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Trondheim, June 2020

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Sammendrag

Systematisk kliniske observasjon ved bruk av ABCDE (Airway, Breathing, Circulation, Disability, Exposure) metodikken er en generell ferdighet som personell i helsetjenesten har behov for. Likevel mangler en del helsepersonell denne kompetansen, og effektive og bærekraftige læringsmetoder er nødvendige. Simulering har vist seg å være en god metode, men det mangler kunnskap om kvaliteten på det som gjøres endrer seg under gjentatt simulering.

I en utforskende observasjonsstudie (Artikkel I) ble derfor endringer i utførelsen av kliniske tiltak under gjentatte in-situ simuleringer med tre ulike caser beskrevet. Tre team fra tre forskjellige institusjoner deltok. Vurderingen ble gjort av fire uavhengige og blindede eksperter. Ekspertene kommenterte at det var en generell mangel på bruk av ABCDE metodikken, og skåringen deres viste ingen konsistent forbedring under de gjentatte in-situ simuleringene.

Den forventede forbedringen i bruk av ABCDE metodikken på tvers av diagnoser ble ikke funnet. En mulig tolkning var at en kognitiv overbelastning hindret læring. Dette funnet i artikkel I, sammen med behov for å innføre systematisk klinisk observasjon tidlig i grunnutdanning, var motivasjonen for å utvikle en virtuell virkelighet (VR) applikasjon for opplæring i ABCDE metodikken (VirSam ABCDE VR application) og teste effekten av denne.

I to randomiserte kontrollerte studier, med 289 første-års medisin- og sykepleiestudenter i hver, ble det undersøkt om individuelle (Artikkel II) og gruppebaserte (Artikkel III) øvinger på egenhånd i 20-minutter i en realistisk og interaktiv VR applikasjon i sanntid, gav et læringsutbytte som ikke var dårligere enn tradisjonell øving på egenhånd (TP).

Å trene VR individuelt og VR i gruppe ga ikke et dårligere læringsutbytte sammenlignet med TP individuell og TP i gruppe. Det primære utfallsmålet viste at 27% i TP individuell og 25% i VR individuell (Artikkel II) og 21% i TP i gruppe og 20% i VR i gruppe (Artikkel III) dokumenterte

de åtte utvalgte observasjonene i ABCDE metodikken i riktig rekkefølge i en praktisk test på en simulatordukke.

Nesten alle de andre sekundære utfallsmålene ga lignende resultat mellom intervensjonene i begge RCT-ene. Det ble funnet at flere studenter i VR individuell svarte at de likte måten å øve på, de scoret brukervennligheten høyere og fullførte full ABCDE undersøkelse flere ganger sammenlignet med de i TP individuell (Artikkel II). Flere studenter i VR gruppe rapporterte at de ikke hadde nok tid til å øve, de scoret brukervennligheten likt og fullførte full ABCDE undersøkelse færre ganger sammenlignet med TP i gruppe (Artikkel III).

Det er behov flere studier som gir kvantitative data om endringer under gjentatte in-situ simuleringer. Å øve på ABCDE metodikken både individuelt og i grupper i VR ga ikke dårligere læringsutbytte enn trening med tradisjonelt utstyr.

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Summary

Systematic clinical observations, such as the ABCDE approach, constitute a generic skill needed across healthcare settings. Still, this competency is lacking among many healthcare professionals and effective and feasible learning methods are needed. Simulation has been shown to be a good method but there is a shortage of knowledge about changes in quality during repeated simulations.

Thus, in an exploratory observational study (Paper I), changes in the performance of clinical actions during repeated in-situ simulations with three different cases were described. The assessment was based on scoring by four independent and blinded assessors. Three teams in three different healthcare units took part. The assessors commented on an overall lack of use of the ABCDE approach and the scoring showed no consistent improvement during the repeated in-situ simulations.

Thus, the intended learning, to improve participants' skill in using the ABCDE approach across cases, was not met. One interpretation is that there was a cognitive overload that prevented this learning. This finding in Paper I and a requirement for the early introduction of systematic clinical observation in undergraduate education were the motivations to develop and test the effect of a virtual reality (VR) application to practice the ABCDE approach (The VirSam ABCDE VR application).

Two randomised controlled trials (RCTs) with 289 novice medical and nurse students in each investigated whether 20 minutes of self-practice, either individually (Paper II) or in a group (Paper III), in a real-time immersive and interactive VR application produced a non-inferior learning outcome compared with traditional practice (TP).

