Design of a Simulation-Based Training for Flexible Bronchoscopy

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Abstract

Background/aim: Medical training based on simulators is a patient-safe and cost-effective addition to the traditional apprenticeship model. Instead of letting patients bear the burden of beginner's mistakes, trainees can acquire skills for flexible bronchoscopy (FB) before the first patient contact on simulators. This study's aim was to gain insight into the required skills for FB, their underlying cognitive aspects (e.g. cues, goals, difficulties) and to what extent they can be trained on simulators.

Method: (1) Qualitative Document Analysis of four established FB guidelines and a simulation-based curriculum. (2) Qualitative Interview Study: Four Dutch pulmonologists, one resident and one technical physician performed a diagnostic FB on a virtual reality (VR) simulator (10-22 min.) which was video-recorded. Participants engaged in retrospective think-aloud while watching their performance on video. A semi-structured interview helped clarify concepts and opinions about simulation-based training.

Results: Seven skills were identified which are crucial for performing a FB. Participants agreed that only two of them can be trained on the VR simulator: (1) Handling the bronchoscope and (2) Inspecting the airway. For the other skills, the VR simulator was considered too inaccurate to serve as a training modality. The results provide detailed descriptions of a diagnostic FB performance (e.g. cues, goals, difficulties) and the VR simulator's (in)adequacy for training and assessing these skills.

Conclusion: Simulation-based training should combine different types of simulators. The VR simulator's inaccuracies should be improved to optimize learning experiences. Disagreements about execution of skills should be resolved among experts to reach consensus about what to train and thus, how to assess the level of skill of a trainee. Often discarded but worth mentioning is the VR simulator's potential to serve as a device for training and assessing decision-making and communication skills by presenting trainees with various medical scenarios (e.g. complications) in which they have to appropriately react and effectively work and communicate with assistants.

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1. Introduction

Medical training based on simulators has proven to be an efficient, if not superior, way of acquiring basic skills for flexible bronchoscopy compared to the traditional apprenticeship model (Blum, Powers, Sundaresan, 2004). Flexible bronchoscopy is a medical, invasive procedure which is used to examine the airways of a patient (Naur, Nilsson, Pietersen, Clementsen and Konge, 2017; American Thoracic Society, 2015). Figure 1 illustrates a flexible bronchoscopy. By viewing the breathing passages of the lungs and acquiring samples of its mucus or tissue, pulmonologists can diagnose patients with various diseases and complications such as lung cancer, infections and inflammation (American Thoracic Society, 2015; Naur et al., 2017). A bronchoscope which is a thin instrument resembling a tube, is placed in either the mouth or nose of a patient and is inserted into the lungs. The instrument carries a camera which transfers pictures of the airway onto a video screen, enabling a visual exam of the airways. (American Thoracic Society, 2015).

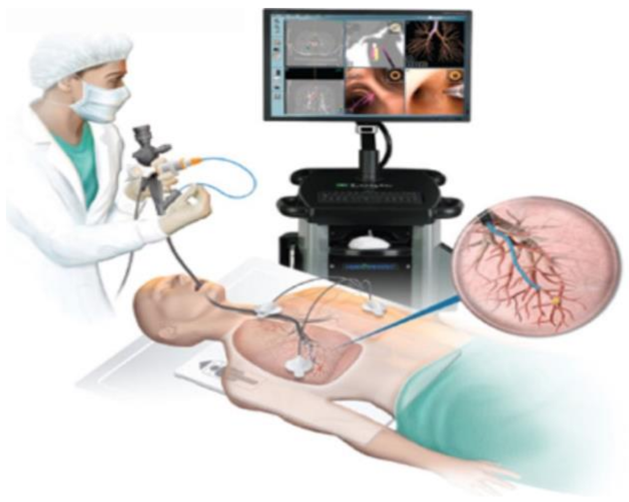

Figure 1: A flexible bronchoscopy procedure (Sydney Respiratory & Sleep Physician, n.d., Retrieved from: https://www.sydneyrespiratoryspecialist.com.au/flexible-bronchoscopy.html)

Traditionally, novice bronchoscopists are trained based on the apprenticeship model: letting trainees observe how experts perform the procedure and then have them gradually gain own experience by practicing on fully awake or consciously sedated patients under supervision (Colt, 2009; Colt, 2001). Different practices exist for establishing a trainee’s basic competency. For instance, British and US guidelines require a trainee to have performed a minimum of 100 flexible bronchoscopies under supervision. However, demanding a fixed number of performed procedures is controversial as trainees differ greatly in their dexterity and confidence. Assessing competency based on performance seems to be a more useful alternative (Konge, Arendrup, Buchwald & Ringsted, 2011).

An essential rationale for the inclusion of simulator is the concern for patient safety: on simulators, trainees can learn surgical skills and make mistakes without harming human patients (Bjerrum, Thomsen, Nayahangan, & Konge, 2018). The simulators' cost-effective, patient-safe characteristics as well as empirically proven efficacy render it vital to include simulation-based training in medical education for flexible bronchoscopy. In order to maximize productivity of this training, it needs to be tailored to the specific needs of the trainees. Simulation-based training is often based on personal opinions of educators or surgeons and on what is feasible and available. An objective needs assessment is needed in order to shift the focus from personal opinions and feasibility to relevance; to identify which skills need to be trained (Nayahangan, Stefanidis & Konge, 2018). Although different flexible bronchoscopy curricula exist, differences in geographical locations, specialities and regional differences in resources render it necessary to explore specific, local learning needs of pulmonologists in the Netherlands in order to contribute to the effort of establishing a national curriculum (Nayahangan, Stefanidis & Konge, 2018). This study aims to explore the procedures, processes, concepts and decision-making of Dutch pulmonologists of different experience levels in order to design a simulation-based training.

1.1 Time for Change: Supplementing the Apprenticeship Model

The traditional apprenticeship model has been a subject of criticism. Practicing on human beings in order to gain experience and bronchoscopy skills puts risks on patients' safety and lacks efficiency: there are neither objective measures of skills nor constant feedback (Davoudi & Colt, 2009). More specifically, Colt et al. (2001) assert that training on real patients may lead to extended invasive procedures, false diagnoses and patient discomfort and morbidity. Konge et al. (2011) note that during the first trimester of training, novice bronchoscopists' procedures have an increased complication rate.

Alternative ways of gaining experience are the use of animals or plastic inanimate models. However, in order for both of these ways to foster learning, a costly supervisor needs to be present to give constructive criticism. The applicability of those modes of learning to human patients is also questionable as animal and inanimate models are not able to reproduce human processes such as respiratory movements, coughing, closure of the vocal cord or obstructions of airway secretions (Colt, 2001). Furthermore, practicing on animal subjects raises ethical and monetary concerns (Blum, 2004).

Numerous studies show that bronchoscopy education can be enhanced by including simulator training (Davoudi & Colt, 2009). Simulators, or virtual reality (VR), are computer-based environments characterized by advanced hard- and software, graphics and perhaps most importantly, tactile, auditory and visual feedback. Through its characteristics, simulators are able to provide users a close-to-reality experience (Colt, Crawford & Galbraith, 2001). For example, the study by Colt (2001) describes the simulator as follows: including a proxy flexible bronchoscope with close resemblance to a conventional one and showing virtual anatomy and realistic images when navigating the proxy bronchoscope through the virtual patient. The images of the airway are based on CT sets. Motions of the proxy bronchoscope are detected by an interface device and the forces normally felt during such movements by a surgeon are reproduced and felt by the user of the simulator. The simulated patient is represented realistically as well by changes in vital signs, breathing, bleeding and coughing.

Studies on the efficacy of simulators have demonstrated simulators to be effective, patient-safe and cost-effective (Davoudi & Colt, 2009). Simulator training allow trainees to practice their skills at their own pace without harming a patient, are less expensive than the costs of supervision needed for real-life procedures (Colt et al., 2001) and ease resident and patient anxiety since trainees can familiarize themselves with the instrument, technique and anatomy before the first patient contact (Ost, DeRosiers, Britt, 2001; Blum, Powers, Sundaresan, 2004). Its objective assessment of trainee skills make it an efficient training device, addressing the issue of time contraints for residents and instructors. Naur et al. (2017) conducted a systematic review of articles on flexible bronchoscopy and simulator-training and concluded that simulation-based training is more efficient than the traditional apprenticeship model. A study by Colt, Crawford and Galbraith (2001) showed that after their specific curriculum of training with a virtual reality bronchoscopy simulator, novice trainees had fewer contact with the bronchial wall and less neglect of segments. Moreover, novice trainees performed equally well after the simulation training as skilled physicians who were trained in the traditional way. Additionally, compared to skilled physicians, novices trained with the simulator executed more meticulous procedures and neglected significantly less segments (Colt et al., 2001). Moreover, simulators offer the opportunity to practice case management skills: learning how to deal with complications which arise only rarely in real-life.

Flin, Yule, Paterson-Brown, Maran, Rowley and Youngson (2007) recognize the importance of the cognitive and social skills underlying technical performance. Similarly, Vergis and Hardy (2017) note that technical expertise (the focus of most simulation-based programs) requires multiple abilities in addition to technical dexterity such as decision-making skills. This study aims at uncovering different decision-making points of pulmonologists during a FB.

1.2 Simulation-based Training

According to Blum et al. (2004), residency training is characterized by eighty-hour work weeks and reduced time at the hospital, demonstrating the urgency of maximum training productivity. Although simulators are efficient, each trainee with a different experience level has different bronchoscopy skill acquisition needs. Therefore, it needs to be specified which skills are needed and how they can be practiced in order to become a competent bronchoscopist (Davoudi & Colt, 2009). Training curricula have already included simulators for learning surgical procedures such as bronchoscopy (Konge, Bjerrum, Nayahangan, Schroeder, 2015) and this study aims to gain more insight into the different features needed to achieve a successful simulation-based training. A similar study has been conducted by Tijam, Schout, Hendrikx, Scherpbier, Witjes, Van Merriënboer & Van Merriënboer (2012) which identified tasks, sub-tasks and blueprints for the execution of a nephrostomy procedure which could be used to design a simulator-based training. While psychomotor skills and theoretical, and procedural knowledge is vital to perform a bronchoscopy, studies which evaluate simulators usually ignore the importance of appropriate decision-making points (Tijam et al., 2012). In addition, uniformly designed training programs are inappropriate as trainees with different experience levels may aim to acquire distinct skills (Konge et al., 2011).

Cognitive Task Analysis is an ideal method to gain more insight into cognitive processes and events that emerge when pulmonologists perform flexible bronchoscopy on a simulator. It is an ideal method since it specifies all the cognitive aspects involved in a performance and how they could be elicited and analysed. It helps to extract their knowledge, perception, thoughts regarding performing a flexible bronchoscopy. Thus, by means of a Cognitive Task Analysis, this study aims to explore the following research question: W*hat are the learning needs of trainees in pulmonology in a simulation-based training program?*

1.3 Overview of Current Research Paper

According to Nayahangan, Stefanidis & Konge (2018), a curriculum is developed in six steps, the first constituting problem identification and general needs assessment. In this step, the focus is on clarifying the gap between how a curriculum currently tackles a health care problem and how it should ideally be tackled (Nayahangan et al., 2018). More precisely, this qualitative study addresses the questions of how simulators are currently incorporated in flexible bronchoscopy training and in what manner they can be optimally included in a FB curriculum. Figure 1 shows an overview of the organisation of this research. Therefore, in the first part of this research, the starting point is a review of literature and established curricula, gaining an overview of and integrating information from different sources on basic skills and knowledge needed for FB. In the second part of this study, interviews with expert pulmonologists are conducted which allow to extract more detailed ideas of the specific learning needs and objectives of pulmonologists in the Netherlands and thus, reach preliminary consensus of experts about the contents of a simulation-based FB curriculum in the Netherlands.

