests and skill assessment.

Variables	**E-learning group**	**Control group**	**p value**
Knowledge test			
-Pre-test	12 (8-15)	13 (10-13)	0.31
-Post-test	14 (11-15)	13 (12-14)	0.48
Technical skill	50 (47-52.5)	46.5 (36.5-50)	0.06

Table 4. Results of reported usability from the survey.

Question (domain of usability)	**E-learning group**	**Control group**	**p value**
The content of the given provided material about chest tube insertion adequately provided me with new knowledge. (Effectiveness)	5 (4-5)	4 (3-5)	0.06
The content of the material about chest tube insertion helped me gain a new skill or strengthen the skill. (Effectiveness)	5 (4-5)	4 (3-5)	0.06
The content in the provided material about the chest tube insertion reflect the learning objectives. (Effectiveness)	5 (4-5)	5 (3-5)	0.62
I was able to understand the content on chest tube insertion in an appropriate amount of time. (Efficiency)	5 (4-5)	5 (3-5)	0.62
The content of the given material was easy to understand. (Efficiency)	5 (4-5)	5 (2-5)	0.29
I enjoyed learning with the provided material. (Satisfaction)	5 (4-5)	4 (2-5)	0.20

Table 5. Results of reported cognitive load from the survey.

Question (type of cognitive load)	**E-learning group**	**Control group**	**p value**
The topics covered in the materials were very complex. (Intrinsic cognitive load)	2 (0-5)	2 (1-7)	0.32
The provided materials covered surgical technique that I perceived as very complex. (Intrinsic cognitive load)	2 (0-7)	3 (1-8)	0.28
The provided materials covered concepts that I perceived as very complex. (Intrinsic cognitive load)	2 (0-4)	3 (1-7)	0.21
The instructions in the provided materials were very unclear. (Extraneous cognitive load)	1 (0-3)	1 (0-6)	0.20
The instructions were, in terms of learning, very ineffective. (Extraneous cognitive load)	0(0-2)	1 (1-7)	0.06
The instructions in the module were full of unclear language. (Extraneous cognitive load)	0(0-1)	2 (1-4)	0.008
The provided materials really enhanced my understanding of the topics covered. (Germane cognitive load)	10 (6-10)	5 (1-10)	0.046
The provided materials really enhanced my knowledge and understanding of chest tube insertion. (Germane cognitive load)	10 (6-10)	8 (4-10)	0.20
The provided materials really enhanced my understanding of the surgical procedure. (Germane cognitive load)	10 (7-10)	8 (4-10)	0.20
The provided materials really enhanced my understanding of concepts and definitions. (Germane cognitive load)	10 (7-10)	8 (4-10)	0.12
Mean of intrinsic cognitive load	1.9 (0-4.25)	3.4 (1-7.8)	0.37
Mean of extraneous cognitive load	0.4 (0-1)	2.1 (0.7-5.7)	0.04
Mean of germane cognitive load	9.2 (6.5-10)	6.5 (4-9.8)	0.03

Figure 2. CONSORT flow diagram of study recruitment.