Practicing VR individually and as a group produced non-inferior learning outcomes compared to individual and group TP. For the primary outcome, 27% in individual TP and 25% in individual VR (Paper II), and 21% in group TP and 20% in group VR (Paper III) documented all the

predefined observations in the ABCDE approach in the correct order on a practical test on a simulator manikin.

Nearly all the other secondary outcomes gave similar results between the interventions in both RCTs. More students in individual VR than in individual TP said that the method was preferable, and they scored the usability as higher and completed a full ABCDE examination more often (Paper II). More students in group VR than in group TP reported having insufficient time to practice, however; they scored usability equally highly but completed a full ABCDE examination fewer times than did those in group TP (Paper III).

In conclusion, more studies are needed to objectively document the learning process in repeated in-situ simulations. The VirSam ABCDE VR application can be used for training novice medical and nursing students in the fundamentals of the ABCDE approach.

Contents

Abbreviations

VR	Virtual Reality
TP	Traditional Practice
RCT	Randomized Controlled Trials
ABCDE	Airways, Breathing, Circulation, Disability, Environment/Exposure
NTNU	The Norwegian university of Science and Technology
VirSam	In Norwegian VIRtuell SAMhandling, virtual cooperation

List of included papers

Paper I

Berg H, Båtnes R and Steinsbekk A. *Changes in performance during repeated in-situ simulation with different cases*. Revised version submitted to BMJ Simulation and Technology Enhanced Learning.

Paper II

Berg H, Steinsbekk A. *Is individual practice in an immersive and interactive virtual reality application non-inferior to practicing with traditional equipment in learning systematic clinical observation? A randomized controlled trial.* Published in BMC Medical Education

Paper III

Berg H, Steinsbekk A. *The Effect of Self-practicing Systematic Clinical Observations in a Multiplayer, Immersive, Interactive Virtual Reality Application versus with Traditional equipment. A randomized controlled trial.* Submitted to Advances in Health Sciences Education

1. Introduction

Detection and management of deteriorating patients is a central skill for those working in healthcare, but several studies have found that both healthcare professionals and healthcare students lack this competency (Stayt et al., 2015, Purling and King, 2012, Smith and Bowden, 2017, Olgers et al., 2017). Furthermore, authors have pointed out the need to start practicing these skills early in undergraduate education (Say et al., 2019) and to provide practice for health professionals (Cant et al., 2020). There are a range of skills needed to manage deteriorating patients, but it all starts with observing the patient.

1.1 Systematic clinical observations – the ABCDE approach

As implied by the phrase, the term 'systematic clinical observations' refers to the practice of conducting clinical observations in a systematic manner. It is a general concept that is used by health professionals and other helpers in a range of circumstances and situations, both to save lives and to assess the clinical status of patients.

The Airways, Breathing, Circulation, Disability, Environment/Exposure (ABCDE) approach to systematic clinical observations is used to assess the clinical status of any patient. The ABCDE approach has been developed over time by healthcare professionals in different settings in their efforts to save lives (Brunker, 2010). In recent years, it has been included in international guidelines, and is the basis for current resuscitation guidelines (Resuscitation Counsil UK, 2015, Nolan et al., 2015). It is used as a quick way to assess the condition of any patient in order to obtain an overview of the patient's situation, ensure that relevant information can be conveyed when requesting help and determine which potential lifesaving actions should be prioritised (Thim et al., 2012).

1.1.1 Observations in the ABCDE approach

The pedagogical principle of the ABCDE approach is to help ensure a systematic assessment of the patient according to the importance of possible life-threatening conditions. The acronym denotes the order in which to observe vital areas. In an everyday setting without any equipment, the ABCDE approach can be used as follows (Thim et al., 2012):

Always start with the A for airways and make sure these are not obstructed. The airways can be secured by tilting the head back and lifting the chin to open the airways. Then continue with B for breathing; check if the person is breathing and count the respiration frequency. Next is C for circulation; check for a pulse on the person's wrist and count the heart rate. If there is no breath or circulation, call for help and start cardiopulmonary resuscitation according to guidelines (Perkins et al., 2015). In this case, do not continue with D and E. If the person does not suffer from breathing or circulation problems, continue to assess D for disability, using AVPU (Alert, Voice responsive, Pain responsive, Unresponsive) and move to E for exposure, in which the full body is inspected for injuries, markings and temperature.

In acute situations where health professionals are present and have access to medical equipment, an extended or advanced version of the ABCDE approach is used, based on the same underlying pedagogical principles, although there are some minor differences in the guidelines and literature regarding the observations to be included. Table 1 provides a list of the observations recommended by the UK Resuscitation Council with a few additions from other sources. Comparing Table 1 to the observations in a simple ABCDE approach as presented above illustrates both the variations in and the flexibility of the ABCDE approach.