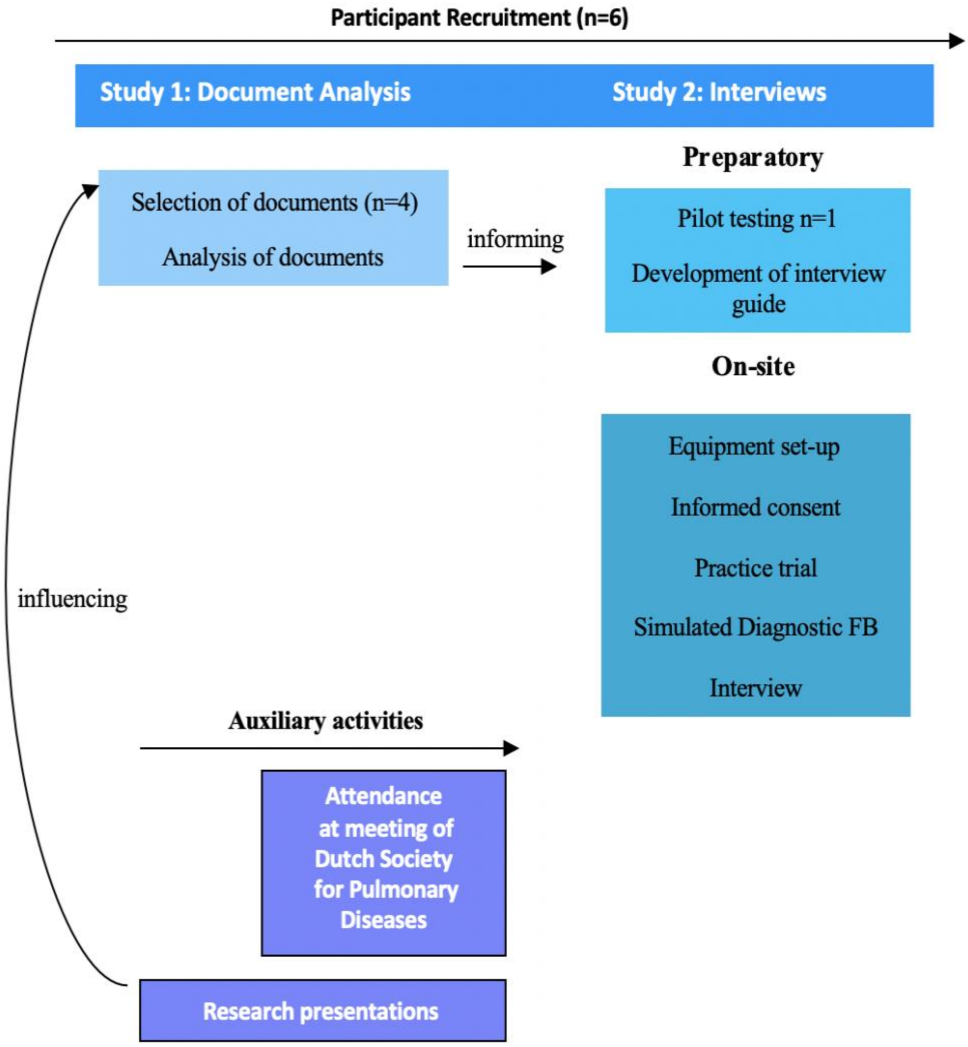

Figure 1*:* Overview of whole procedures for this research paper.

2. Document Analysis Study

2.1 Method

Design.

As a first step in conducting the needs assessment, five documents were qualitatively content-analysed to serve multiple purposes: (1) to identify basic skills and knowledge required for performing a flexible bronchoscopy, (2) to compare flexible bronchoscopy curricula and by that, to (3) inform the development of interview guidelines and guide the researcher in extracting relevant information during the interviews. The research question guiding the analyses was: *"What are the processes, steps, concepts and decision points involved in a flexible bronchoscopy?".*

Selection of documents.

Documents that were considered admissible were already developed (inter)national training curricula for FB training and a textbook on flexible bronchoscopy. The latter was considered necessary to include in order to understand the general concepts involved in flexible bronchoscopy and to make sense of the curricula. Exclusion criteria for the curricula were documents that were not written in English and published prior to 2011. One exception to the latter exclusion criterion was the European Respiratory curriculum which was included after suggestion of pulmonologists during presentations of the research proposal in hospitals. Based on Bowen's (2009) listing of functions of documents, the documents used in this study have the following functions: they suggest questions and processes to be asked and observed during the interviews and they also contextualise the data that results from the interviews.

Documents were sampled online (the first three) and from the University of Twente library (the textbook). Table 1 outlines the characteristics of the four selected documents. One document used was the British Thoracic Society Guideline for diagnostic flexible bronchoscopy in adults (2013). This document's target audience are respiratory practitioners in the UK which will perform FB. It underlines specific steps, processes and decision-making points involved in FB procedures. Another document is an established, Danish, simulation-based training curriculum for flexible bronchoscopy (2016). This curriculum specifies the use of simulators as well as important skills and knowledge vital for performing a FB. Moreover, it provides an assessment tool based on bronchoscopy simulators. The European Respiratory Statement on Interventional Pulmonology (2002) includes short descriptions of necessary equipment, techniques, indications, complications and training requirements for transbronchial needle aspiration. Lastly, a textbook on flexible bronchoscopy (2004) was included which explains the procedure of a diagnostic bronchoscopy in detail.

Table 1

Characteristics of the documents (N=4).

Type of document	Purpose/topics addressed
British Thoracic Society Guidelines for Diagnostic Flexible Bronchoscopy in Adults (2013)	- Steps, processes, decision-making points in FB procedures
Danish Introduction to Simulation Based Education in Bronchoscopy (2016)	- Use of simulators, technical skills - Assessment tool
European Respiratory Statement on Interventional Pulmonology (2002)	- Transbronchial needle aspiration
Textbook: Flexible Bronchoscopy (2004)	- Detailed explanation of diagnostic bronchoscopy procedure

Analysis of documents.

Document analysis consists of an iterative process of superficially skimming, thoroughly examining and interpreting documents (Bowen, 2009). During this process, aspects of content analysis and thematic analysis are incorporated; meaningful text passages are identified, coded and then categorized into similar themes (Bowen, 2009). After skimming through the first document (guidelines), the researcher started inductively developing preliminary sets of codes. The researcher's initial strategy consisted in finding answers (codes) to the rather general question: "What are important steps, processes, concepts and decision-making points in performing flexible bronchoscopy?".

Guiding the development of codes and categories was the goal of not summarizing existent declarative knowledge but focusing on the perspective of the doctor with regard to his or her cognition: What does the doctor need to know and do generally? Information that was too detailed and technical was skimmed; the approach to coding was taking a "birds-eyes" view with basic information of concepts. For example, when information as given about the variations in anatomy, anatomical details of those variations were skipped and a code relating to the knowing the anatomy was given.

The coding unit was a theme, a new code was developed when a new answer to the research question was identified. The same code was applied several times to different text passages if appropriate which later helped to develop definitions for the codes. For example, different text passages involved a description of the way of holding a bronchoscope to which the code “handling the bronchoscope” was applied. After reviewing the different portions of text, an all-inclusive definition was established for the specific code. Codes were revised, deleted and added during the process if appropriate.

After coding all four documents, the resulting coding scheme was examined and the codes were categorised into larger themes, into aspects of FB prior to, during, after the procedure and FB’s contextual, non-procedural aspects (see Table 2). The last step consisted in comparing the three documents, identifying gaps, similarities and differences.

2.2 Results

The document analysis elucidated several aspects of flexible bronchoscopy including steps, required knowledge, skills and decision points, chronologically separated into those relevant prior to the procedure, for the procedure itself and after the procedure. Moreover, contextual aspects of FB were identified. In the following, first, the different guidelines are compared in the topics and detail they include. Afterwards, all the identified basic skills and knowledge from the documents are presented.

Comparison of FB guidelines/curricula.

The British and European curricula were similar in the amount of detail they provided but were conceptually different, as the European curricula focused on a specific aspect of FB, Tranbronchial Needle Aspiration. In contrast, the British guidelines included a more encompassing guide on FB from “A to Z”: precautions, complications, patient considerations, diagnostic accuracy, sedation, anesthesia, disinfection, staff, patient satisfaction. The Danish curriculum focused more on the technical details of performing FB and how to train those on different simulators. In general, the documents complemented each other well, while the textbook and Danish curriculum sometimes respectively included information not found in other documents, due to their specific purpose: providing details of FB and incorporating simulators to train FB. Table 2 summarizes the emergent themes.

Simulation-based curriculum.

The Danish Practical Handbook for Bronchoscopy (2016) was the single document which demonstrated a simulation-based training program. The program includes four basic aspects:

1) basic theoretical knowledge
2) introduction to procedure and simulators
3) self-training on simulators and phantoms

4) an assessment

The theoretical knowledge contained in the curriculum is rather concise and the authors recommend self-study with additional literature. In this case, the British and European curricula as well as the textbook would seem to provide more detailed theoretical knowledge. Moreover, the British and European guidelines and the textbook describe knowledge and processes that were not mentioned in the Danish curriculum (e.g. improving diagnostic yield). While the Danish curriculum mentions similar topics as the other documents (e.g. treatment of bleedings), not all concepts described in the Danish curriculm are also translated into the practical simulation-based training (e.g. dealing appropriately with complications such as bleeding).

The second aspect is that trainees are introduced to both the flexible bronchoscopy procedure in general and the simulators. This is executed by experts from pulmonary medicine.

Later, the simulators and phantoms will be used to transfer knowledge and practice different skills. The VR simulators are mainly used for technical skill acquisition: handling the bronchoscope, learning to navigate through the anatomy and mastering sampling techniques. However, those skills are not exclusively trained on the VR simulators. Instead, lung models phantom models, a real bronchoscope and sampling equipment are used as well for the same purposes. Although this is self-training, it will be supervised by other medical students and nurses familiar with the simulators and equipment.

Lastly, after self-training, an assessment is conducted. The assessment tool given in the document is based on scores from either the VR CAE simulator or the VR Symbionix simulator. Scores are given by simulators for correct localization of pathology and performance of sampling techniques (divided into sub-aspects such as at least one lavage performed in middle lobe, correct amount of suction). In addition to the scores, simulators record the time and the test is passed when 28 points are reached in maximum 70 minutes. After passing, trainees are considered ready to start with the clinical training on patients.

Basic skills and knowledge required for FB.

Table 2 shows the results of the document analysis; the basic skills and knowledge that are paramount for a flexible bronchoscopy. Pre-procedure and aftercare aspects were identified but will not be not elaborated on as this study focuses on the procedure of FB itself. The relevant aspects are highlighted in grey in the table.

The majority of aspects of FB that were identified were for the use during the procedure. As the basis, it is important to be familiar with the 4) anatomy of the bronchial tree. Here, the textbook was very specific regarding the aspects to be known. These include the anatomic orientation, the normal anatomy but also anatomic variations which are not clinically relevant. Pathological abnormalities, and knowledge of resectabilities of lesions should be known as well.

In addition to knowing the anatomy, bronchoscopists should be skilled in the 1) different diagnostic techniques such as Transbronchical Lung Biopsy (TBLB), Transbronchical Needle Aspiration (TBNA), Bronchial Brushing and Biopsy and Bronchoalveolar Lavage. Details to each procedure (e.g. selecting the proper needle, not damaging biopsy specimens) should be known, also taking into account the context of the patient. For example, in one document, it is noted:

"At least five biopsy samples should be taken when endobronchial tumor is visible [...]." (British Thoracic Society, 2013, p.2).

Another important skill relates to the 2) handling of the bronchoscope. The bronchoscope should be chosen appropriately in terms of selecting the appropriate diameter of the bronchoscope for each case. The bronchoscope should be manoeuvred correctly without causing any damage to the bronchoscope. A lot of detail about the bronchoscope was included in the Danish simulation-based curriculum. Another important aspect was mentioned exclusively in the textbook which is the 9) systematic inspection of airways. Since the bronchoscopist is immediately drawn toward the abnormalities of the airways, the inspection should be started in the airways which are considered to not be involved in any pathology.

Another recurrent theme was 3) improving diagnostic yield, *the probability that the techniques used result in a clear-cut diagnosis*. Bronchoscopists should be concerned with knowing which techniques could improve the diagnostic yield in which procedure, also taking into account the context of the patient's condition. For example:

"When endobronchial tumour is visible, brushings and washings can increase the diagnostic yield of the procedure." (British Thoracic Society, 2013, p.2).

Two related skills refer to improving the tolerance of the patient to the procedure: 6) deciding (how) to sedate and 8) giving topical anesthesia. In each case, the appropriate drug/solution, the adequate amount and the preference of the patient should be taken into account. It is not only sufficient to engage only in preparations for ensuring the patients' tolerance; bronchoscopists also need to 7) constantly monitor the patients' tolerance, symptoms, vital signs and act appropriately in case of crucial changes.

Moreover, bronchoscopists should be prepared to know of 5) possible problems and complications which could occur during the procedure. Problems relate to confinement issues (having impaired vision of the airway due to mucus or blood), irritation, decreased toleration of the patient and losing anatomical orientation. A complication which could occur is bleeding which can be caused my malignant diseases 25% of the time and also chronic inflammatory processes, being the source of bleeding 50% of the time. Thus, bronchoscopists should know how to prevent problems and complications, if possible. For instance:

"Irritation by frequent passage of airways under local anesthesia can be avoided if a tube is inserted over the bronchoscope." (Wang, Mehta & Turner, 2004).

Lastly, more contextual and non-procedural aspects of FB were identified by analyzing the documents. These include having an appropriately trained staff, being assisted by a dedicated person, and having prepared, disinfected instruments available. Moreover, the bronchoscopist's performance should be continually assessed. Criteria include the efficacy, the diagnostic accuracy, occurred complications and patient satisfaction. In the context of training for flexible bronchoscopy, the documents mentioned the necessity or having an instructor to teach and guide trainees.

Table 2

Results of the document analysis: Aspects of flexible bronchoscopy.