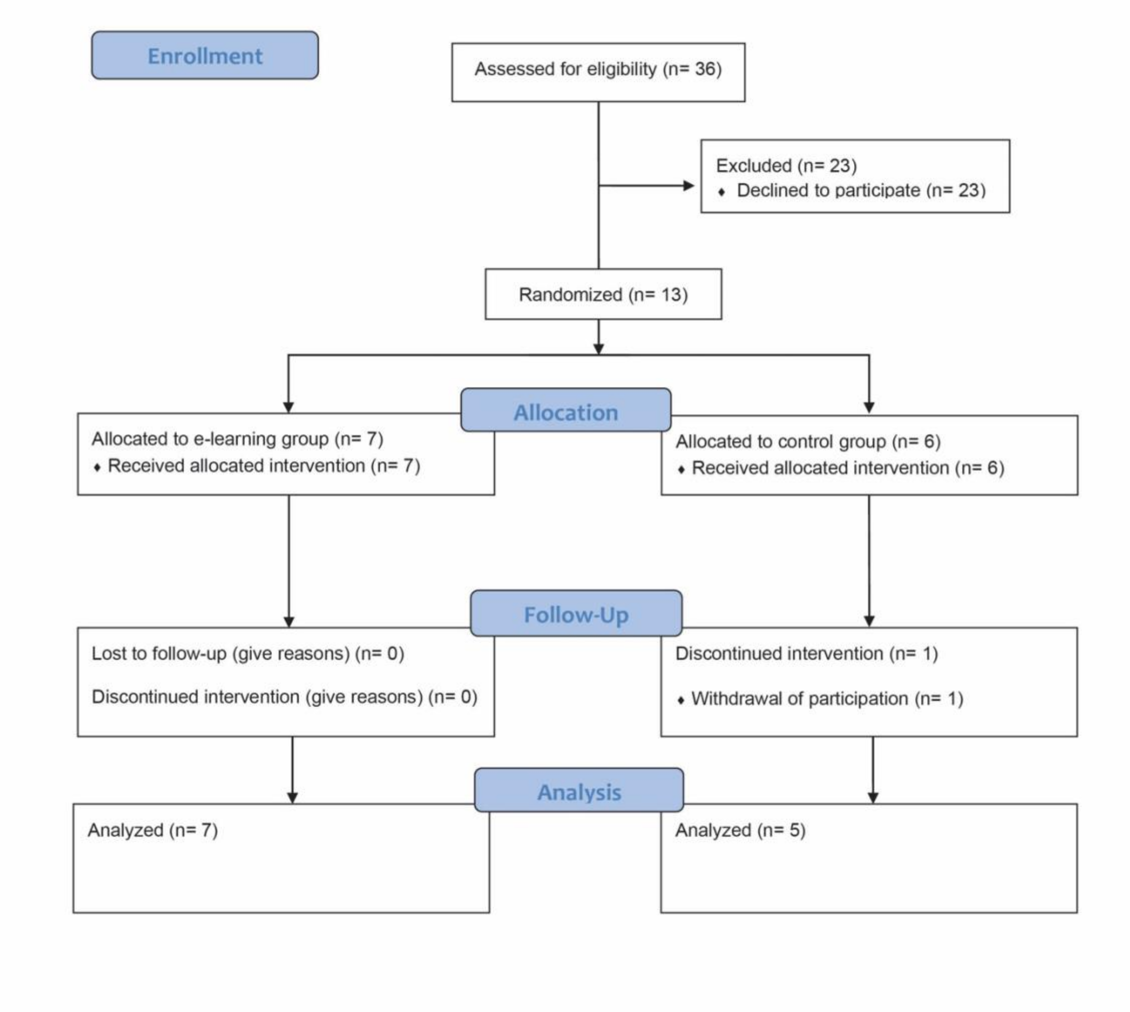


Figure 3. Scores in knowledge tests.

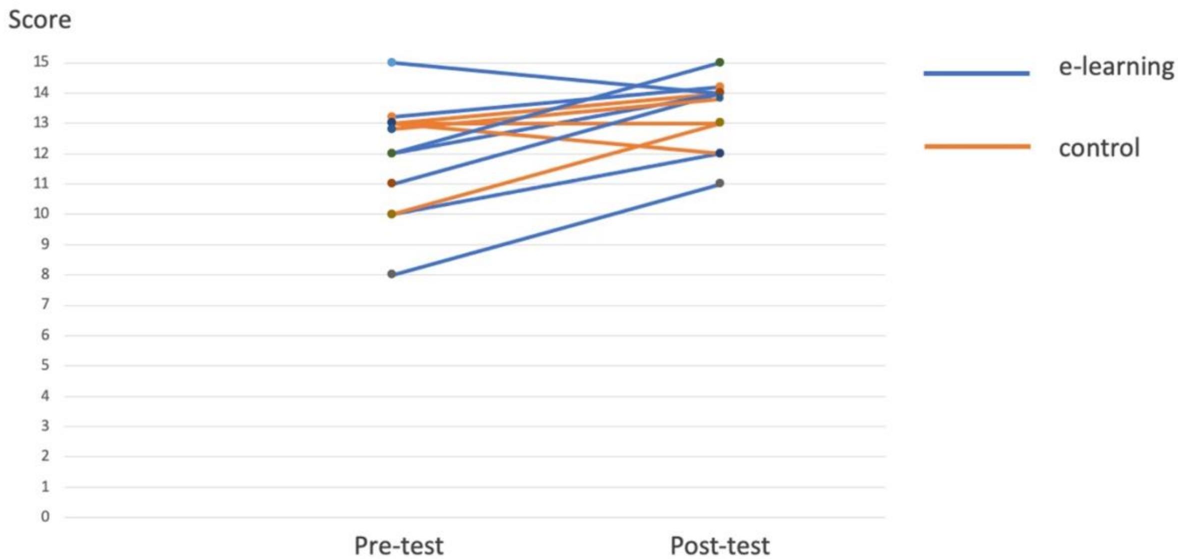