Table 1. Observations that can be included in an advanced ABCDE approach for systematic clinical observations (Resuscitation Counsil UK, 2015, Smith and Bowden, 2017, Thim et al., 2012).

Area	**Observations**
Airways	- look for obstruction - look for paradoxical chest and abdominal movements - listen for 'see-saw' respirations - look for use of the accessory muscles of respiration - look for central cyanosis - listen to breath sounds at the mouth or nose

Breathing	- look, listen and feel for the general signs of respiratory distress: sweating, central cyanosis, abdominal breathing and use of the accessory muscles of respiration - count the respiratory rate - assess the depth of each breath, the pattern (rhythm) of respiration and whether chest expansion is equal on both sides - note any chest deformity - record the inspired oxygen concentration (%) and the SpO_2 reading of the pulse oximeter - listen to the patient's breath sounds a short distance from their face - percuss the chest - auscultate the chest - check the position of the trachea in the suprasternal notch - feel the chest wall
Circulation	- look at the colour of the hands and digits - assess limb temperature - measure the capillary refill time (CRT) - assess the state of the veins - count the patient's pulse rate (or preferably heart rate by listening to the heart with a stethoscope) - palpate peripheral and central pulses, assessing for presence, rate, quality, regularity and equality - measure the patient's blood pressure - auscultate the heart - look for other signs of poor cardiac output, such as reduced conscious level and, if the patient has a urinary catheter, oliguria - look thoroughly for external haemorrhage from wounds or drains or evidence of concealed haemorrhage
Disability	- review and treat the ABCs: exclude or treat hypoxia and hypotension - check the patient's drug chart for reversible drug-induced causes of depressed consciousness - examine the pupils (size, equality and reaction to light) - make a rapid initial assessment of the patient's consciousness level using the AVPU method: Alert, responds to Vocal stimuli, responds to Painful stimuli or Unresponsive to all stimuli - measure blood glucose - assess the patient's limb power*
Exposure	- examine the patient properly full exposure of the body - take the patient's temperature*

*Additions

1.1.2 Using the ABCDE approach

In non-emergency settings like hospital wards, nursing homes or home nursing care, the ABCDE approach can be used to obtain baseline clinical values, which is important for detecting changes and especially deteriorations at an early stage (Smith and Bowden, 2017). Sepsis is an example of a condition that can be difficult to recognise at an early stage In these unclear situations, it can be difficult, but important, for the healthcare staff to decide when to take action and it is therefore important to have tools for decision support. These are often based on the ABCDE approach. One example is the use of the ABCDE approach to assess and obtain the clinical values needed to calculate the National Early Warning Score, which is used to help healthcare professionals to respond to deterioration at an early stage (Smith et al., 2013, Pirneskoski et al., 2019). The observed clinical values are aggregated into a score that indicates how severe the situation is, with a corresponding recommended action.

In an emergency setting like a car accident in which many people are injured, the helpers or the paramedics use the ABCDE approach to triage those injured (Iserson and Moskop, 2007, Kravitz, 2019, Olgers et al., 2017). A short assessment of ABC (excluding DE) decides who can wait and who needs lifesaving help. A similar approach is used in emergency departments and out-of-hours general practice to prioritise patients. Furthermore, it is especially important in acute situations that an initial ABCDE assessment be followed by regular re-assessments.

1.1.3 Learning to use the ABCDE approach

Given the approach's wide range of use and its potential importance in life-threatening situations, mastering it is a skill that needs to be learned and practiced by medical and healthcare professionals and students (Fuhrmann et al., 2009, Stayt et al., 2015). The use of the ABCDE approach will likely increase in the future due to the growing elderly population, the increasing complexity of healthcare provision and the relative lack of intensive care and high-dependency beds. Still, a lack of competency in performing the ABCDE approach has been documented (Liaw et al., 2011c, Purling and King, 2012, Stayt and Merriman, 2013), as has its lack of use in some cases, with the consequence that deteriorating patients may not be identified as early as they could be (Olgers et al., 2017).

National and international patient safety campaigns have used several pedagogical approaches to help implement the ABCDE approach in different clinical and healthcare units (WHO, 2011, Norwegian Health Directorate, 2016). One example of the recommended approaches is to teach the approach to two professionals from each unit, using lectures and simulation practice, and then to provide them with a manual for a teaching programme and give them the responsibility to teach the rest of the unit; in other words, a train-the-trainer approach (Orfaly et al., 2005).