Categories	Subcategories	Definition	Example
Pre-procedure	Assessing fitness of patient for procedure	Physically examining (lab tests, x-rays, CT) and assessing the patient's history, recognizing risk factors which could introduce complications and appropriately deciding whether a patient is fit for the procedure.	"Patients in the ICU should be considered at high risk from complications when undergoing bronchoscopy."
	Adapting procedure to patients' medical conditions	Taking precautionary measures for patients with medical conditions (e.g. asthma, heart disease).	"FB should ideally be delayed for 4 weeks after myocardial infarction."
	Preparing necessary equipment	Considering all required instruments including those which may be required due to potential complications due to patients' medical conditions.	"When patients require non-invasive ventilation prior to bronchoscopy, the procedure should be conducted in an environment where intubation and ventilatory support are readily accessible."
During procedure	1) Mastering diagnostic procedures	Being able to decide when to use specific method is necessary to be employed performing it correctly and efficiently (including biopsy sampling/TBLB, TBNA, etc.). Knowing the specifics of each procedure (e.g. selecting proper needle etc.)	"At least five biopsy samples should be taken when endobronchial tumour is visible […]"
	2) Handling the bronchoscope	Choosing appropriate bronchoscope settings and manoeuvring the bronchoscope safely through the airway.	"Damage to the flexible bronchoscope during TBNA is a genuine concern and can be avoided by rigorously following optimal procedures."
	3) How to improve diagnostic yield	Knowing what to do in which situations to improve diagnostic yield of the procedure.	"When endobronchial tumour is visible, brushings and washings can increase the diagnostic yield of the procedure."
	4) Knowing anatomy	Knowing the anatomy of the bronchial tree.	"The teacher demonstrates the anatomy including the four landmarks."
	5) Handling problems and complications	Knowing about possible problems and complications and how to prevent and/or deal with them.	"Self-limited minor bleeding, pneumothorax, […], can be avoided through proper knowledge of the mediastinal anatomy as well as a thorough review of the CT of the chest".

	6) Deciding (how) to sedate	Choosing an appropriate drug, an adequate amount of the drug and incorporating patient preference.	"Intravenous midazolam is the preferred drug for sedation, […] no more than 5 mg midazolam for patients under age of 70, 2mg for patients over 70 […]".
	7) Patient monitoring during procedure	Observing the patients' heart rate, respiratory rate, blood pressure, oxygen saturation and symptoms during the procedure, recognizing changes and responding appropriately.	"Patients should be monitored by continuous pulse oximetry during bronchoscopy".
	8) Giving topical anaesthesia	Deciding which is the appropriate way of giving topical anaesthesia.	"1% lidocaine solution should be used for spray-as-you-go administration".
	9) Systematic inspection of airways	Navigating through the airway in a systematic way.	"[…] first examine airways that are apparently uninvolved in pathology."
Aftercare		All immediate and remote activities after the procedure from preparing cytological specimens to monitoring patients and informing patients.	"Patients should be advised of the potential for delayed complications following TBLB and provided with written information regarding likely symptoms and action required."
Context and non-procedural aspects	Including an instructor for teaching purposes	Letting an instructor demonstrating relevant skills and guiding trainees.	"The instructor will guide the student as the student brushes and biopsies an airway abnormality".
	Assessing performance	Performance should be assessed periodically according to specified criteria (efficacy, record of personal diagnostic accuracy for FB, complications, patient satisfaction surveys).	"The participant should describe the pathology and its exact location in the bronchial tree."
	Having an assistant	Performing the procedure together with a helping assistant.	"In addition to the bronchoscopist, the procedure requires a dedicated assistant."
	Disinfecting instruments	Having cleaned, decontaminated bronchoscopes and storing instruments appropriately.	"Bronchoscopes must be cleaned and disinfected before and after placing in carrying cases as these cases cannot be disinfected […]."
	Staff	Having staff with appropriate training.	"All Trusts should have a 'safe sedation policy' and ensure all bronchoscopy unit staff, including trainees, receive appropriate training."

2.3 Conclusion and Discussion

The purpose of the document analysis study was to extract from existent FB curricula, (and a textbook) the basic knowledge and skills that trainees should learn to perform FB. This study is the basis for a subsequent interview study, specifically the interview scheme used to interview pulmonologists about performing FB on a simulator. In general, during the procedure different technical skills, knowledge and decision-making skills are required. Technical skills include the mastery of diagnostic techniques, handling of the bronchoscope and systematic inspection of airways which in turn requires a thorough knowledge of the anatomy. Decision-making skills are handling problems and complications, sedating, anaesthetising, improving diagnostic yield and patient monitoring. Important contextual aspects of a training environment for FB are experienced staff, assistants, instructors, disinfected instruments and assessment of performance.

In light of the empirically supported efficiency of simulators for training of endoscopic skills (Blum, Powers, Sundaresan, 2004), it is a perhaps surprising finding that it was rather difficult to find curricula which incorporate simulators for training FB. Though the Danish curriculum focused on the use of simulators for technical skill acquisition, it was not exclusively restricted to VR simulators; inanimate lung models were included as well for the training of the same technical skills. This may point to a potential inadequacy of VR simulators as a sufficient training modality in itself. Similarly, Bjerrum et al. (2018) note that a holistic skill acquisition can only be achieved through integrating different simulators.

Thus, the use of the VR simulator in the Danish simulation-based curriculum was restricted to the acquisition of skills regarding handling the bronchoscope, exploring the anatomy and mastering diagnostic techniques which are more technical skills. Little attention was given in general to using any kind of simulator for acquiring decision-making skills to improve diagnostic yield, handling problems and complications or responding to crucial changes in the patient’s vital signs and symptoms. This finding is in line with Tijam et al. (2012) who claim that studies which evaluate simulators often discard the importance of decision-making points in favour of training psychomotor skills and theoretical, procedural knowledge.

The British, European curricula and the textbook on FB provided more information on the decision-making required during a FB including detailed descriptions of taking into account patient medical conditions, its influence on the procedure, possible complications and related preventative measures as well as more sophisticated decision-making with regard to giving sedation and topical anaesthesia. Although the documents mentioned that complications are rare, Konge et al. (2001)'s finding that novice bronchoscopists have an increased complication rate during the first trimester of training, underlines exactly the point that those decision-making points are important to train as well, in addition to purely technical skills.

Nonetheless, it must be pointed out that the Danish curriculum indeed included theoretical knowledge about treatment of complications, for instance. This kind of knowledge was recommended to be supplemented by self-study of further literature. Although study of potential complications and how to handle them increases theoretical knowledge, applying this knowledge in real-life scenarios may require appropriate decision-making skills. Hence, it may be worthwhile to inspect the possibility of training and assessing decision-making skills on VR simulators.

Next, the Danish curriculum put emphasis on having a teacher who demonstrates the anatomy to students (on lung models and the simulator). According to Colt (2001), such instructors are rather costly. The question may arise whether the use of simulators could completely waive the presence of teachers. However, not only are instructors included in the Danish simulation-based training, assistants and staff were considered essential by the British and European guidelines for a FB procedure. Since assistants and staff are crucial during a real bronchoscopy, a simulated environment might need company too.

Regarding the goal of the document analysis study to inform the development of interview guidelines for the interview study, it has to be said that the goal was achieved sufficiently, giving the researcher a basic theoretical background of a flexible bronchoscopy and FB training. However, more information on incorporation of the simulator would have helped the researcher to get a better sense of what the simulator is capable of and how it can be used.

All in all, the documents provided an encompassing view of FB but for the purpose of identifying learning needs involved during a flexible bronchoscopy, the pre-procedure and aftercare codes were discarded for the interview guide. The contextual aspects however, may be important to discuss with pulmonologists in the interview study. Thus, all "during procedure" and "contextual and non-procedural aspects" will be included in the interview scheme for the semi-structured interview with Dutch pulmonologists in order to investigate their learning needs for FB in a simulation-based training.

3. Interview Study

3.1 Method

Design.

A semi-structured interview was conducted in English with six Dutch professionals in order to identify the learning needs of trainees in pulmonology for a simulation-based flexible bronchoscopy training. Participants performed a diagnostic bronchoscopy task on a simulator (10-22 min.) during which they freely inspected the airway and sampled tissue, using tools of choice. Their performance was video-recorded. Participants were asked to retrospectively think aloud while watching the video-recording and specific questions regarding their performance, the FB procedure in general and the usefulness of the simulator were asked. The interviews were audio-recorded and transcribed. Cognitive Task Analysis of the interviews resulted in a list of learning needs of Dutch pulmonologists which was combined with the list of aspects of FB resulting from the document analysis study.

Participants.

A purposive sample of four Dutch pulmonologists, one pulmonology resident and one Technical Physician in training was included in this study based on their prior experience in performing a flexible bronchoscopy. In the Netherlands, according to law, both pulmonologists and technical physicians are allowed to perform flexible bronchoscopies. At the time of the study, the participating Technical Physician has performed over 100 flexible bronchoscopies under supervision. Moreover, the participant has developed a surgical simulator before. Thus, by including a Technical Physician, insight into the procedures and especially simulators, could be gained from a technical perspective as well.

Participants had varying experiences and skills which is determined by the amount of years in their profession and the number of performed flexible bronchoscopies (self-reported). Excluding trainees, years spent in profession ranged from 2 to over 30 years. The number of performed flexible bronchoscopies varied from 100 to 7000. Participants also varied in their degree of familiarity with the simulator. While some participants (n=3) were familiar with the simulator due to frequent or recent use, other participants have used a simulator before but were less familiar with it (n=3).

Materials.

Simulator environment.

The 3D Systems GI-BRONCH Mentor™ (see Figure 3) is a virtual learning environment for acquiring psychomotor, cognitive and coordinative skills and diagnostic and therapeutic clinical experience for clinical procedures. It is a combined simulator for both GI endoscopy and flexible bronchoscopy. It includes basic skill tasks as well as complete clinical procedures (3D Systems, 2017). Regarding flexible bronchoscopy, the BRONCH Mentor features an authentic bronchoscope which can be inserted into the mouth of the plastic mannequin and a master tool and a syringe (3D Systems, n.d.b) which are inserted into the scope. After insertion of the master tool, users can choose a method for tissue sampling by touching the screen. Pulling and pushing the master tool results in opening and closing of the tool selected. Similarly, the syringe must be drawn back before inserting it into the scope and pressed down when inserted in order to draw up and distribute fluid into the virtual airway, respectively.

Figure 3: 3D Systems Bronch Mentor ™ simulator (left) and master tools (right).

Simulator task: Diagnostic Bronchoscopy.

The 3D Systems BRONCH Mentor™ offers a diagnostic bronchoscopy module which comprises six cases with different patient histories and conditions (3D Systems, n.d.a). The user has to perform a visual airway inspection and can choose between several methods for endobronchial and transbronchial tissue sampling including biopsy forceps, cytology brush, aspiration needle and bronchi alveolar lavage. During the procedure, the virtual patient’s condition is displayed on the screen, allowing the user to check the vital signs, topical anaesthesia, moderate sedation, level of consciousness and oxygen supplement (3D Systems, n.d.a).

Prior to starting the diagnostic bronchoscopy, the user reads a short patient history, looks at measured vital signs, test and imaging results and selects pre-medication including Lidocaine 4% nebulize 200mg, Midazolam, 2mg and Meperidine, 50mg. Figure 4 shows the information displayed on the screen during the procedure including the main view (scope's video), main view controls (e.g. full screen or anatomical compass), the tool panel, patient monitoring and management and complementary displays (e.g. X-rays, anatomy atlas or 3D map of the scope within the bronchial tree).

Figure 4: Screenshot of VR simulator display during a participant's performance on "diagnostic bronchoscopy" task. The tool panel "Fluids Endobronchially" on the left appears, suggesting that the participant has inserted the syringe into the scope and is attempting to anaesthetise the airway.

Patient cases were varied for some participants to avoid overlap of information. Overall, adult cases 1, 3, and 6 were selected. Case 1 included a 58-year-old male patient, who weighs 98 kg, was a smoker for 15 years before quitting 7 years earlier, has symptoms of persistent cough and the X-ray of the chest did not show abnormalities. Case 3 described a 56-year-old female who weighs 52 kg and suffers from shortness of breath and fatigue. A thoracic CT scan revealed two masses in the left upper and lower lobe, enlarged subcarinal and 11L lymph nodes. Lastly, in case 6, the virtual patient was a 54-year-old male with symptoms of cough, severe dyspnoea and tiredness without fever or night sweats. A chest CT showed diffused reticulonodular infiltrates and multiple enlarged lymph nodes.

Interview guide.

An open-ended, semi-structured interview guide (see Table 3) was developed based on open-ended, cognitive probing questions (Crandall, Klein and Hoffman, 2006) and the results of the document analysis. In addition to the interview guide, during the interview, the tabulated results of the document analysis were used to suggest possible content areas of questioning (e.g. questions related to the bronchoscope or anaesthesia), depending on the flow of the individual conversation.