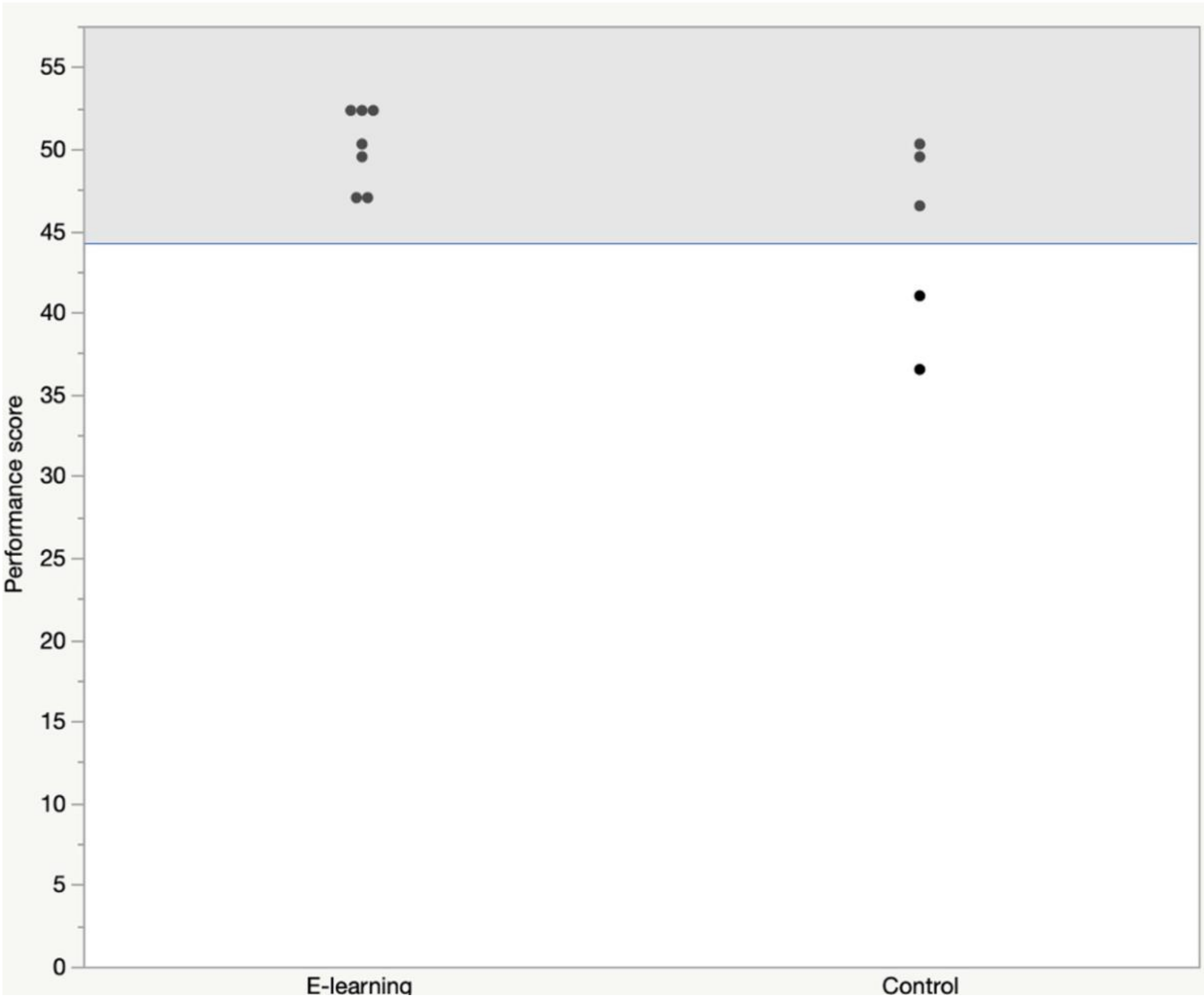
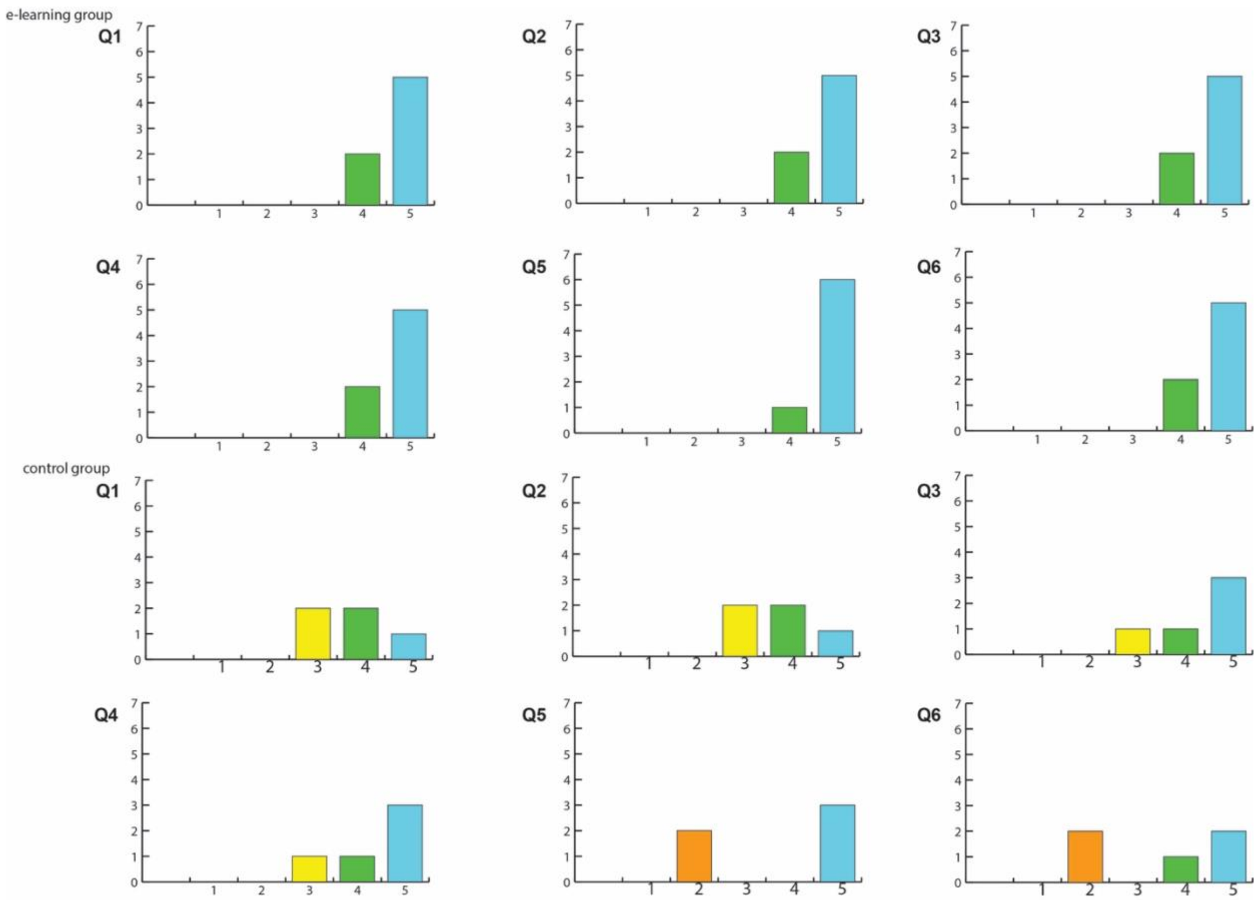