Reviews and meta-analyses have found simulations to be a better way to learn the ABCDE approach than traditional lectures are (Stayt et al., 2015, Orique and Phillips, 2017). One example of a successful approach is documented in an RCT including first-year nursing students (Stayt et al., 2015). The intervention group took part in a two-hour simulation in a clinical skills laboratory while the control group attended the normal teaching intervention, which was a traditional one-hour lecture. The students in the simulation group watched the facilitator conduct a systematic ABCDE assessment and the management process on a medium-fidelity patient simulator using a clinical scenario of an acutely unwell patient. There was one facilitator to five or six students, and the students practiced the ABCDE process individually on the patient simulator while receiving individual verbal feedback on their performance. The students in the intervention group did significantly better in the post-objective structured clinical examination than the students in the control group.

As evident from this example, learning the ABCDE approach through simulations requires more resources than the traditional lecture does (Stayt et al., 2015). Still, simulation gives better effect and might be worthwhile despite the relative high cost. Nevertheless, it raises the question if it is possible to use less resource demanding simulations to learn the ABCDE approach (Stayt et al., 2015, Orique and Phillips, 2017).

1.2 Simulation

There are several definitions of simulation in the literature. The Society for Simulation in Healthcare provides the following to the point definition: 'simulation is the imitation or representation of one act or system by another' (Simulation Society, 2020). In practice, this means that simulation is about creating an artificial situation that mirrors aspects of real life.

1.2.1 Clinical simulation history

In medical and healthcare practice and education, imitation of procedures, operations and anatomic models has been used as long as medical practice has existed (Rosen, 2013). The practical training has traditionally been done on real patients in real environments under the supervision of an experienced medical practitioner (Issenberg and Scalese, 2008). The need to practice in safe environments increased as medical treatment became more advanced and the organisation of the healthcare system became more complex (Cant et al., 2020). The vision of starting with simulations in healthcare education has been driven by the increased demand for patient safety (Gaba, 2004, Aebersold, 2016). Today, simulation-based education is acknowledged as superior to traditional education for practicing a range of clinical skills (La Cerra et al., 2019, McGaghie et al., 2011, Merriman et al., 2014, Osborne et al., 2019).

The technological development of simulators and simulation activity has advanced considerably over the decades. The Norwegian company Laerdal Medical, which has become a worldwide simulator supplier, released its first simulator manikin, Rescue Annie, in 1960 (Laerdal, 2020). Rescue Annie was made for training mouth-to-mouth ventilation and manual chest compressions. The first high-fidelity simulator was developed in the late 1960s for use in anaesthesia, but because of the cost it was not a great success (Bradley, 2006). It was in the 1980s that high-fidelity simulators were first implemented for professional anaesthetists to practice in hospitals, and later in the 1990s for students in healthcare education.

1.2.2 Fidelity

Fidelity is the standard industry term to describe the degree of realism and technical complexity of simulator models (Sahu et al., 2019). High-fidelity simulators are highly advanced and can talk, breathe, blink, bleed, urinate, sweat, have heart and lung sounds and can be monitored with all clinical values. These simulators respond to intervention and are not dependent on an operator. Medium-fidelity simulators also have software but are dependent on the operator to change clinical values. Low-fidelity simulators are static manikins for training in intubation, laparoscopy, cardiopulmonary resuscitation and so on. The idea behind the fidelity of simulation is based on the assumption that the more the learning context resembles the context of practice, the better the learning. However, which level of simulation fidelity is more effective is a matter for debate and can depend on the level of the learner (Kim et al., 2016a). High-fidelity simulation can result in cognitive overload if the learner does not have specific information or skills automated (van Merrienboer and Sweller, 2010, Andersen et al., 2016b). The simulation fidelity must therefore be related to the nature of the task for practice; thus, there are no unidimensional and linear relationships between simulation fidelity and learning (Norman et al., 2012).

1.2.3 In-situ simulation

Simulation training commonly takes place in dedicated training rooms in hospitals or in educational institutions. Simulation in the practice field is called in-situ simulation (Sørensen et al., 2017). Examples of in-situ simulation include practicing clinical skills and teamwork, identifying safety threats and evaluating new facilities (Fent et al., 2015). However, it can be difficult to establish in-situ simulations. One study from an emergency department highlights the importance of the anchoring process from both front-line workers and hospital administration to success in establishing in-situ simulations (Petrosoniak et al., 2017). Furthermore, care had to be taken to minimise the impact on emergency department workflow by having the total session length of the simulation not exceed 30 minutes, with 10–15 minutes spent on practicing the scenario and 10–15 minutes on debriefing.