Crandall et al.'s (2006) *Working Minds* was browsed and relevant cognitive probing questions that were considered appropriate regarding the goals of the study were included in the interview guide. Areas of cognitive probing constituted sensory cues (What were you seeing, hearing, feeling?), goals (What were you trying to inspect?), alternative actions (How was another possible course of action chosen and others rejected?), common mistakes, helpful prior experience, aids, mental models, decision making, difficulty and used information. In addition, two specific probing areas relating to the accuracy of the simulator have been formulated. These probes pertained to (1) necessary skills and knowledge for FB which may not have been included in the simulator and (2) the helpfulness and accuracy of the simulator's assessment metrics. Wording of the questions was not always exactly as outlined in the interview guide in order to allow for a natural, instead of an interrogatory atmosphere, facilitating the conversation. After some interviews, more specific questions that came up during those interviews, were noted on the interview guide as well.

Table 3

Interview guide.

Interview guide

General probing questions

1. **Cues:** What were you seeing, noticing, feeling, hearing? What cues do you use to ensure that you were successful?
2. **Goals:** What were your specific goals at the time? What was most important to accomplish at this point? What were you trying to inspect?
3. **Alternative actions:** Were there other courses of action available to you? How was this option chosen or others rejected?
4. **Mistakes: What are common mistakes? How do you know when something is going wrong?** If a novice had been in charge at this point, what type of error might he or she make and why? Would they have noticed what you noticed? Would they have known to do X?
5. **Experience:** What specific training or experience was helpful in making this decision?
6. **Aids:** What knowledge, information, or tools/technologies could have helped?
7. **Mental models:** Did you imagine the possible consequences of this action? Did you create a picture in your head? Did you imagine the events and how they would unfold?
8. **Decision making:**
   a. What steps do you follow before arriving at this decision?
   b. What makes this decision tough?
   c. What let you know that this was the right thing to do at this point?
   d. How much time pressure was involved in making this decision?
9. **Difficulty**: What is the most difficult element of the task and why?
10. **Information:** What information did you use in making this decision or judgment? How and where did you get this information, from whom?

Rules of thumb?

Probe deeper when response: “It was obvious that”, “My gut told me that”

Specific questions

1. **Skills/Knowledge**: Are there skills or knowledge that you feel are important to perform a FB but are not included in the simulation-based task?

2. **Assessing performance:** Do you think that simulation-based assessment metrics are appropriate to evaluate a trainee’s FB skills? How would you assess whether a student has sufficient basic FB skills? Which metrics do you think could distinguish between novice/intermediate/expert performance?

3. **Any own comments?**

Procedures.

Preparation.

A summary of the procedures of this study is displayed in Figure 5. Ethical approval for the study was obtained from the BMS Ethics Committee at the University of Twente. A pilot test was conducted with a volunteer student in order to test the accuracy of the video- and audio-recording. Participants were purposefully sampled through professional contact networks both before and throughout the whole data collection process. The researcher wrote emails to both potential participants and those who already agreed to participate during presentations of the research at hospitals. Due to participants' tight schedules and the limited availability of the simulator, some participants could not partake in the study.

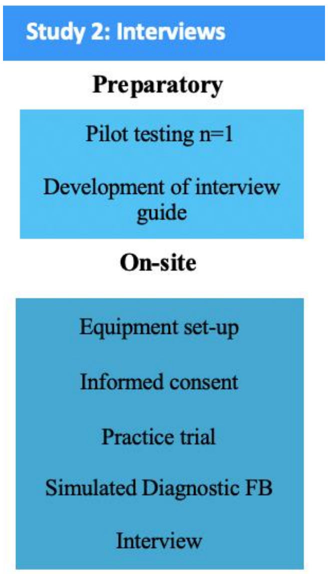

Figure 5. Flowchart of procedures in the interview study including preparatory and on-site procedures.

On-site.

On site, the equipment was set up including a video-camera, tripod, laptop and smartphone (for audio-recording). Participants were first asked to sign the informed consent form. During or afterwards, participants were asked about the number of years in their profession and the number of performed flexible bronchoscopies. Depending on whether the participant was familiar with the simulator, they were offered a test trial to familiarize themselves with the simulated procedure.

Before starting, participants chose their preferred standing position and the video-camera's position was adjusted in order to capture the simulator display and hand movements.

Due to moving during the procedure, sometimes, the view of either the display or hand movements was entirely or partially obstructed. Participants were shown the case history and imaging results related to the specific patient case on the simulator and they could choose a pre-medication. The researcher started the video-recording and the participants started to perform the diagnostic bronchoscopy task on the simulator which took 10-21 minutes. For the first two participants, the researcher stood behind the camera and helped whenever necessary.

Afterwards, the video-recording was displayed on a laptop, the participant and researcher sat down to start with the retrospective think aloud which was followed by a semi-structured interview if additional information was needed. Participants were told to mention everything that was going through their minds during their performance on the simulator parallel to what the video was showing. The interview was audio-recorded and occasionally, notes were taken of the participants' utterances. Whenever a participant wanted to explain something in more detail, the video-recording was stopped in order not to miss important parts of the video that could have been missed otherwise. After the video ended, the researcher focused on asking participants specific questions, letting them explain the steps they took and clarify concepts which were not clear to the researcher. With respect to the flow of the conversation, appropriate cognitive probing questions and specific questions as outlined in the interview guide were asked. Whenever necessary, the researcher skimmed through the printed tabulated results of the document analysis in order to get ideas for further areas of probing. The interview duration was about an hour.

Analysis.

The audiotaped interviews were transcribed verbatim. If participants also explained their considerations during the procedure, videotapes were transcribed too. Cognitive task analysis of the textual data was conducted in two main phases with the help of the ATLAS.ti program, an analysis software program ATLAS.ti™ which is particularly useful for coding textual data (ATLAS.ti, n.d.). A first analysis was done with two interview transcriptions and a second with all six interviews.

First, transcripts were read freely. The coding of the data was done inductively as codes emerged from the data. Coding units were themes, a new code was applied to a text when it represented a new information related to the cognition, process or context of performing a FB. The experience from coding different FB documents facilitated the creation of codes to describe a specific process of FB (e.g. "systematic inspection", "anatomical orientation"). However, the goal of coding in this interview study was more specific: to find (cognitive) aspects involved during the procedure of a diagnostic bronchoscopy that are relevant to develop a simulator training. More specifically, to find cognitive aspects, the following questions adapted from Crandall et al. (2006) were guides**:**

1) What is the participant paying attention to and ignoring?
2) Which senses is the participant using?
3) What is the participant thinking about?
4) What information is the participant seeking, from where?

These questions allowed to focus on how exactly the general processes of FB come about and hence, to extract the skill-set needed to perform a diagnostic bronchoscopy. However, attention was also paid to the opinions of participants towards the accuracy of the simulator and its potential use for a FB training program. When a concept has been mentioned by several participants but in slightly different or complementing ways, the same code has been applied to those textual parts in order to easily review the variation within the code between participants (through Atlas.ti). After coding all the transcriptions, codes were reviewed and compared to the codes that emerged from the document analysis study which were merged together into higher categories of the same general concepts. For example, the general concept of "dealing with complications" was created to include the sub-codes of complication cues, dealing with bleedings and dealing with infections, to name a few.

3.2 Results

This study's aim was to identify the learning needs that trainees in pulmonology have for learning flexible bronchoscopy in a simulation-based environment. The following sections describe the skill-set which needs to be acquired for performing a diagnostic flexible bronchoscopy (see Table 4). For each main skill, cues, goals and difficulties are mentioned, whenever pointed out by participants. Moreover, remarks of participants on the VR simulator's adequacy for training each skill and assessment are included.

Table 4

Training requirements for simulation-based flexible bronchoscopy.

	Categories	**Sub-categories**
Skills	1) Mastering diagnostic procedures	Bronchial brushing Biopsy TBNA, EBUS/EUS Bronchial washing Sample locations Deciding for technique(s) Order of techniques Selection of different kinds of instruments Amount of samples
	2) Handling the bronchoscope	Introduction Manoeuvring Inserting and removing tools
	3) Inspecting the airway	Interpreting imaging results Anatomical orientation Systematic inspection Visually recognizing abnormalities
	4) Preventing and dealing with complications	Knowledge of possible complications Preventing bleedings Dealing with bleedings

	5) Administering anaesthetics and sedatives	Cues Systematic administration Amount
	6) Patient monitoring	Paying attention to vital signs, oxygen saturation Auditory cues
Context	7) Working with an assistant	Teamwork Communication

Skills.

1) Mastering diagnostic procedures.

Four main diagnostic techniques to be used during a FB were identified: Bronchial brushing, biopsy, Transbronchial Needle Aspiration (TBNA), Endobronchial Ultrasonography (EBUS) and bronchial washing. The VR simulator was considered inadequate by participants for training of these skills mainly due to missing tactile feedback. According to a participant, physical simulators and dry labs are more accurate due to providing haptic feedback and seeing the “real effects” (P6, p.12).

Bronchial brushing.

One technique to be mastered is bronchial brushing. As one participant puts it, the purpose of brushing is to collect, with a brush, cells from the abnormality (e.g. a tumor) (P1, p.1). Another participant adds that a brush is rubbed against the mucosa, making cells loose which are collected on the brush (P3, p.3). She adds that the brush is to be examined by the pathologist (P3, p.3).

It is important to ensure that samples are successfully collected. Ensuring this is not possible during brushing: a participant mentions that while brushing, cells cannot be seen in the brush (P4, p.3). However, in a real bronchoscopy, after the brushing, another participant describes that the brush is taken out and the samples are put onto a glass which is when he would be able to see if samples have indeed been obtained or not (P6, p.9). In the VR simulator, such samples could not be seen directly (neither during nor after the brushing), leading participants unsure about whether to continue obtaining samples or not. The only cue participants were given by the simulator is bleeding. Although a bleeding could be a reaction to obtained samples (P3, p.3), one participant says that in real life, it does not necessarily have to bleed afterwards (P6, p.9). Only after the complete simulated bronchoscopy, assessment metrics gave information about the amount of samples that were obtained successfully. However, one participant mentioned that those metrics may not be accurately reflecting the actual performance. Moreover, a participant mentions that during a real bronchoscopy, while brushing, resistance can be felt sometimes too (P5, p.7). The VR simulator in this study did not give any tactile feedback.

Biopsy.

With a biopsy, tissue is sampled (P1, p.5). A younger participant mentions that a biopsy is always the preferred technique (P3, p.7). Similar to the brushing, a participant mentions that while doing a biopsy in real-life, it is not known whether the obtained sample is representative; the obtained sample must firstly be put into a glass container. Again, bleeding was the sole cue given by the VR simulator. During the simulation, one participant noticed that a little bleeding occurred, concluding that “you definitely know you didn’t grab air, but you grabbed tissue” (P5, p.2). After seeing the assessment metrics, one participant added: “it was very handy to know that I did take some samples.” (P3, p.10).

A participant describes the general processes involved in taking a biopsy. As soon as resistance is felt from the forceps, it can be closed in order to take a sample. Thereafter, the forceps is removed from the scope and the sample secured “in the unit with the saline so you can see if there is a biopsy” (P3, p.3). However, the participant did not feel any resistance in the VR simulation (P3, p.3). Another problem encountered with the VR simulator is when selecting the tools: one participant wanted to change the selected tool, but it stayed the same (P1, p.2). It has to be added that the tool selection panel shows on the display only for a short amount of time, before disappearing (P2, p.5). When taking off the sample from a tumor, normally you feel some kind of resistance, according to a participant, which was absent in the VR simulator (P2, p.6). One participant mentions that given feedback during the procedure from the VR simulator was faulty when the display said “wrong sample location” (P4, p.3).

Difficulties.

Another participant also explains how to take a proper biopsy from a tumor which can be rather difficult according to him:

> *“[...] You look at the abnormal place, where is the most important abnormality, if you have the top of the tumor, it’s often necrosis, so the tumor has gone, has died because of lack of blood and so on. The top, it’s just debris, just all kind of rubbish so you should go deeper to be in the real-life tumor. [...] but not too deep that you can get bleeding.”* (P2, p.8).

The difficulty of doing biopsies in a real bronchoscopy according to a younger participant is in the view which may be obstructed by blood and saliva (P3, p.8). The participant describes that there are two ways to deal with the obstructed view: (1) using the suction device and (2) flushing with saline (P3, p.8). However, in the VR simulator, this obstructed view was not incorporated (P3, p.8), rather showing a clean lung without saliva or mucus (P5). Moreover, according to participants, the suction device was not working.

Another difficulty lies in taking biopsies from specific types of tumors. An experienced participant mentions that biopsies are “normally not a problem” (P1, p.2). However, he had a case with a wall-sided tumor which according to him, is rather difficult to biopsy because the “scope slides off it” (P1, p.1). Similarly, a resident mentioned that it is more difficult to get biopsies from wall-sided tumors because of the angle that needs to be made to the wall. Moreover, one participant also mentioned that doing a biopsy (in general) is hampered by the virtual patient’s respiration which causes a movement of the tumor inside the body (P1, p.1).

Transbronchial Needle Aspiration (TBNA) and EBUS.