Figure 4. Scatter plot of score in skill assessment.



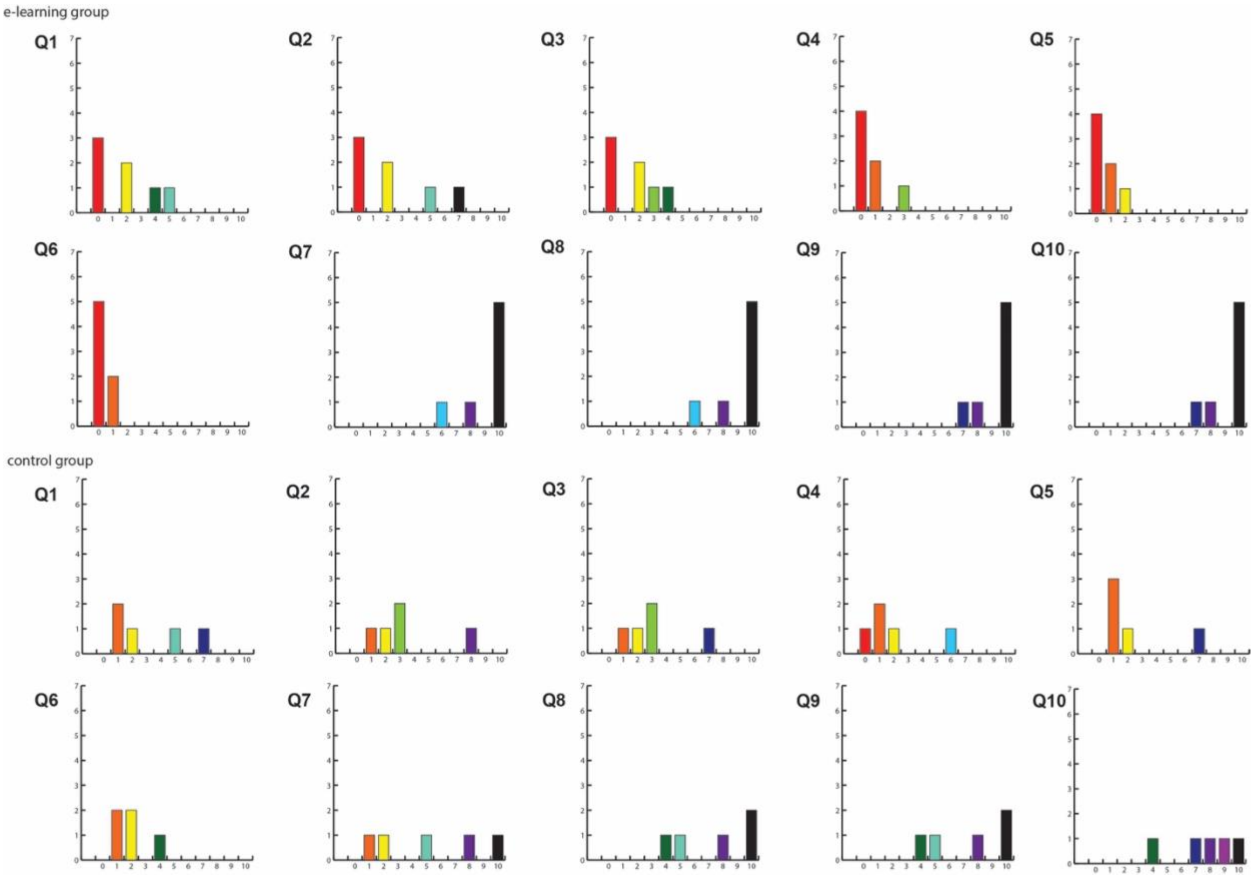
Score >= 44 were considered a proficiency level.

Figure 5. Usability survey results.



X axis shows value, and y axis shows 5-point Likert scale: 1 means strongly disagree, and 5 means strongly agree. Q1: The content of the given provided material about chest tube insertion adequately provided me with new knowledge (Effectiveness). Q2: The content of the material about chest tube insertion helped me gain a new skill or strengthen the skill (Effectiveness). Q3: The content in the provided material about the chest tube insertion reflect the learning objectives (Effectiveness). Q4: I was able to understand the content on chest tube insertion in an appropriate amount of time (Efficiency). Q5: The content of the given material was easy to understand (Efficiency). Q6: I enjoyed learning with the provided material (Satisfaction).

Figure 6. Cognitive load survey results.



X axis shows value, and y axis shows 11-point Likert scale: 0 means not at all the case, and 10 means completely the case. Q1: The topics covered in the materials were very complex (Intrinsic cognitive load). Q2: The provided materials covered surgical technique that I perceived as very complex (Intrinsic cognitive load). Q3: The provided materials covered concepts that I perceived as very complex (Intrinsic cognitive load). Q4: The instructions in the provided materials were very unclear (Extraneous cognitive load). Q5: The instructions were, in terms of learning, very ineffective (Extraneous cognitive load). Q6: The instructions in the module were full of unclear language (Extraneous cognitive load). Q7: The provided materials really enhanced my understanding of the topics covered (Germane cognitive load). Q8: The provided materials really enhanced my knowledge and understanding of chest tube insertion (Germane cognitive load). Q9: The provided materials really enhanced my understanding of the surgical procedure covered (Germane cognitive load). Q10: The provided materials really enhanced my understanding of concepts and definitions (Germane cognitive load).

Supplemental material C. Global rating scale for skill assessment.

	1: Poor	2	3: Sufficient	4	5: Excellent
Correct identification of incision location	The chosen dissection plane deviates tremendously from the suggested site		The chosen dissection plane deviates slightly from the suggested site		4th or 5th intercostal space: mid/anterior axillary line
Correct plane of dissection subcutaneously	Both distance and execution of tunneling lack accuracy		Either distance or execution of tunneling lack accuracy		Both distance and execution of tunneling are accurate
Blunt dissection on top side of rib	Flawed dissection; not carried out on top side of rib		Solid dissection carried out with minor errors		Confident cut through the subcutaneous layers and intercostal muscles
Clamp guarded with other hand during dissection and pulled out without closing the instrument	Hazardous handling that might affect the patient		Improvable handling		Confident handling of the used instruments
Digital exploration of pleural cavity on chest wall to rule out adhesions	No digital exploration		Finger inserted in pleural cavity		Digital exploration in 360-degree with turning of the wrist rules out adhesions
Drain guarded with hand while being inserted	Hazardous handling that might affect the patient		Improvable handling		Confident handling of the used instruments
Drain inserted into pleural cavity	Tube advancement is carried out poorly		Tube advancement is carried out with minor errors		Forceps unclamped in time and tube manually advanced
Estimate made of drain length	Estimate deviates tremendously from rater’s opinion		Estimate deviates slightly from rater’s opinion		Optimal estimate stated
Secure fixation of the tube to the skin	Fixation of the tube to the skin is not done		Tube is fixed to the skin but it’s loose		Tube fixation to the skin is secured by a tight knot
Economy of time and motion	Many unnecessary or disorganized movements		Organized time and motion, some unnecessary movement		Maximum economy of movement and efficiency
Amount of help and assistance needed from instructor	Task couldn’t be carried out without extensive assistance		Trainee only raises important questions in order to maximize performance		Almost no assistance needed; task is carried out confidently

CHAPTER 5. DISCUSSION

5.1 Implications

Throughout this thesis, we identified several gaps to facilitate digital education for procedural training and suggested potential solutions conducting a pilot study. We believe this thesis provide the guidance for creating of an educational program for procedural training with education technology.