Examples of studies on in-situ simulation show a variation in approaches. One study investigated the effects of lecturing alone versus lecturing in combination with in-situ simulation versus no intervention on adverse prenatal outcomes (Riley et al., 2011). The researchers found improvement from the combined in-situ simulation and lecture, no change from lecture only and deterioration from no intervention. Another study found that the number of hospital-acquired severe sepsis/septic shocks and acute respiratory failures improved significantly after introducing in-situ simulations four times per month during a one-year intervention period and monthly during a six-month sustainability period (Braddock et al., 2015).

Studies have found that simulations in the workplace provide focus on improvements for both interdisciplinary teamwork and aspects of patient safety (Fent et al., 2015). The existing literature demonstrates that in-situ training improves patient outcomes either in isolation or within a larger quality improvement programme (Goldshtein et al., 2020). In-situ simulation can be a cost-effective solution for those who do not have a simulation centre, but there seems to be a challenge posed by cancelling rates from the staff because of patient conflicts when practicing in-situ (Kurup et al., 2017). In-situ simulations have been shown to be effective, especially in team, unit and organisational development but also for individual clinical skill practice. The fact that they take place within the clinical environment provides an opportunity to 'identify hazards and deficiencies in the clinical systems, the environment and the provider team' (Patterson et al., 2008). Because in-situ simulations involve actual healthcare team members, they can provide additional benefits to centre-based simulation in improving systems and infrastructure and fostering a culture of safety (Petrosoniak et al., 2017).

1.2.4 Repeating simulations

Before simulators, the way to learn clinical procedures or operations was to 'see one, do one, teach one', but with the available simulation facilities, this practice has been replaced with 'see one, simulate many, do one competently, and teach everyone' (Vozenilek et al., 2004). Common wisdom tells us that if you practice repeatedly, your skills will improve. However, after extensive searches of the literature, little information has been found about what goes on during the repetition of simulations or how repetition affects outcomes. An integrative review of the education and training literature to identify effective training approaches for health workers continuing professional education found that repetitive interventions, rather than single interventions, yield superior learning outcomes (Bluestone et al., 2013). This review also found that case-based learning, clinical simulations, practice and feedback were the most effective educational techniques.

Repetitive in-situ simulations for health professionals are used to maintain and improve competence in rare, high-risk situations. One study with this focus investigated an intervention in a paediatric intensive care unit with a six-month follow-up, finding significant improvements in performance and retention after initial training (Singleton et al., 2018). The intervention aimed to improve nursing code cart competency and used five simulated scenarios that included 22 code cart skills. These were low-frequency, high-stakes skills. The participants received immediate feedback and instruction and repeated each task until mastery during training.

Another study investigated the effect of increasing numbers of training sessions in cardiopulmonary resuscitation (CPR) on trainees' attitudes and CPR quality (Kim et al., 2016b). The study found that repeated CPR training improved trainee attitude and CPR quality. In addition, willingness to start CPR, skill confidence, chest compression depth, no-flow time and mouth-to-mouth ventilation improved for those who did three or more training sessions. Another study found that repeated practice skills acquired under time-distributed practice conditions were retained better than skills acquired when gathered (Andersen et al., 2016a).

1.2.5 Educational challenges

As the complexity and the acuity levels in hospital wards rise, along with shorter hospital stays, a corresponding need for more professionals with advanced clinical competence arises, both in the hospital wards and in the primary healthcare services (Cant et al., 2020). This requires healthcare professionals to engage with continuing professional education throughout their careers. This type of competence is also needed in pre-graduate education. Unfortunately, medical and healthcare students have limited opportunities to practice such skills in their clinical placements (Stayt and Merriman, 2013).

Organisational issues and short rotations in clinical settings do not always allow for training in an interactive way, especially for high-risk, low-incidence clinical events (Kneebone et al., 2007). This challenges educational institutions to give students enough practice while at the same time ensuring patient safety. The use of simulations may seem like an obvious answer, but practical aspects like costs, staff and availability of equipment reduce the possibility of practicing simulation training regularly and repeatedly (Akaike et al., 2012, Krogh et al., 2014). This challenges educational institutions to further develop more available, less resource-demanding and more effective forms of simulation (Maloney and Haines, 2016).

1.3 VR

In this thesis, the definition of VR: 'a computer-generated digital environment that can be experienced and interacted with as if that environment was real' is used (Jerald, 2015). This definition includes a variety of VR platforms, ranging from the use of desktop and other types of screen solutions like caves to head-mounted displays, with or without the possibility of interacting through various inputs, ranging from keyboards and joysticks to hand controllers and body-wear solutions (Figure 1). Depending on the technology used, these solutions can be graded according to the level of immersion and level of interaction in the VR.

Figure 1. VR head mounted display and hand controllers, desktop VR and cave VR.