Cells can also be collected from lymph nodes which are hidden underneath the surface/mucosa (P3, p.4; P3, p.9). According to a participant, a TBNA is performed at the location of the head carina (P4, p.7). During a TBNA, cells are collected from lymph nodes through pinching a needle through the wall and then using a suction device (i.e. aspiration). During the simulation, participants could not use the suction device (e.g. P3, p.5). Moreover, one participant explains:

“in real-life you get to wall and can always put the forceps on wall and open and then it stays there and then you can take a sample. [Here,] I tried to get needle in and take biopsy but it didn’t do it.” (P4, p.2).

A younger participant likens a needle aspiration to a “blind biopsy” (P3, p.9) because the lymph nodes are not visible and it cannot be seen where the needle is put in exactly (P3, p.9). As another participant adds “you’re not 100% sure that you’re in the lymph node.” (P5, p.5.). Another participant mentions that needle aspiration is the most difficult technique because it is used less often in favor of modern techniques like EBUS and EUS which involve an ultrasound, enabling to see the lymph nodes (P3, p.8). For example, another participant mentions “TBNA, I haven’t done it in, […] years. […] Everything I do with EUS, EBUS.” (P5, p.3). Similarly, an experienced participant emphasizes that a needle aspiration for lymph nodes should not be performed blindly; instead the EBUS or EUS bronchial ultrasound procedures should be used. (P4, p.7). However, in this simulator, performing an EBUS was not possible (P4, p.7).

Bronchial washing.

By conducting bronchial washings, one participant describes that cells are collected as well (P1, p.5). Another participant described that one part of the sample is sent to the pathologist (cytology) to examine if there are malignant cells, and another part is sent to the microbiologist to investigate whether there is tuberculosis, infection or bacteria (P5, p.3).

For the washing of the airway, the participant describes that "a physiological saline solution" (P1, p.3) is added into the airway because saline is also contained within human bodies (P1, p.3). Moreover, a younger participant adds that water cannot be used because it is not sterile, containing bacteria (P3, p.4). She also explains that after introducing saline into the airway, coughing is a normal reaction:

"It is not normal to have fluid over there other than your own saliva. So, if I put [...] fluid in, the patient will cough." (P3, p.4).

The participant adds that the fluid then has to be aspirated and collected in order to allow for cytology and microbiology analyses (P1, p.3). The fluid /saline which is aspirated contains cells (P3, p.3). The amount of fluid which can be aspirated depends on the location within the anatomy: in a smaller bronchus, more fluid can be aspirated while the participant was in a bigger bronchus during the simulation, to which she adds "I think I put some fluid and then it didn't come back" (P3, p.3). However, another participant makes clear that this is a fault on side of the VR simulator:

"in real life, you see the saline going into the bronchus and you have to swallow it up to get it back, here you put some saline, and then it's gone." (P4, p.3).

Sample locations.

Samples (e.g. from biopsies, brushings) are taken from the area that is abnormal (e.g. red and swollen) (P3, p.2). However, bronchoscopists may still have to decide where to sample. For example, a participant who had a patient case in which abnormality was present in both the right and the left lung interpreted it as the same disease and was free to choose where to sample, mentioning that *"it doesn't matter if I do the biopsies and the brushing at the right or at the left".* (P5, p.1). In addition, he said, with every intervention, the risk of bleeding increases (P5, p.2). On the other hand, another participant mentioned that in case of abnormalities at different locations, brushing could indeed be done *"on both sides because it* *could be that there are different problems so then you have to do it on both sides.”* (P3, p.5). Thus, it is important to be able to interpret abnormalities and judge, taking into account risks, where to obtain samples.

Deciding for technique(s).

According to one of the experienced pulmonologists, bronchial washings are always part of the procedure, even when nothing abnormal is to be seen (P1, p.5). When no abnormality is recognized, he explains, merely washings (for cells & bacteria) should be conducted (P1, p.5). However, in case of seeing abnormal tissue, in addition to washings, one has to biopsy and brush (P1, p.5).

The bronchoscopist has to decide which technique to use depending on the specifics of each patient case. As an experienced participant puts it:

“When you have […] patients coming with coughing, and there’s no other alarming signs, […] you can get a saline sample, for example. When you have a patient with a tumor, you are searching for, are there abnormalities in the airway that, […] you can get some material to examine from a pathology, microbiology […]. When you have a subcarinal notice, just behind the head carina, you know, this possibility that you can get a needle aspiration. So then you have to [do] […] a biopsy and […] brush and […] saline sample.” (P4, p.6).

Order of techniques.

One participant mentions that using biopsies, brushing and flushing with saline together increases the sensitivity for a diagnosis for the patient (P5, p.3). There may be an order of performing different diagnostic techniques. An experienced participant mentions to always start with 1. brushing followed by a 2. biopsy and then 3. bronchial washing (P1, p.1). For a younger pulmonologist, the preferred action was to start with a biopsy and in case a “good” sample cannot be obtained, she considered brushing “to have something” (P3, p.7). Another more experienced participant takes biopsies, then brushes and then flushes with saline (P4, p.1).

Selection of different kinds of instruments.

The VR simulator gave the option to choose between different kinds of instruments for one purpose (e.g. X options for a forceps, X for a brush, or X for a needle aspiration). One experienced participant mentions that for every procedure, a different forceps is chosen (P2, p.2). He adds that the type of forceps chosen also depends on the abnormality which needs to be sampled (P2, p.2). For example, given the tumor in the simulated case, he mentions that a “big forceps” will increase the chances of causing heavy bleedings (P2, p.4). However, another experienced participant mentioned that in real life, there is no choice between different kinds of forceps’, he mentions that “we only have the forceps without the needle” (P4, p.2). Similarly, he mentions that “we do have only one brush” (P4, p.3).

In addition to that, the VR simulator instruments are a bit wider and larger than in real life. Due to being out of plastic, one participant also mentioned how those instruments do not feel realistic (P6, p.7).

Amount of samples.

An experienced P mentioned that although he usually happens to take two samples, it is advised for students to take 4-6 samples because more samples facilitate the process of making a diagnosis for the pathologist who examines the samples (P1, p.9). During a real bronchoscopy, obtained samples are put into a container (P1, p.9). He explains that depending on the size of the samples that are being obtained, the required quantity of samples may vary: if samples are large, less/two samples can be enough to obtain a “perfect diagnosis” (P1, p.9). Another experienced P usually takes up to seven biopsies (P2, p.6). However, the required quantity of samples varies for him depending on the abnormality (e.g. tumor) and the extent of bleeding. For example, another experienced participant mentions that a tumor-like abnormality’s vascularity is high, meaning that it may bleed heavily (P4, p.2). Therefore, he adds, the first sample must be good, while also aiming to obtain 6 or 7 more samples if possible (P4, p.2). A younger participant mentions that the goal is to get as big a sample as possible since “that’s the most useful for the pathologist to examine” (P3, p.7).

2) Handling the bronchoscope.

That is one of the two main skills that participants emphasized that should be trained on the VR simulator.

Introduction.

A participant explains that introducing the scope differs depending on whether the patient is sitting or lying down (P1, p.10). While the participant mentions that he can do it both ways, he prefers sitting patients (P1, p.10). This skill can be trained on a physical simulator according to a participant. During a real procedure, it is also up to the bronchoscopist to choose to enter through the mouth or the nose which both have benefits and drawbacks.

Some participants mentioned that during the simulation, entering the airway was very easy:

"There is no resistance. Always open. The tongue is out, the whole mouth, larynx is open. In one second, split second, I'm in. I have seen colleagues, sweating." (P1, p.9)

One participant describes that in reality, it is "bleak" (P6, p.13), so one has to "find your way around" in order to end up near the vocal chords (P6, p.13). Similarly, as another participant describes, during a real bronchoscopy, for beginners, entering the airway is very difficult because patients are coughing or vomiting and moving around, causing the bronchoscope to diverge from the track (P2, p.5). This in turn, he adds, may cause novices to accidentally enter the stomach instead of the airway (P2, p.5). Another younger participant adds that one has to "take the right route" in order not to enter into the Esophagus (stomach) (P6, p.13). The experienced participant mentions three ways to overcome this challenge of introduction: proper anaesthesia (which is not always working), having anatomical orientation and working fast (P2, p.5).

The simulator also provides an assessment metric, referring to whether the user tried to introduce the scope while the vocal chords were closed, which according to one participant is important (P6, p.13). However, he also noticed that the VR simulator does not register this information correctly (P6, p.13), referring to a dissociation between actual and recorded performance.

Manoeuvring.

While one participant mentioned to have no specific technique for handling the scope, he adds that he holds the scope in the left hand and uses the right hand for taking biopsies (P5, p.4). Other people, he adds, may hold the scope in the right hand instead. One participant uses his whole body to manoeuvre the scope inside the airway:

"*And that's I think is very elegant if someone takes a bronchoscope and he dances with this scope inside. That's better when someone is always straight and you just have to turn and to turn."* (P2, p.1)

The participant explains that the benefits of this technique are that the scope does not have to be twisted, it is easier to enter the airway and that one is always positioned in the middle (P2, p.2). Another participant mentions that most of the time, one stands behind the patient at the head side. However, he adds, when manoeuvring through the right upper lobe which is very sharp, he turns:

"a little bit to the left, next to the patient and then it's a little bit more straight and not around the corner so that can be nice for your hands" (P4, p.4).

When attempting to take biopsies, one participant mentions that *"you have to try to use all possible positions […] with the scope and there's a wheel on the scope so you can […] look up or down and by moving the scope to the right or the left, you can move it also"* (P3, p.6).

Regarding the VR simulator, one participant mentioned that it was more difficult to "manipulate" the scope (or forceps) in the simulator than it is with a real bronchoscope (P1, p.3). In contrast, the participant prefers the physical inanimate simulator for handling the scope which includes a real hospital scope (P1, p.3).

The VR simulator provided an assessment metric related to the amount of wall contact. While more experienced participants disregarded its importance, mentioning that it does not hurt the patient because the bronchial tree is anaesthetised (e.g. P1, p.5,6), younger participants added that wall contact could cause irritation and then coughing, making the procedure more uncomfortable and difficult for both the patient and bronchoscopist. In that sense, he adds, wall contact is important. Moreover, one participant mentioned that in the VR simulation, it was more difficult to stay in the middle than it would have been realistically (P5, p.5). One participant mentions that the scope should be held as straight as possible and not flex it in a 90 degree angle in order to prevent damage to the scope (P4, p.8).

Inserting and removing tools.

One assessment metric given by the VR simulator was "the scope was flexed while passing the tool". One participant describes that when a tool is to be put in the scope, the scope should not be flexed because otherwise, it could damage the working channel of the scope (P6, p.2). Another metric related to "the scope was navigated with a protruding tool". To that, the participant added that *"normally, I go back centrally, then you insert the tool so that it's just protruding so that […] it cannot damage the working channel when you're navigating afterwards. Then you navigate towards your place of destination, and […] only then you open the tool (needle, forceps, brush)."* (P6, p.2).

Similarly, one participant says that damage to the scope could be done while using the forceps, brush or needle for the TBNA. It is important, according to him, to close the tools before removing them from the scope and to communicate well with the assistant who opens and closes the tools (P5, p.5).

The VR simulator was not accurate in this one because as one participant put it: *"you insert it like five centimetres, then it recognizes the tool already, then you insert it one centimetre more, then it's already visible."* (P6, p.3). Because of this unrealistic procedure, he adds, the normal workflow is disrupted, causing dissociations between how he would act during a real bronchoscopy and how he acts during the simulation (P6, p.3).

3) Inspecting the airway.

In addition to handling the bronchoscope, participants mentioned the VR simulator is Also adequate for learning this skill.

Interpreting imaging results.

CT scans of the lungs may guide bronchoscopists in inspection of the airway. One participant described that based on the scan which showed an abnormality on the left side, she decided to firstly inspect the right side in order to ensure that "everything is seen" (P3, p.1). CT scans also allow to see the condition of the lymph nodes which are usually covered underneath the mucosa (P3, p.2). One participant describes that "on the CT scan, […], you see there is a grey area and that is too large, that should be smaller" (P3, p.4). Thus, this skill is paramount also to the decision-making regarding which techniques to use (e.g. TBNA for enlarged lymph nodes).

Anatomical orientation.

Patient's coughing can cause the scope to move which may result in the trainee losing orientation inside the anatomy (P1, p.1). In such cases, one participant mentions that trainees should aim to go back to the most important landmark, the main carina (the splitting of the right and left) and re-start the navigation from there (P1, p.1). Anatomical orientation is an important skill to have because as one participant explains, the bronchoscopist needs to be able to tell the surgeon where exactly a tumour, for instance, is located. For that, he adds, one has to study the bronchial tree (P1, p.5). Learning this skill can be facilitated by continuously verbalizing “where you are”, according to one participant (P2, p.4).

One participant explains that “75% of patients have a normal anatomy and 25% [do] not” (P4, p.5). Therefore, it is also important to get to know different variations of the anatomy.

Systematic inspection.