The main strength of this thesis is that this the pilot study demonstrated the effectiveness of blended learning with an e-learning module and in-person simulation for procedural training. The evidence for the effectiveness of this blended learning program combining asynchronous and synchronous components has been reported in medical education, but not yet for procedural training [101-103]. In general, the benefit of blended learning is reported its flexibility of the e-learning, in which learners can prepare for the synchronous component with the convenience. Compared to traditional teaching like lectures, e-learning allows access from anywhere, at any time, multiple time of access, and progression by a learner's pace. In addition to this well-known feature of the e-learning, the present study highlighted the importance of design of the asynchronous component in blended learning because both groups experienced blended learning through the same learning management system and the same simulation training. In the pilot study, we found the addition of an online educational module, containing multimedia and a high level of interactivity, led to improved knowledge and skill, better usability and more optimal cognitive load than the control group, who received only reading materials prior to in-person simulation training. This successful development of the e-learning module was possible because we designed this module to address the clinical issues and gaps found in our literature review.

There are barriers for educators to create and facilitate e-learning because most clinicians have not received formal training as clinical educators [107-109]. Educational theories and learning principles are not always considered well in surgical training programs with education technology, but this study demonstrated, the first author, as a clinician, and a novice for creating educational programs, successfully developed the procedural training under the appropriate guidance of an expert of e-learning and education technology. When creating the e-learning module, we used the ADDIE as a framework of instructional design. Through its iterative and analytical process, credibility is added to the products. The ADDIE framework can provide the practical procedural guidance for creation of educational programs [116].

We have also recognized some difficulties in training for surgical residents: it is challenging for surgical trainees to engage in traditional training programs because they are occupied with clinical duties. Further, it is also difficult for surgical trainees to reach sufficient proficiency of knowledge and technical skills with only one-time simulation training. We assumed that educational intervention in procedural training for chest tube insertion would be a good example because the procedure is widely taught to surgical trainees and is high stakes [9]. In addition, because McGill University offers simulation training for first-year surgical residents for chest tube insertion, we could provide the e-learning module in advance of the simulation training as the blended learning without major logistical challenges.

We first conducted a literature review "Digital Education in General Thoracic Surgery" [14] because general thoracic surgery requires surgical trainees to master high stakes procedures. From this review it was evident that chest tube insertion was one of the most frequently taught procedures using digital education technology. The literature review identified three randomized controlled trials (with two single cohort studies). The value of these studies was limited due to experimental design. For example, Haubrcuk, et al. assessed the effect of app-based serious games on procedural skill, for chest tube insertion and thoracentesis [27]. Although the intervention led to better performance, the design of the controls may not be appropriate because the control group were instructed in a different procedure. This literature review provided valuable information for us to design our study to better compare different teaching strategies. Another finding from the literature review was the lack of standard assessment tool, and the generalization of subjective evaluation of learning experience has been challenging. As we found in the work of "Digital Education in General Thoracic Surgery" [14], there are a variety of items evaluated for assessment of learning experience. However, the validity of these items has not been considered. For example, usefulness and confidence were frequently evaluated items as well as satisfaction. The term of usefulness is considered to include general perceptions on training programs, but the definitions were vague among studies [18, 20]. About confidence, it is unclear if high-level confidence is directly associated with high-level competency. Especially, during surgical procedures, it is critical to be aware of safety and to pay attention to every detail anytime so that overconfidence should be avoided. Therefore, we did not include usefulness and confidence in the manuscript of the pilot study. Concepts of usability and cognitive load theory are important considerations when designing educational interventions. Because these properties can be measured, feedback regarding these factors can be used to modify the educational program and optimize the learning experience.

The pilot study demonstrated that the blended learning program, combining an e-learning module and in-person simulation, resulted in lower extraneous and greater germane cognitive load. Theoretically, it is recommended that extraneous load should be minimized because extraneous load results from unclear instructions and distractions, while germane load should be increased to promote learning. A prior study by Sewell, et al., shows that extraneous cognitive load increased with learners' fatigue, and we know how demanding residents' clinical duties are [87]. It is safe to say, from the findings in the pilot study, we could provide a more efficient and effective training program by alleviating the demands on trainees while they are learning. There are few studies that evaluate the relationship between blended learning and cognitive load. By incorporating an asynchronous component within a blended learning program, that can be accessed when convenient for the learner, we have planned our intervention to diminish extraneous cognitive load. Nazari, et al., investigated the effects of preparation with an instructional video for procedural training (open inguinal hernia repair) on cognitive load and surgical performance [82]. They demonstrated that a segmented instructional video resulted in lower extraneous cognitive load and better surgical performance than a continuous video. We hypothesize that segmentation provides smaller portions of information with pauses, allowing learners to prepare at their own pace. Since the concept of segmentation was also applied in our pilot study, this prior study is consistent with our results. Thus, we suggest that the methodology and conceptual framework used in this pilot study can be applied to other surgical procedural training programs. Arora, et al. reported that usability evaluation has been used much for blended learning programs in healthcare education, and suggested effectiveness, efficiency, and satisfaction are critical domains of usability of blended learning, adopting the framework suggested by ISO [124-126]. Although the data collection for validation of their suggestions regarding useability is still ongoing, we expect it will be an important contribution to optimize the learning experience with education technology, in addition to application of principles of cognitive load.

5.2 Limitations

In the manuscript of "Blending E-learning and Simulation Educational Program for Procedural Training: A Pilot Study of Design and Assessment," we mentioned limitations of the pilot study: small sample size, low inter-rater reliability, lack of baseline assessment of technical skill, validity of the questionnaires, and necessity of investigation of retention and clinical transferability.