Several other terms are used for different VR technologies. The most commonly used is extended reality (XR), a term referring to all real and virtual combined environments (Wikipedia, 2020a). XR is also used as an umbrella term, covering a number of simulations:

- Augmented reality (AR), composed of images produced by a computer and used with or as an overlay view of the real world (Cambridge University, 2020).

- Mixed reality (MR), a blend of physical and virtual worlds that includes both real and computer-generated objects, in which the user can navigate this environment and interact with both real and virtual objects (TechTerms, 2020).
- VR, in which the environment is entirely virtual.

As evident from the title of this thesis, the focus will be on VR, mainly on the experience of VR through head-mounted displays for immersion and hand controllers for interacting with the virtual world.

1.3.1 History

VR is not a new technology. The first person to have mentioned VR, not as a concept but as an idea, is said to have been the science-fiction author Stanley G. Weinbaum in 1935, in the story ‘Pygmalion's Spectacles’, in which a VR model and the experience of using it were described (Weinbaum, 1935). In the story, a man experiences another reality by wearing a pair of goggles described as a military gas mask. The history presented in the goggles was uploaded through a fluid in which the reality was captured. Wearing the goggles, the man was involved in the new place from a first-person perspective, being able to move around, converse with people and smell and feel the environment.

The first mechanical prototype of VR was built in 1962 by Morton Heilig and named the Sensorama (Boas, 2013). It used 3D visual, audio, haptic, olfactory and wind effects to make the experience as real as possible (Figure 2). The purpose of this invention was to simulate a real experience, with the aim of using it for training to prevent men from risk and equipment from damage. The invention was meant for use in education, the military and industry (Heilig, 1962).

Figure 2. Morten Heiling's Sensorama. Source: Pinterest (https://no.pinterest.com/pin/397161260873126060/)

In 1968, the first head-mounted display, called the Sword of Damocles, was developed by Ivan Sutherland (Figure 3) (Wikipedia, 2020b). Featuring a tracking system to identify the head, this display was heavy and had to be fixed to the ceiling in order to be worn. It was connected to a computer and the 3D models changed perspective when the user moved their head, thanks to the tracking system.

Figure 3. Ivan Sutherland's Sword of Damocles. Source: Pinterest (https://www.pinterest.com.mx/pin/862861609825999982/)

In the 1980s, a range of VR devices were invented, leading to a breakthrough for development in this area, and in the 1990s, the public got access to the first VR gaming consoles (Wikipedia, 2020c). In 2007, Google introduced Street View, and in 2010, this became available with a stereoscopic 3D mode through the output of two images, one intended for each eye, creating the illusion of depth. This could be viewed with 3D goggles and provided a 360-degree view.

The same year, 2010, saw the first Oculus Rift prototype; the Rift was first presented in 2012 in a trade event for the video game industry and was not made available for the public, but there were developer versions that could be obtained. In 2016, the first consumer versions of VR head-mounted display were released for the public, namely, the Oculus Rift (Figure 4) and HTC Vive. Later, other companies released similar solutions, including for the Sony PlayStation in 2017. The first versions of these devices still had some of the weaknesses known from the developer versions, such as unstable technology, and many users experienced nausea and dizziness when looking around and moving in VR (Prasolova-Førland et al., 2018). The first versions were dependent on their connection to a computer with a powerful graphic card and external sensors to track movements of the head-mounted display and the controllers. In 2019, the first advanced VR headset, the Oculus Quest, which could be used independently of a computer and with integrated tracking sensors, was released (Picture 4).

Figure 4. Oculus Quest (left) with no cable to a compute, and Oculus Rift (right).

1.3.2 Immersion and sense of presence

As described above, the different solutions used for VR give different experiences of the reality being experienced, described in terms of immersion and sense of presence. The use of these concepts in the literature is not consistent and they are often used interchangeably but immersion can be defined as the technological quality of media, and sense of presence can be defined as the psychological experience of being there (Cummings and Bailenson, 2016). The sense of presence will thus be affected by the immersion quality.

When the user wears a head-mounted display made for VR, the real world is completely occluded from the field of view; that is, the user can only see what is displayed in the head mounted display (Martirosov and Kopecek, 2018). Research has found that the immersive (technological) features that can increase a sense of presence are vision, sound, environmental quality, the possibility of interactions with the environment (tracking), user perspective and haptic feedback from the hand controller (Cummings and Bailenson, 2016). In addition, the user perspective can be either first-person, that is, through the eyes of the user, or third-person, that is, from behind or over the shoulder of the user.