Participants started inspecting the side of the lung where no abnormalities are expected (e.g. P2, p.1). As one participant describes, it is important to inspect all the branches (not just those with expected abnormalities) in order not to miss another possible abnormality (P3, p.7). However, complete inspection may depend on time and also the condition of the patient during the procedure (P3, p.7). While inspecting the airway, one participant mentioned that he is constantly developing a plan in his head: *“I already know I want to take biopsies, and brush, and flush for pathology and cytology and microbiology examination.”* (P5, p.1).

The VR simulator sometimes hindered inspection because the display froze (P2, p.1). Another participant explains this with the fact that the *“probe is going too far and then the program doesn’t have any algorithm, so that’s end of the program.”* (P4, p.1). Moreover, one participant describes:

> *“Sometimes it goes I want to insert the scope further but it doesn’t go. I feel resistance. And then like you roll something over and then it goes again. That was strange”* (P5, p.5).

Visually recognizing abnormalities.

It is important to be able to recognize and categorize different abnormalities and its consistence (e.g. strong, thick, hard, soft, elastic, red, swollen, irregular) seen in the airway in order to prevent bleeding complications, for example. During the simulation, one participant mentioned: *“It looks like a carcinoma, that’s one type of a relatively benign bronchial tumor but it bleeds like hell.”* (P2, p.2). The participant adds that in addition to visual classification, *“I touch it and I feel that it’s not moving so I go with the forceps a bit to find out about the material, I play with it.”* (P2, p.2). On the other hand, another participant mentioned that in even during a real bronchoscopy, tactile feedback is limited: *“You can feel a little bit but not much.”* (P6, p.10). The VR simulator, he adds, had no feedback at all (P6, p.10). One participant used the prominence of blood vessels for recognition: "*It can be an infection because it's more blood vessels over there […] but that could be because he also has some lymph nodes that are enlarged that could also be the indication it's cancer or infection."* (P3, p.1). Some abnormalities may be difficult to recognize for beginners (e.g. swelling beneath the mucosa) which *"you have to see many times before seeing the difference [between normal mucosa and swelling underneath]"* (P3, p.8).

An important factor influencing this ability is also the clarity of the airway. As one participant mentions, the lungs in the VR simulator were fully clean which is not realistic:

"That's strange because […] the walls were so pathologic, then you think there would be more saliva, sputum or something like that. […] But we didn't see anything […] saliva or something like that, or sputum, no." (P5, p.8). Another participant adds that in case of a lot of saliva, one has to "suck it away" (P3, p.9), however, the suction device did not work in the simulator as well.

4) Preventing and dealing with complications.

Possible complications.

One participant mentions that a possible complication is bleeding which normally occurs, to some extent, after each biopsy that is taken (P1, p.8). In addition to bleeding, he adds, a possible complication might be the introduction of infections when the materials are not clean (P1, p.7). Moreover, exacerbations of chronic, obstructive pulmonary diseases (COPD) could be caused (P1, p.7). Furthermore, one participant mentions that in the past, it happened often that the patient started shaking as a result of giving too much sedation (P2, p.4). Another result of too much anaesthesia might be arrhythmias (P4, p.5) which is rare however. Respiratory insufficiency is another complication where the patient has difficulties breathing due to full of sputum which can then cause heart problems (P2, p.8). At this point, one can only stop the procedure and reanimate the patient (P2, p.8). Lastly, Desaturation (P4, p.9) and damage to the vocal chords (P5, p.11) are potential complications as well.

Preventing bleedings.

A participant describes that if an abnormality may suggest heavy bleeding after a biopsy (e.g. due to heavy vessels), he attempts to prevent this by doing a biopsy at a location distant from those vessels (P2, p.3). Moreover, he adds, that in this case, he avoids using a big forceps which increases the chances of heavy bleeding (P2, p.4). However, one participant mentions that after brushing, bleedings (though not heavy) are normal (P3, p.5). Visual recognition of abnormalities is vital in this case, in order to avoid snapping a vessel which could cause bleedings (P3, p.8).

Treating bleedings.

One participant mentions that after taking a biopsy, bleeding can occur. To treat the bleeding, he says, one has to apply *"cold physiological salt solution […] Cold. About 5-7 degrees."* (P1, p.6). Another participant explains that the saline solution stops the bleeding a bit due to constricting the vessels (P2, p.7). If this is not sufficient, another participant adds, adrenaline-like solution could be introduced (P1, p.7). Another participant similarly suggests the introduction of *"xylometazoline"* (P4, p.3). Moreover, one participant mentions the bleeding may be uncontrollable and people could die as a result of a bronchoscopy (P2, p.7). He adds that the blood should be aspirated and fluids could be added to clean the airway (P2, p.7). One participant describes that some small bleedings can stop on their own (P3, p.4). However, to make sure that it stopped, she adds, one can go back to the location and take a look during the procedure (P3, p.4).

5) Administering anaesthetics or sedatives.

Among participants, the cue for giving local anaesthesia has consistently been coughing (e.g. P1, p,1). A systematic administration of local anaesthesia has been observed among and mentioned by participants (e.g. P2, p.1): first giving lidocaine to the vocal chords, then after entering, also to the left and right lung which spreads throughout the whole lung to decrease both coughing and as one participant says, also anxiety (P4, p.7). Occasionally, general anaesthesia is given (P2, p.3). The amount given to patients varies per each individual bronchoscopist's own clinical judgment, while general guidelines exist. One participant mentions using 10ml of a 2% solution (P2, p.3). Another participant adds to give anaesthetics preventatively before taking a biopsy or brushing to decrease the irritation and coughing (P3, p.2). Moreover, she mentions that when using sedatives like midazolam, it is more comfortable for the patient, but it also increases the hospital stay duration (P3, p.6). One participant adds that coughing is not only uncomfortable for the patient, but also for the bronchoscopist (P5, p.4). In addition to coughing, a cue for giving sedation, according to one participant, is if the ECG sounds increase greatly (P6, p.11).

However, one participant admitted that during the VR simulation, although noticing coughing of the patient, he abstained from giving additional lidocaine or midazolam because as he puts it *"I thought well, it's a simulation, we'll manage, we'll manage."* (P6, p.3). As an improvement to the simulator, he noted that the simulator should integrate immediate feedback saying for example "Hey this patient is coughing too much. Do something about it." (P6, p.5). The way in which the VR simulator presents the anaesthesia tools is not intuitive: "I thought is should be there, but it was there." (P2, p.1)

6) Patient monitoring.

One participant mentions that during the procedure, the heart rate, blood pressure, respiration rate and oxygen saturation is to be measured (P1, p.8). However, based on observations, the participant had difficulties in finding those measures in the VR simulator. He adds, that for learning purposes, in the VR simulator, warnings pertaining to changes in vital signs (doubled heart rate, saturation under 85%) should be made louder which would introduce a sense of urgency, making it more difficult to ignore (P1, p.8). One participant mentions that when the oxygen saturation decreases rapidly, the procedure should be stopped (P2, p.9). Another participant gets more specific mentioning that the procedure is to be stopped if the oxygen saturation goes below 90 (P3, p.6). Another participant mentions that during the simulation, she checked the saturation occasionally and listened to the sound of the ECG but nothing irregular was recognized (P3, p.6). Moreover, she said, if midazolam is given, the patients should be monitored more carefully since they are a bit sedated (P3, p.6). During the simulation, one participant mentioned to have noticed an increase in the virtual patient's heart rate, making him introduce lidocaine which decreased and stabilised the heart rate again (P4, p. 7).

One participant mentioned that during the whole procedure, one has to decide constantly whether to continue the procedure or to stop it based on balance patient well-being (anxiety, discomfort, desaturation) and what is good to get samples (P4, p.6). he mentions due to "feeling". Similarly, to the anaesthesia tool panel, one participant mentions that for a patients' vital signs, during a real procedure is a separate device instead of fitting everything into one screen, as in the VR simulator (P5, p.9).

Context

7) Working with an assistant.

Participants mentioned that normally, an assistant is present during the procedure who is responsible for introducing and using the diagnostic tools (forceps or perhaps also brush) into the scope and physically administering anaesthetics (e.g. P1, p.7). Another participant describes the communication with the assistant during a biopsy: "So I say [to the assistant who operates the forceps] open, close, open, bite, close and then I take it off" (P2, p.6). He describes that the assistant should know the procedure and what the problem is to be able to assist properly (P2, p.10). For the same reason, one participant explains that prior to the procedure he tells the assistant what he will be doing (P4, p.6). For example, he adds that the assistant may recognize a bleeding and then ask whether to introduce saline (P2, p.10). According to one participant, both verbal and nonverbal communication are important (P4, p.10). The assistant is also responsible for securing the obtained samples from a biopsy or brushing in a small glass container (P6, p.1). One participant mentioned to usually have two assistants present during the procedure (P6, p.2). For training purposes in a simulator, a participant adds that a trained assistant would be helpful in guiding the trainee and hinting towards action steps to be taken during the procedure (P6, p.4).

3.3 Discussion

The overarching goal of this research paper was to identify the requirements for a simulation-based training for flexible bronchoscopy. As results of this study suggest, requirements for a real flexible bronchoscopy are the acquisition of the following skills:

1) Mastering diagnostic techniques
2) Handling the bronchoscope
3) Inspecting the airway
4) Preventing and dealing with complications
5) Administering anaesthetics and sedatives
6) Patient monitoring
7) Working with an assistant

Deliberate practice is a training method which suggests that in order to achieve a high competency on a given skill, “tasks need to be *deliberately* chosen for their ability to improve performance and maintain it at the highest level” (Crochet, Aggarwal, Dubb, Ziprin, Rajaretnam, Grantcharov et al., 2011, p.2). In a study conducted by Palter and Grantcharov (2014), deliberate practice on a VR simulator has led to improvements of technical skills, as indicated by performance in the operating room. This study provides a starting point for designing such tasks for deliberate practice in a simulation-based curriculum. In particular, this study contributed to knowledge in:

1) creating a realistic training environment by suggesting incorporation of identified required features (e.g. sensations, cues) into a simulator and

2) gaining insight into the intraoperative decisions that are being made

Participants in this study agreed that the virtual reality (VR) simulator is only adequate for the skill acquisition of handling the bronchoscope and inspecting the airway/anatomy. Indeed, in an already existent Danish simulation-based curriculum for flexible bronchoscopy, those were the two skills for which a VR simulator was used. For training of the other skills, especially diagnostic procedures, the results of this study suggest that the VR simulator needs to be improved, making it more accurate. This (rather representative) quote by a participant summarizes how he felt when performing the *diagnostic* bronchoscopy on the simulator:

“there’s a lot of factors which make you doubt how realistic it is and then you tend to take the detailedness out of the procedure and you tend to go back to okay, then, I just gonna do, I’m just gonna do the rough part of the stuff and omit the detailed part of the stuff because it doesn’t know how to manage it anyhow.” (P6, p.8).

Table 5. Results of this study combined with suggestions for improving the VR simulator: Technical and non-technical skills training. Composition of table adapted from Clementsen, Nayahangan, Konge (2016) who have developed an assessment tool for a Danish Introduction to Simulation Based Education in Bronchoscopy.

Skill	Sub-skill	Simulator	Improvement points for VR simulator
Mastering diagnostic techniques	Brushing, biopsy, washing	Physical simulator or dry lab	• Giving immediate feedback if samples have been obtained or not • Tactile feedback (resistance) • Giving feedback on whether sample is representative • Excluding the option to select tools <u>during</u> procedure • Checking and improving <u>faulty</u> feedback and assessment metrics • Incorporate obstructed view (saliva, sputum, blood) • Checking and improving navigational accuracy • Improving suction device • Incorporate diagnostic technique EBUS • Improve accuracy of the reactions of fluids within the airway • Improving the master tools (forceps) to more closely resemble real tools
Handling the bronchoscope	Introducing the scope	Physical/Inanimate simulator	• Making scope similar to real hospital scope • Including resistance and realistic reactions of tongue, mouth to resemble realistic, rather difficult introduction • Including the possibility of inserting scope based on virtual patient's position: sitting or lying down • Check and improve accuracy of assessment metric

	Manoeuvring the scope	Physical/ Inanimate simulator	• Including haptic feedback • Comparing scope to real scope and improving technical resemblance • Improving navigational accuracy
	Inserting and removing tools	VR	• Improving accuracy in relationship between length of tool and the time it takes to insert it to become visible
Inspection of airway	Anatomical Orientation	VR	Frozen display -> better feedback
	Systematic inspection	VR	Frozen display -> better feedback
	Visually recognizing abnormalities	VR	• Including feature of obstructed view: incorporating saliva, sputum • Fixing suction device • Tactile feedback to feel consistence
	Interpreting Imaging Results	VR	• Excluding interpretation of CT scan in description and test correct interpretation objectively (e.g. with Q&A).
Preventing and dealing with complications		VR	• Incorporating realistic, reactive complications • Incorporate realistic measures to be taken in case of complications (e.g. introducing cold, 5-7 degree saline solution) • Improve suction device
Administering anaesthetics or sedatives		VR	• Make anaesthesia options easier to find in display
Patient monitoring		VR	• Making the display of vital signs more obvious and realistic

1) Handling the Bronchoscope

This skill consists out of the sub-skills of introducing the scope, manoeuvring the scope through the airway and inserting tools into and removing tools from the scope. Participants pointed out that the manoeuvring of the scope could be adequately trained on the VR simulator.