In addition to these limitations, because the participation to the study was voluntary basis, it is assumed that participants were more motivated population than general surgical resident population; results of this present study might have been biased. Further, we did not undertake analysis for one participant who dropout in the control group. Because of clinical emergency, the participant did not complete pre-test, pre-survey, and reading material. It could be assumed that the participant may have been suffered from overload at that moment from the clinical duty, and the study participation may have been overwhelming. In a study with a larger sample size, association between completion rate and participants' workload at that time may be investigated.

Although the flexibility is widely considered as a major advantage of e-learning, we did not include its assessment in the present study. As mentioned above, because the control group also experienced asynchronous learning through the same online learning management system, participants in the control group could have prepared with reading materials as flexibly as those in the e-learning group. However, compared to traditional passive training learning, the flexible nature of e-learning is obviously beneficial for residents who have restrictions of training time.

We conducted a pilot study with an e-learning module and blended learning as one representative type of digital education and in training for one representative procedure. Although the study showed feasible results in terms of learning experience, we still lack evidence to generalize our findings to other procedures, modalities. and technology. Indeed, further studies are needed to investigate the feasibility of integrating the theories of cognitive load and usability into educational programs with technology in surgery.

5.3 Future Directions

Because the pilot study showed feasible results, we may be able to integrate this blended learning program into the formal training course for surgical residents. When it is realized, another study with a larger sample size to address the limitations of the present study is expected. Through the work of this thesis, we recognize a series of skills how to create and facilitate an e-learning module and blended learning for procedural training. Incorporation of the cognitive load theory, the concept of usability, and use of framework of instructional design can be applied not only to training programs for other surgical procedures but also to training programs widely in medical education. Although available technology in surgery will change overtime by its advancement, the important considerations for creating educational programs still remain. Further, this thesis suggests more versatile possibilities of evaluation of the learning experience. Because cognitive load suggests gaps between the level of trainees' competency [62, 64, 70] and the level of learning task [78], educational programs designed based on data of cognitive load would be more individualized and precise, which is desired in this competency-based medical education era. In addition, we expect that the concept of usability would be widespread in the field of surgical education, and we could generalize the evaluation of usability of each education technology.

5.4 Conclusions

In conclusion, this thesis explored how to design and assess an educational program with education technology for procedural training. First, we identified gaps in the surgical education through the literature review. Lack of standard assessment tool for evaluation of learning experience, barriers to create e-learning among clinical educators, and a difficulty in logistics for residents' procedural training were revealed. To fill the gap, we developed a blended learning program for procedural training, combining an e-learning module with multimedia and interactive content and in-person simulation, and the program successfully improved learning experience, knowledge, and technical skill. Instructional design principles, cognitive load theory, and concepts of usability were incorporated in design and evaluation of the blended learning program. This thesis demonstrated the effectiveness of blended learning for procedural training and highlights a necessary teaching strategy in surgical education.

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CHAPTER 7. APPENDICES

Appendix A. Consent form for residents.

McGill

CONSENT FORM FOR EDUCATIONAL RESEARCH

(Resident)

Study Title: Chest tube insertion: a randomized controlled trial of feasibility and efficacy of an e-learning curriculum for knowledge and skill acquisition in junior surgical residents
Principal Investigator: Dr. Gerald Fried
Co-investigators: Dr. Gabriela Ghitulescu, MD, Dr. Junko Tokuno, MD.
Institution: McGill University, Department of surgery
Sponsor: Ingram Exchange Scholarship

Background:
Chest tube insertion is a life-saving procedure required for pleural disorders, such as pneumothorax and hemothorax. Traditionally, it is taught in lectures and/or with hands-on training. E-learning modules are a potential alternative to improve knowledge and skill acquisition in junior surgical trainees. The value of this educational approach on the acquisition of skills related to chest tube insertion is currently unknown.

Purpose of the Study:
The purpose of this study is to examine the effectiveness of an online teaching module on the acquisition of knowledge and technical skills related to chest tube insertion.

Study Procedures*:*
If you agree to participate in the study, you will be randomly assigned (similar to a flip of a coin) to one of the two groups in this study.
The chest tube insertion procedure is included in the standard educational course for surgical residents. It is organized by the McGill University Surgical foundation and held at the Steinberg centre for Simulation and Interactive learning. Basic surgical skills such as chest tube NG tube, foley catheter, tracheostomy, etc. are included in the hands-on course.
Participants in both groups will receive a list with recommended educational materials about chest tube insertion. The recommended educational materials are available on-line. We will ask you to prepare for the hand-on course using these materials. We will provide the list about one week prior to the date of the standard hands-on course. The online materials will include indications, equipment, techniques, and complications of the chest tube procedure; however, the presentation format of the materials will differ between the two groups. A member of the study team, not involved in formal training, will be available to help if any questions arise. It may take about 1 to 2 hour(s) to complete the online materials, however it will be entirely up to you to access the materials as many times as you want. *We kindly ask you not to share with your colleagues the content of the online materials you have will access to.*
During the standard teaching course two assessors will observe you when you perform the chest tube insertion only. After the course is finished, the assessors will complete the objective

structured assessment of technical skills tool for chest tube insertion (OSATS) to evaluate your skills of the procedure. ***The OSATS is not part and will not be used in any of your formal evaluations.***

To assess your knowledge about the chest tube procedure, we will ask you to respond to two multiple choice questions tests: 1) before you receive the information sheet with the study online materials and 2) after the standard hands-on course. In addition, we will ask you few demographic questions (e.g., age, handedness, prior clinical exposure to chest tube insertion etc.), and your perspectives regarding the provided teaching methods. Responding to these questions will take about 20 minutes.

Confidentiality:

All data obtained will be coded and kept confidential. To protect your privacy, the information collected for study will be identified only with a code. Only the investigators of the study will have access to the password protected file that links your personal information (i.e., name) to the study code. The file linking the ID number of participants and their experience will be password protected with only investigators having access to it. The study investigator will use the study information collected about you for research purposes, only to reach the study goals as they are explained in this Information and Consent Document. The results of the evaluations will be kept confidential. The participation in this study provides no additional risk to the participants.