Sense of presence does not only depend on the level of immersion; the user's involvement in the activity in the virtual environment as a social actor is also important (Lombard and Ditton, 1997). One example is the possibilities to interact with other people. Where the perception of the reality of interaction, like the realism of the others presence, the users feeling of being there like the real you, the sense of being a part of what's goes on, and how exciting the user think the participation in the actual activity are, increase the sense of presence (Lombard and Ditton, 1997).

A study showed that immersive environments could provide participants with a holistic experience of real-world environments that are otherwise too expensive, impractical or unethical to provide (Schott and Marshall, 2018). Research have also found that immersion can aid memory recall of large amounts of information organized using the idea of *virtual memory palaces* (Krokos et al., 2019), where pictures and surroundings were supposed to help the user to remember.

1.3.3 Development of VR applications

The reality in VR is delivered through programmed applications. There are different frameworks for the development of VR applications that can help the developers organise the virtual environment in such way that the user understands the possibilities in the environment. One example is the ISO standard for human-centred design for interactive systems, which emphasises that the design of the application be based on the explicit understanding of the users, the tasks to be performed and the environments for the activity (ISO, 2019). Another theoretical framework is the theory of affordances, which can be understood as the understanding one has of how to utilise the environment in which one is present (Gibson, 2014). Significant affordances are tasks that lead to enhanced spatial knowledge, opportunities for experiential learning, increased motivation/engagement, improved contextualisation of learning and richer/more effective collaborative learning (Dalgarno and Lee, 2010).

To make a VR application, platforms for programming games are used. Common platforms include Unity (https://unity.com/) and Unreal (https://www.unrealengine.com/en-US/). Looking at sites for buying VR applications, such as the Oculus Store and Steam, most of the applications are created for entertainment. Among the most popular VR applications on the Oculus Store are titles like Beat Saber (https://www.oculus.com/experiences/rift/1304877726278670), Superhot (https://www.oculus.com/experiences/rift/1012593518800648) and Star Wars Vader Immortal (https://www.oculus.com/experiences/rift/2031736060288351). However, there are also educational titles, such as VR applications for learning anatomy and physiology. We have not been able to find applications for practicing clinical skills or team practice in these stores.

1.3.4 VR in education

It has been suggested that virtual reality has the potential to revolutionize the medical and health education (Best, 2019, Pottle, 2019, Rudran and Logishetty, 2018). The arguments are the ranges from the possibilities to practice procedures in safe environments to for team training where the team members can join from different geographical places. Thus, experiential learning is incorporated in the interactive VR nature, where the user can try, reflect and retry, in a continuing reconstruction of experience (Kolb and Kolb, 2005). It also gives the possibility to provide situated learning because VR can provide authentic contexts, activities, and assessment with guidance and feedback (Dede, 2009).

The incorporation of VR technologies into learning in higher education started approximately 10 years ago (Radianti et al., 2020). It was most common in desktop solutions, such as virtual patients. VR with the use of head mounted displays and hand controllers has been used in education only for the last few years, following the release of consumer versions, mostly for experiential use. A recent systematic review and meta-analysis of VR for health professionals included 31 studies (Kyaw et al., 2019). The authors evaluated the effectiveness of VR on health professionals' knowledge, cognitive skills and attitudes, and satisfaction with VR use. The earliest study included was from 2005, which compared the effect of 3D animations to those of traditional surgical videos (Prinz et al., 2005). None of the included studies used head mounted displays, but some of the studies were interactive. The study concluded that VR improves post-intervention knowledge and skills, and that VR with high interactivity showed more effectiveness than those with low interactivity did. The study also found that there is a lack of research on immersive VR, which is to be expected because of the recent release of this technology.

That said, a recent systematic review from 2020 aimed at immersive VR applications for higher education included 38 studies in which five came from medicine and nursing (Radianti et al., 2020). In these, the level of immersion and interactivity varied; only one study was both interactive and immersive, using an head mounted display (Shattuck, 2018). Multiple users were able to share the same virtual space, but they had to be in the same physical room to communicate because there was no sound implemented in the VR. There was no avatar representing the user in this application. Another study evaluated a trauma decision-making VR simulator (Harrington et al., 2018). This application was both immersive and interactive, with one user at a time handling trauma patients in an emergency department environment. A third study investigated the experience of two levels of immersion, desktop and head-mounted display, in both of which students practiced an interactive decontamination procedure (Farra et al., 2018). A fourth study investigated the same application as the Farra article, comparing desktop and head-mounted displays (Smith et al., 2018). No significant differences in outcomes were noted between groups in either of these two studies, but the students found the head-mounted display in VR simulations to be more interactive.