Manoeuvring the scope

On the VR simulator, trainees can learn to assume an ergonomic position for their hands while rotating the scope to inspect different segments of the airway. Participants in this study had different or no techniques for holding the scope during the procedure. For assessment purposes, experts need to agree on a technique(s) to be acquired for optimal scope handling. These techniques can vary in how the trainee is positioned to the VR patient (behind or beside), in which hand the scope is held, and how the trainee should move around the VR patient. Although technical dexterity is assessed by the VR simulator (3D Systems, n.d.c), an outside scorer is needed to evaluate the positioning of the scopist. In general, participants agreed on that it is to be avoided to twist the scope in order not to damage it. Participants disagreed on whether the scope is to be held in the midline of the airway, with arguments being that contact with the wall does no harm, while others being that it could irritate the bronchial walls. As outlined in a teaching video on FB from the School of Respirology at VUmc Amsterdam (2016), holding the scope in the midline also helps to identify the anatomical landmarks in addition to minimizing patient discomfort. Lastly, the functionalities of the scope should be learned, such as moving the tip of the scope with the help of the wheel on the scope.

1) Improvement points for VR simulator

3D Systems (n.d.c.) already includes an Essential Bronchoscopy Module for training scope control, eye-hand coordination and detailed anatomical knowledge (for orientation). A participant in this study acknowledged the accuracy and helpfulness of the aforementioned module. However, when considering to use the 3D Systems Symbionix VR simulator, it needs to be pointed out that a participant in this study also mentioned that the VR scope is not entirely similar to a real scope due to it being “difficult to manipulate”, while another added that in the VR simulation, it was more difficult to stay in the midline than it would have been realistically. In contrast, according to a participant, a physical simulator includes a real hospital scope, with the navigation being equally similar as in real-life. However, it can be argued that the VR simulator provides helpful immediate feedback and objective assessment metrics in the Essential FB Module which the physical simulator is not able to give. In this case, the VR simulator eliminates the need for a constantly present instructor and assessor.

Inserting and removing tools

While not specifically mentioned by participants, the VR simulator could also help in training the skill of inserting tools in and removing tools (e.g. forceps, brush) out of the scope without damaging the working channel. The simulator includes appropriate assessment metrics such as "The scope was flexed while passing the tool" or "Navigation with protruding tool", both of which should be avoided according to a participant. Another participant emphasised the importance of closing the tools before removing them and communicating well with the assistant who opens and closes the tools (see section 7 for working with assistant).

2) Improvement points for VR simulator

However, the VR simulator might not train a correct sense of the relationship between the length of the tool and the time it takes to insert it. For example, in this study, a participant described that in the simulator you insert the tool approximately five centimetres after which the system recognizes the tool. After inserting it one centimetre more, the tool is already visible. This process is different with a real hospital scope. Thus, a "re-learning" might have to take place after simulation-based training, causing a worse learning curve.

Introducing the scope

For acquiring the skill of introducing the scope in the airway, the physical simulator was considered more appropriate as a learning tool by a participant. Participants agreed that the VR simulator does not provide the crucial realistic experience, normally encountered in the introduction of the scope.

Trainees should learn how to introduce the scope in both sitting and lying patients which are considerably different experiences. The physical simulator mannequin could be positioned both ways. Similarly, the scope can be introduced orally and nasally; hospitals differ in their teaching methods. Considering that there are advantages and disadvantages to each method, experts should agree on which method should be trained, if not both. According to the School of Respirology VUmc Amsterdam (2016), this selection depends on the route of insertion, the location of the target in the airway and the patient's preference. The VR simulator however, only allows for oral introduction. The next aspect which needs to be learned is to deal with the resistance of the patient indicated by coughing, vomiting, all of which impede introducing the scope in the vocal chords. For example, trainees may end up entering the Esophagus instead, due to disorientation caused by the coughing. In this respect, the VR simulator provides a realistic learning environment due to being able to simulate coughing. Still, participants criticised how easy it is to enter the airway in the VR simulator, since not much resistance or disorientation is encountered. This skill is closely connected with the skill of administering anaesthesia (to reduce coughing) (see section 5) and anatomical orientation (see section 2). However, it needs to be mentioned that the VR simulator does provide immediate feedback at some points, for example, when accidentally entering the Esophagus (see Figure 6). Still, Figure 7 provides an example of a rather illegible feedback from the VR simulator which should be adapted to be displayed as in Figure 6.

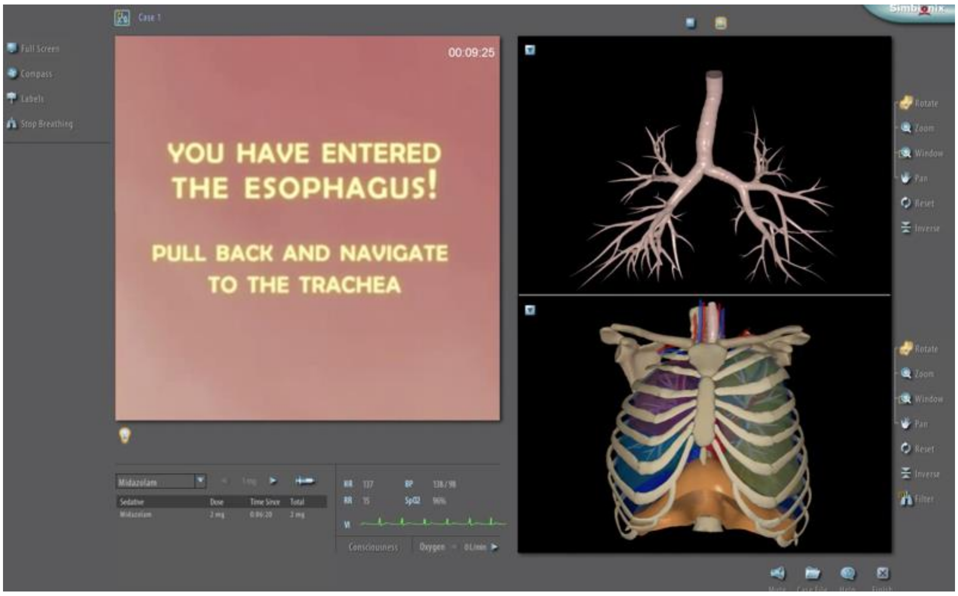

Figure 6. Screenshot of VR simulator display during participant's performance of the diagnostic flexible bronchoscopy task, showing immediate feedback on wrong introduction of the scope into the Esophagus.

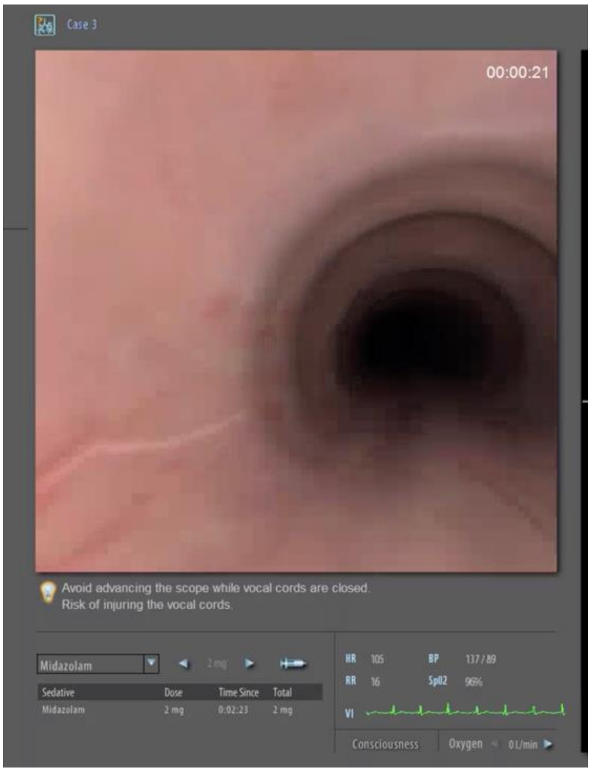

Figure 7. Immediate, illegible feedback given by the VR simulator located under the scope video next to an “enlightened” light bulb.

3) Improvement points for VR simulator

Due to the VR simulator’s general accuracy of representing the visual anatomy and ability to simulate coughing, it could be considered an appropriate learning tool for this skill after improving the following. Resistance of the virtual patient (e.g. tongue, coughing, vomiting) should be incorporated more accurately and the ability to find and reach the vocal chords should be appropriately tested by including realistic features that impede vision or orientation during a normal procedure. The ability to choose a sitting or lying virtual patient and entering through mouth or nose and simulating the respective differences should be incorporated as well. The assessment metrics should be tested for their accuracy in recording the actual performance, as this study found that some metrics to be inaccurate.

2) Inspecting the Airway/Anatomy

Interpreting Imaging Results

Although not mentioned by participants, the VR simulator could also prove as appropriate for assessing the ability to interpret CT scans accurately. Trainees can take a look at CT scans of different virtual patients with distinct conditions and learn the ability to recognize abnormalities. This ability guides the inspection of the airway (starting at non-pathological side of the lung) and the decision to use a TBNA, for instance (expecting abnormalities in the visually obstructed lymph nodes). For that purpose, however, the VR simulator needs to exclude the given interpretation in the patient descriptions and instead let trainees interpret it and giving them feedback on whether it is correct (e.g. in form of multiple-choice or open-ended questions.

Anatomical Orientation

As mentioned before, the VR simulator already includes an Essential Bronchoscopy Module in which anatomical orientation is trained and assessed accurately, according to participants. Trainees should navigate through different simulated anatomies to encounter anatomical variations which the VR simulator offers. Moreover, trainees should be able to correctly identify the location for example, of an abnormality. In the Danish simulation-based curriculum (2016), this skill was assessed with the VR simulator, by letting trainees photograph the areas and describe the location. Trainees' anatomical orientation can also be assessed by letting them verbalize where they are within the anatomy during an inspection of the airway. Acquiring knowledge of the anatomy can either be acquired separately during self-study, but the VR simulator also provides an effective learning tool of the anatomy for beginners, especially for learning the 3D-vision which cannot be accurately acquired through textbooks. For example, while navigating, trainees are given feedback on the exact location by descriptions on the screen (in the Essential Bronchoscopy Module).

Systematic Inspection

Trainees should be assessed on whether they inspect all branches. Experts agreed on that first, the non-pathological side of the airway should be inspected in order to not miss any abnormality (because they expect to concentrate and work on the pathological side). Despite conducting an inspection that is complete, it should also be rather quick which is also dependent on the condition of the patient during the procedure. Time is one factor which is already included in the VR simulator.

4) Improvement points for VR simulator

During the simulated inspection of the airway, participants encountered a sudden frozen display when attempting to inspect the airway further. This might be a software error that needs to improve, or it could indicate a technical limitation of the VR software's end of the simulated anatomical program. Similarly, a participant mentioned how during inspection, he encountered resistance, unreasonably which disappeared after rolling over some unidentified element in the simulator. Both findings necessitate further investigations.

Visually Recognizing Abnormalities

The VR simulator could be a fairly adequate learning tool for this skill in its current form, while improvements are needed. Trainees should be provided with different simulated abnormalities which they have to visually recognize and categorize and also perhaps describe its consistence. The Diagnostic Bronchoscopy Module provides different patient cases with a variety of abnormalities to choose from. Trainees may need not only name the abnormality and its characteristics, but also indicate which consequences this finding has on subsequent steps (e.g. where to sample from the abnormality, which complications it is associated with). The VR simulator should include different difficulty levels of recognition of abnormalities as some may be easier to recognize as others. For instance, according to a participant, it took experience to differentiate a swelling beneath the mucosa from normal mucosa. The VR simulator may be the best, cost-effective learning tool for this skill, as it can offer learning of multiple abnormalities by simply incorporating different patient cases, which is not possible in the physical simulator.

5) Improvement points for VR simulator

A factor which impedes the view during a bronchoscopy is the presence of saliva and sputum in the airway which was not included in the VR simulator, rather showing a clean airway. Similarly, a suction device to aspirate saliva was not working in the simulator. Lastly, tactile feedback should be included to let participants "feel out" the consistence of the abnormality.

3) Mastering diagnostic techniques

In its current form as used in this study, the VR simulator was considered inadequate for the training of diagnostic techniques, mainly due to missing tactile and immediate feedback and several inaccuracies (compared to real-life) in the sampling procedure. In contrast, physical simulators or dry labs were considered as an alternative. The following describes learning needs for these skills and how the VR simulator needs to be improved to enable the skill acquisition of mastering diagnostic techniques.