The evaluations will not be used for the purposes of promotion and formal evaluation. Data will be kept on a password protected computer and the data will be stored at the Steinberg-Bernstein Centre for Minimally Invasive surgery, Montreal General Hospital (Montreal, QC) and will be made available only to the investigators in this study. The data will be kept for 7 years after the study completion and then discarded.

Risk and Benefits:

We do not anticipate any risks associated with this study. You are not expected to directly benefit from participating in this study; however, your participation in this study may help you to improve your knowledge and skills of chest tube insertion.

Questions and contact information:

If you have any questions regarding the study, you may contact the investigators: Dr. Gerald Fried or Dr. Junko Tokuno, tel: 514-9341934, ext. 42745. For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact the McGill University ethics office at 514-398-8302.

Voluntary participation and/or withdrawal:

Your participation in the study is voluntary. Refusal to participate or withdrawal from the study at any time will not involve any penalty or prejudice. We may use the data collected prior to your withdrawal unless you advise us that you would like all your previous data to be destroyed or not to be used.

Consent:

I am aware that participation is voluntary and that refusal to participate or withdrawal from the study at any time will not involve any penalty or prejudice. I have read the above information and have had the opportunity to have all of my questions answered to my satisfaction. I agree to participate in this study, and I have been given a signed copy of the research information and consent form. I am aware that by signing this form I do not give up any of my legal rights.

Signature of Participant	Signature of Person performing informed consent
Name of Participant	Name of Person performing informed consent
Date	Date

Appendix B. Multiple choice questions for pre-test.

(Item with * is the correct answer)

1. Which of the following symptoms or signs <u>is least likely</u> to be found in patients with tension pneumothorax?

    a. Air hunger
    b. Tachypnea
    c. Tracheal deviation
    d. Neck vein distension
    e. Dull to percussion *

2. Which of the following symptoms or signs <u>is least likely</u> to be found in patients with massive hemothorax?

    a. Tachypnea
    b. Tachycardia
    c. Hypotension
    d. Decreased breath sounds
    e. Neck vein distension *

3. Which of the following is most correct about tension pneumothorax?

    a. In tension pneumothorax, the mediastinum is deviated to the side of the injury.
    b. Differential diagnosis of tension pneumothorax from cardiac tamponade can be difficult. *
    c. Bilateral absence of breath sounds is observed.
    d. Tension pneumothorax cannot be detected by clinical findings.
    e. Distended neck vein is a sign of increased venous return caused by positive pressure in the thoracic cavity.

4. Which of the following is most correct about massive hemothorax?

    a. Massive hemothorax is defined as more than 1500mL blood accumulation in the chest cavity. *
    b. A chest tube of 18 Fr is optimal for drainage.
    c. Tracheal deviation is observed commonly.
    d. A patient with the rate of continuing blood loss (200 mL/h over 2 hrs) is an absolute indication for thoracotomy.
    e. CT scan should be the first radiologic investigation if massive hemothorax is suspected.

5. Of the following, which condition is <u>least likely</u> to require treatment by chest tube drainage?

    a. Pleural effusion due to congestive heart failure *

b. Pleural effusion after cardiac surgery
c. Empyema
d. Chylothorax
e. Simple pneumothorax under positive ventilation

6. What of the following is <u>least</u> relevant information prior to consideration of tube thoracotomy?

   a. Coagulopathy
   b. Skin infection over the incision site
   c. History of the past chest surgery
   d. Vital signs
   e. Alcohol intake *

7. All of the following should be included in a chest tube insertion set EXCEPT:

   a. Scalpel
   b. Kelly clamp
   c. 10cc syringe
   d. 20 G IV catheter *
   e. Nonabsorbable suture

8. What is/are possible complication(s) of chest tube insertion? Select all.

   1. Hemothorax
   2. Diaphragm injury
   3. Pulmonary edema
   4. Empyema
   5. Aortic injury

   a. (1, 2)
   b. (1, 2, 3)
   c. (2, 3, 4)
   d. (1, 2, 3, 4, 5) *
   e. None of the above

9. According to ATLS guidelines, where is the most appropriate location of the incision for placement of chest tube for a patient with traumatic pneumothorax?

   a. 5th intercostal space-mid-axillary line *
   b. 4th intercostal space-mid-clavicular line
   c. 4th intercostal space-posterior axillary line
   d. 2nd intercostal space-mid-clavicular line
   e. 2nd intercostal space-anterior axillary line

10. Which is correct about landmarks localizing the incision site for chest tube placement?

a. Nipple is a marker for the 4th intercostal space *
b. Inferior mammary line is an accurate way to locate 7th intercostal space
c. Xiphoid process identifies best location to place chest tube for drainage of pleural fluid
d. Never insert a chest tube posterior to the pectoralis major
e. Chest tube insertion should be placed through the latissimus dorsi

11. Local anesthesia should include all of the following layers EXCEPT?

a. Visceral pleura *
b. Fascia of intercostal muscle
c. Subcutaneous tissue
d. Periosteum of a rib
e. Skin

12. According to ATLS guidelines, which size of incision is recommended for chest tube insertion for a patient with traumatic pneumothorax?

a. 1 cm
b. 3 cm *
c. 6 cm
d. 8 cm
e. 10 cm

13. Which is correct description during chest tube insertion?

a. A tube should be directed towards apex of pleural cavity for drainage of pleural effusion
b. Dissection should be performed at the upper edge of a rib. *
c. Skin incision should be made vertically between 2 ribs.
d. For tension pneumothorax the chest tube should be connected to wall suction to rapidly relieve pneumothorax.
e. Fogging of the lumen of the tube after insertion describes incorrect placement of the tube.

14. Which is correct description during chest tube insertion?

a. Estimate the depth of the chest tube by placing the tip near clavicle. *
b. Finger sweep is performed to enlarge the intercostal space.
c. For adult thoracic trauma, chest tubes smaller than 18 Fr should be selected to drain massive hemothorax.
d. Digital exploration is unnecessary when you hear clear pop sound after insertion of Kelly clamp into chest cavity.
e. The Kelly clamp should be held with only the dominant hand for entry into the pleural space for optimal control.

15. Which is the most appropriate description after chest tube insertion?

   a. Tube can be advanced deeper if the drainage is not efficient.
   b. Suction should be set -5 cmH_2O.
   c. Position of the chest tube can be identified by chest X-ray. *
   d. Tube should always be clamped when changing the patient’s position in bed.
   e. Keep the wound open to make it dry.

Appendix C. Multiple choice questions for post-test.

(Item with * is the correct answer)

1. Which of the following symptoms or signs <u>is least likely</u> to be found in patients with tension pneumothorax?

   a. Tracheal deviation
   b. Air hunger
   c. Neck vein distension
   d. Dull to percussion *
   e. Tachypnea

2. Which of the following is correct about tension pneumothorax?

   a. In tension pneumothorax, the mediastinum is deviated to the opposite side of initial wound. *
   b. Bilateral absence of breath sounds is observed.
   c. Tension pneumothorax cannot be detected by clinical findings.
   d. X-ray examination before drainage is necessary.
   e. Differential diagnosis of left-sided tension pneumothorax from cardiac tamponade is easy.

3. Which of the following symptoms or signs <u>is least likely</u> to be found in patients with massive hemothorax?

   a. Respiratory distress
   b. Tracheal deviation *
   c. Tachycardia
   d. Decreased breath sounds
   e. Dull to percussion

4. Which of the following is most likely to be the indication for thoracotomy in a case of hemothorax?

   a. The rate of continuing blood loss (200 mL/h over 1 hr)
   b. Initial amount of drainage over 800 mL.
   c. Penetrating wound in the anterior mediastinal box. *
   d. 1000 mL or more blood accumulation in the chest cavity.
   e. The rate of continuing blood loss (100 mL/h over 4 hrs)

5. Of the following, which condition is <u>least likely</u> to require treatment by chest tube drainage?

   a. Empyema

b. Malignant effusion
c. Pneumothorax without symptoms *
d. After lung resection
e. After cardiac surgery

6. What of the following is <u>least</u> relevant information prior to consideration of tube thoracotomy?

a. Last meal *
b. Skin infection over the incision site
c. Hemodynamic stability
d. Medication
e. History of the past chest surgery

7. All of the following should be included in a chest tube insertion set EXCEPT:

a. Local anesthesia
b. Sterilized gloves
c. Disinfect
d. Drapes
e. Ultrasonography *

8. What is/are possible complication (s) of chest tube insertion? Select all.
1. Liver injury
2. Local infection of the site of incision
3. Intercostal neuralgia
4. Subcutaneous emphysema
5. Tube blockage

a. (1, 2, 3)
b. (1, 3, 5)
c. (2, 4, 5)
d. (1, 2, 3, 4, 5) *
e. None of the above

9. According to ATLS guidelines, where is the most appropriate location of the incision for placement of chest tube for a patient with traumatic pneumothorax?

a. 2^{nd} intercostal space on anterior axillary line
b. 4^{th} intercostal space on mid-axillary line *
c. 4^{th} intercostal space on mid-clavicular line
d. 5^{th} intercostal space on posterior axillary line
e. 5^{th} intercostal space on mid-clavicular line

10. Which is correct about landmarks localizing the incision site for chest tube placement?

a. The inferior angle of scapula is a marker for the 4th intercostal space.
b. Inferior mammary line can be a landmark especially for female patient. *
c. Nipple is a marker for the 3rd intercostal space.
d. Never insert a chest tube anterior to latissimus dorsi.
e. Penetrating external abdominal oblique should be avoided.

11. Local anesthesia should include all of the following layers EXCEPT?

a. Parietal pleura
b. Skin
c. Fascia of intercostal muscle
d. Intercostal vessels *
e. Subcutaneous tissue

12. According to ATLS guidelines, which incision is recommended for chest tube insertion for a patient with traumatic pneumothorax?

a. 0.5 cm vertical to the rib
b. 1 cm horizontal
c. 2 cm parallel to the rib *
d. 4 cm vertical to the rib
e. 5 cm horizontal

13. Which is correct description during chest tube insertion?

a. Estimate the depth of the chest tube by placing the tip near the clavicle. *
b. Blunt dissection should be avoided.
c. A tube should be directed towards anterior and the apex of pleural cavity for drainage of pleural effusion.
d. Subcutaneous anesthesia is effective for the parietal pleura too.
e. Dissection should be performed at the lower edge of a rib.

14. Which is correct description during chest tube insertion?

a. Insert the tube deeper if the drainage is not efficient after fixation.
b. To drain massive hemothorax, chest tubes greater than 28 Fr should be selected. *
c. When using 32 Fr chest tube, tube blockage never happens.
d. Fogging of the lumen of the tube after insertion describes incorrect placement of the tube.
e. Tube should be clamped when changing the patient's position in bed to control the intrathoracic pressure.

15. Which is the most appropriate description after chest tube insertion?

a. Monitoring of SpO2 is necessary even if the patient's breathing is improved by the drainage. *
b. After chest tube insertion, if drainage of blood, clear fluid or air is observed, it means the placement is done correctly, so X-ray confirmation is not necessary.
c. Tube should be fixed loosely to the skin so that it can be removed or replaced easily.
d. Pop sound is heard when puncturing intercostal muscles.
e. Insert the entire length of the chest tube into the pleural cavity.

Appendix D. Terms and definitions.

General thoracic surgery: a field of surgery mainly focusing on benign and malignant lung and mediastinal diseases, not involving the heart and aorta.

Blended learning: combination of asynchronous learning (e.g., e-learning) and in-person/synchronous learning.

Education technology: technologies used to facilitate educational programs.

Digital education: educational programs using digital technologies, such as e-learning and virtual reality simulation.