Trainees should master: bronchial brushing, biopsy, EBUS and bronchial washing. Participants in this study considered TBNA an outdated, “blind biopsy” procedure to which EBUS provides a more effective alternative by allowing a better visual access to the lymph nodes. For brushing and biopsy, trainees should learn to successfully collect a sufficient amount of samples and representative samples from different types of abnormalities. For that, immediate feedback from the VR simulator would be crucial, pertaining to whether samples were obtained at all and whether they are of good quality. Representativeness of samples for the bronchoscopist (not the pathologist) is defined by a big-sized sample. Trainees need to be given feedback on how large their obtained samples are and how they can improve their technique. While 4-6 samples are normally advised to take, trainees need to judge for themselves if this is possible, considering the type of abnormality (e.g. high vascularity of tumour) and potential complications, as every intervention increases the probability of bleedings. Thus, the VR simulator could provide trainees with various scenarios and abnormalities where such decisions (balance sensitivity for diagnosis with patient safety) need to be made. Trainees should also judge where exactly to obtain samples from (e.g. avoid top of tumour which is necrosis or in case of double-sided pathology: sampling from both sides or one side). As participants in this study used different orders for performing the techniques, experts should agree on an order for learning and assessment purposes.

6) Improvement points for VR simulator

In addition to providing immediate feedback on obtained samples during the procedure, tactile feedback and resistance should be incorporated which is normally used as a cue to close the forceps and also is a cue for having obtained a sample successfully. In a real FB, the procedure is impeded again, by an obstructed view, calling for a need for incorporating saliva and mucus, as well as a working suction device in the VR simulator. Moreover, the representation of fluids within the airway should be carried out more accurately; in the VR simulator, once fluid is introduced in the airway, it disappears. This eliminates the possibility to suction it back for analyses (bronchial washing). Furthermore, participants noticed that during the VR simulator, sometimes, it was not possible to reach the wall (the scope “sliding off” the tumour) which is an error in the software and needs to be fixed. Sometimes, faulty feedback was given, saying that the participant is at a wrong sample location which is not accurate according to the participant. Assessment metrics and feedback need to be checked and improved. Lastly, most participants agreed on that normally, they do not choose between different types of tools of one kind, but rather work with the ones provided by the department in the hospital. One participant argued to choose one type of tool, depending on the abnormalities he encounters. The VR simulator should incorporate the feature to choose instruments beforehand only once and the ability to (dis)enable the feature for during the procedure, depending on the practices preferred and agreed upon. Moreover, participants agreed on that the sampling tools (forceps, needle) are represented wider and larger in the simulation than they are realistically which should be fixed.

4) Preventing and dealing with complications

Serious complications are a rare occurrence in flexible bronchoscopy, happening in less than 1% of cases according to Konge et al. (2011). Marshall (2012) notes the potential of using simulators for thoracic surgical education: teaching “cognitive knowledge, patient scenarios, diseases management, operative planning, technical skills, judgment, leadership and crisis management” (Marshall, 2012, p.1). The VR simulator particularly has the potential to be used as a means for cognitive skill acquisition, by being able to present the trainee with cues as in a realistic environment to which the trainee will have to react with decision-making (Tichon, 2007). By incorporating different complications, the VR simulator could provide a good learning experience for dealing with those rare complications.

Trainees should know of potential complications through self-study. The application of dealing with them in a realistic patient scenario is crucial, as different factors such as stress and time pressure could impede one’s performance. Indeed, according to Hull, Arora, Aggarwal, Darzi, Vincent and Sevdalis (2012), adverse events during surgery may be more of a result of deficient non-technical skills than poor technical skills. For this, the Diagnostic Bronchoscopy Module would prove effective, since it includes rather realistic patient scenarios, where trainees are required to prevent complications (e.g. by attending to cues such as a heavy vessel and deciding to carefully obtain samples distant from those vessels to avoid heavy bleeding).

7) Improvement points for VR simulator

The treatment of bleedings however, could be improved in the VR simulator. Different options should be given to treat the complications which should be identified by future research. In this study, cold physiological solution (5-7 degrees) and xylometazoline were identified as treatment options. Moreover, the blood should be aspirated and fluid should be added to clean the airway and view, emphasizing the need for fixing the suction device.

5) Administering anaesthetics or sedatives

No major critique points for training this skill on the VR simulator have been given by participants in this study. Most participants had a systematic way of giving anaesthesia which is to first give it to the vocal chords, and then to the left and right; thereafter it is given, when cues necessitate it. Trainees need to recognize when to give (local) anaesthetics, by attending to cues such as coughing and an ECG sound increase in heart rate. Some participants also gave anaesthetics preventatively just before doing a biopsy or brushing, to minimize irritation and coughing. However, participants also mentioned that there is a limit to how much anaesthetics could be given during a procedure. Thus, this skill requires appropriate training and decision-making skills. Experts should agree on the use of anaesthetics and how and when they should be administered for assessment purposes. The Diagnostic Bronchoscopy Module would provide a good learning platform for training of this skill.

8) Improvement points for VR simulator

For training purposes, one participant would have found it helpful to get immediate feedback by the VR simulator, telling him: ”The patient is coughing too much. Do something about it.” Moreover, the tools to give anaesthesia on the display were not very intuitive, causing some troubles for participants to find it. This should be improved to optimize the learning experience.

6) Patient monitoring

While some participants mentioned that the assistant is normally more focused on recognizing changes in heart rate, blood pressure, respiration rate and oxygen saturation during the procedure, they also emphasised the importance of always checking major changes and responding correctly. Trainees should learn to decide when to stop the procedure and what to do when major changes occur. While one participant named that oxygen saturation needs to be below 90, another one said that if it is below 85, bronchoscopists should take action. Experts should agree upon those guidelines. A participant summarized that constantly, during the procedure, the bronchoscopist has to decide whether to continue or stop the procedure depending on a balance of the patient’s well-being and obtaining good quality samples. As these are more decision-making skills, the VR simulator may only serve as a means to an end here in that assessment should be conducted independently of the simulator's own metrics.

9) Improvement points for VR simulator

As trainees should be constantly checking and noticing changes in vital signs, the VR simulator could perhaps give immediate feedback by letting trainees know that major changes occurred and that they should respond with appropriate measures. These measures should be identified more clearly by experts. Moreover, one participant gave the idea to give louder warning signs (e.g. when doubled heart rate) so that trainees are less inclined to ignore it due to it being a simulator and not a real patient.

7) Working with an assistant

Among participants, teamwork with the assistant has been identified as crucial. Trainees should ideally have an assistant by their side who has knowledge about the procedures and especially, how to introduce and use master tools. Here, the VR simulator could merely function as a device to elicit the communication between bronchoscopist and assistant. Prior to the (simulated) procedure, the bronchoscopist should discuss their plan for the procedure so teamwork can be optimized. In addition to verbal skills, a participant also emphasised the importance of non-verbal communication skills, although not identified more specifically. Ideally, this skill could be trained with two students at a time which would provide learning for both.

One of the frameworks for defining and assessing non-technical skills in the surgical area is the taxonomy of non-technical skills for surgeons (NOTSS) (Flin, Yule, Paterson-Brown, Maran, Rowley, Youngson, 2007). This taxonomy includes abilities for being aware of and understanding the given situation, decision-making, communication and teamwork and leadership (Flin et al., 2007). This could be one of the frameworks with which to assess a trainee's communication skills. Reliability for the NOTSS Behavior Rating System, an assessment tool for non-technical skills for surgeons, was supported by Yule, Flin, Maran, Rowley, Youngson and Paterson-Brown (2008).

Future research.

Future studies are paramount in order to put in use the findings of this study, to help in the creation of a simulation-based curriculum for flexible bronchoscopy. Studies need to examine the accuracy of the VR simulator's assessment metrics, as previously mentioned, perhaps by comparing evaluations of experts and the VR simulators assessment metrics with regarding to performances of trainees on the diagnostic task on the simulator. Participants also mentioned deviation from reality in the “behavior” of the scope (e.g. normally it is easy to punch through the wall with needle, in simulator it was just gliding off) or in the navigation (e.g. it was more difficult to stay in the middle and not have wall contact without apparent reason (P5). Future research needs to investigate these concerns and work on improvements for the VR simulator. Another point of future research could be to establish metrics which distinguish between experts and novices. This could be done by including tasks of varying difficulty and a sufficient amount of procedures (Konge et al., 2011). However, first, difficulty levels should be identified for each skill. Lastly, different options should be given to treat the complications which should be identified by future research. Future research should also investigate how the acquired skills on the simulator transfer into real-life flexible bronchoscopy procedures.

Strengths and limitations of the study.

The study was the first (to the knowledge of the researcher) to conduct an encompassing, objective needs assessment for flexible bronchoscopy using a VR simulator. The input of six experienced professionals yielded the elicitation of more in-depth information about the requirements for performing a FB procedure. However, several limitations of this study might decrease the validity and reliability of the findings. One limitation includes the potential language barriers as the interview was conducted in English with Dutch native speakers. Potentially, participants could not express their thoughts entirely and accurately, due to having to translate them into English. Moreover, when selecting documents for the document analysis, the researcher’s restriction to the English language limited the selection due to not understanding developed training programs, written in Dutch. The retrospective think aloud method could have led to missing out on crucial information on decision-making, as participants could have forgotten all the thoughts and plans that were going on during their performance on the task.

Conclusion.

This study represents a general needs assessment which is only the first step to developing a curriculum. Several learning needs for a flexible bronchoscopy were identified but VR simulators were only restricted to satisfying the more technical learning needs, and even those not to complete satisfaction. As in its current form, the VR simulator must be used in conjunction with inanimate models to train bronchoscopic skills. The VR simulator necessarily needs to incorporate immediate feedback to let participants know about their performance. Moreover, in order for the deliberate practice method to work, in addition to repetition, immediate feedback on the trainees' performance is crucial (Crochet et al., 2011).

Still, this study also illuminated the potential of the VR simulator as a training modality for training of non-technical skills (preventing and dealing with complications, administering anaesthesia, monitoring the patient, teamwork). Assessment tools such as the NOTSS Rating System exist for assessing non-technical skills of trainees.

Assessment of skills given by the VR simulator are a result of the tracking of instrument movement which provides objective assessment metrics (Cosman et al., 2002). However, as this study suggests, the metrics were not accurate, showing a dissonance between actual and recorded performance. For example, the simulator recorded that a participant has attempted to pass the vocal chords when in reality this has not been the case. However, the VR simulator also has various benefits such as offering multiple medical scenarios. As Cosman, Cregan, Martin and Cartmill (2002) suggest, to avoid learning the simulation, the simulated tasks should be varied. Varying the tasks has another benefit which is that trainees learn to get to know different physiologies and anatomies (Cosman et al., 2002) which can be incorporated in a VR simulator more easily and cost-effectively, than in a physical, inanimate simulator. The VR simulator in this study included six patient cases in total, making this a realistic training goal.

Future research needs to resolve all discrepancies identified in this study and continue in the six-step approach to curriculum design and define the learning goals more clearly.

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Appendix: Informed Consent Form

Research Information: “Design of a Simulation-Based Training for Flexible Bronchoscopy”

Purpose of the research

Training for flexible bronchoscopy (FB) needs to be efficient and safe. Simulators have proven to be effective in offering trainees to practice FB skills without risking patient safety. Training curricula are often based on subjective opinions and on what is feasible and available. This study conducts an objective (learning) needs assessment of pulmonologists in Enschede and Nijmegen in order to contribute to the development of a Dutch training curriculum based on FB simulators.

Voluntary Participation

Participation is voluntary and you can choose to withdraw at any point of the study without justification. Note that the data provided by you, up to the moment of withdrawal of consent, can be used in the research.

Procedures

You will perform the full diagnostic flexible bronchoscopy task on the simulator. Your behavior (e.g. operation of instruments) will be video-recorded. Afterwards, while watching the video-recording, you will be asked to retrospectively “think aloud”; to disclose your thoughts and ideas you had during the performance. Lastly, interview questions will be asked (and audio-recorded) for the purpose of clarification and perhaps addition of omitted thoughts and ideas.

Duration

The estimated duration of this study is about an hour. However, the total time of this study may vary with respect to individual contexts.

Confidentiality

The researcher will store all personal data (video-recordings, audio-recordings) confidentially on an encrypted hard drive. The audio-recordings will be transcribed as text. All personal data will be fully anonymised for the research report.

If you want to receive a summary of the research results, please let the researcher know.

Consent Form for "Design of a Simulation-Based Training for Flexible Bronchoscopy"

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes.	**Yes**
Taking part in the study	
I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○
Use of the information in the study	
I understand that taking part in the study involves a video-recording of my performance on the simulator, an audio-recorded interview and accompanying hand-written notes. It is clear to me that the audio-recordings will be transcribed as text and the video-, audio-recordings and notes will be stored confidentially. I know that all research data I provide will be fully anonymised in the research report.	○
I understand that personal information collected about me that can identify me will not be shared beyond the study team.	○
I agree that my information can be quoted in research outputs.	○
Future use and reuse of the information by others	
I give permission for the information that I provide to be archived in a database so it can be used for future research and learning.	○
I agree that my information may be shared with other researchers for future research studies that may be similar to this study or may be completely different. The information shared with other researchers will not include any information that can directly identify me.	○

Signature

___________________________	_______________________	_________
Name of participant [printed]	Signature	Date