In medical and healthcare education, the introduction of VR has been referred to as a paradigm shift, predicted to transform medical education (Rudran and Logishetty, 2018, Pottle, 2019). This claim is based on the accessibility and affordability of VR technology and the fact that VR is suitable for practicing technical skills and team performance. In VR, interprofessional practice can happen independently of geography, and the learners have the possibility of practicing their knowledge outside of classrooms and laboratories but still in safe environments.

1.4 Repeated in-situ simulation to learn ABCDE

As outlined above, healthcare practitioners and students will need competency in the ABCDE approach. This approach can be used to identify a deteriorating patient and to connect their symptoms to possible underlying causes and pathophysiology (Smith and Bowden, 2017). To gain this competency, practitioners and students need training. Those providing such training should be aware that studies show that a rapid loss of skills occurs after initial training (Zieber and Sedgewick, 2018, Auerbach et al., 2018). An obvious solution is to provide repeated practice, which has been found to lead to retention of skills among all types of healthcare professionals (Tabangin et al., 2018, Kim et al., 2016b). Thus, it can be expected that practicing the same skill several times is needed to learn the ABCDE approach (Wiet et al., 2017).

One solution for repeated practice in a safe environment is to provide simulation training or in-situ simulation conducted in the field of practice (Sørensen et al., 2017, Connell et al., 2016, Liaw et al., 2011a). However, searches of PubMed and Google Scholar did not yield any publications describing changes in performance of repeated in-situ simulations focused on the ABCDE approach. These searches identified a few publications on the outcome of repeated in-situ simulations for health professionals; these were conducted in rare, high-risk situations, using the same clinical case (Singleton et al., 2018, Bluestone et al., 2013, Kim et al., 2016b). These studies are described in the 'repeating simulation' paragraph.

If training focuses only on practice for one specific clinical case, it is not likely that the learner will be able to apply their knowledge to other cases. Healthcare professionals encounter a range of different clinical situations in which they need to be able to employ the ABCDE approach. In a study aiming to test a simulation-based educational programme on recognising, responding to and reporting physiological signs of deterioration, the researchers used only one clinical case for the simulation testing (Liaw et al., 2011a). They concluded that the use of different clinical cases in the testing would yield more reliable estimates of performances. Such data can provide greater insight into approaches to developing repeated in-situ simulations for practicing the ABCDE approach.

1.5 VR simulation to learn ABCDE

As described above, research on the effect of different types of VR applications in different settings have shown that VR has similar or in some cases better effects than do other forms of training (Maier et al., 2019, Guedes et al., 2019, Khan et al., 2018, Piromchai et al., 2015, Kyaw et al., 2019). One of the obvious advantages lies in the possibilities given by VR to practice in a safe environment. This is important in practicing the ABCDE approach because this approach can be used with critically ill patients. However, searches for research publications in which the ABCDE approach for systematic clinical observation is practiced in a fully immersive and interactive virtual environment did not yield any results. We found a mere two experimental studies investigating the effect of serious games in which ABCDE skills were one of the outcome measures; these found the results of such games to be similar to other forms of training (Dankbaar et al., 2017, Dankbaar et al., 2016).

The starting point for VR use in teaching the ABCDE approach is the development of a suitable VR application. Given the evidence from the literature on ABCDE training, features needed in such a VR application will include the ability to interact with the environment and conduct clinical observations, to generate an environment in which the user feels present, the capacity to provide feedback and the ability for participants to communicate with other persons if practicing in a group.

When making a VR application for practicing the ABCDE approach, the learner's level of knowledge needs to be taken into account (Motola et al., 2013, Farra et al., 2016, ISO, 2019). As previously described, the ABCDE approach can be used in situations ranging from the highly acute and dramatic to the observation of healthy persons (Smith and Bowden, 2017, Olgers et al., 2017). In emergency situations, the learners will typically be experienced healthcare personnel working in emergency care or healthcare students in their last year or in continuing education, while the observation of a healthy person can be an ideal starting point for a healthcare student who has just embarked on their education.

When making a VR application for those learning the ABCDE approach early in their education, the learning goals must meet their level of competence (ISO, 2019). The application must provide feedback to the students and give them the opportunity and motivation for repetitive practice. It is also important that all the users have their own tasks and responsibilities in the VR, so that they stay engaged (Creutzfeldt et al., 2016). It is also worth considering whether the VR application will be used for individual practice, group practice, or both. In individual practice, there is no need for online facilities. In group VR, online facilities must be provided, as well as facilities for organising the users so that they can co-operate during practice.

Most of the research on the effects of using VR applications in the training of healthcare personnel is based on individual practice. For instance, in the two latest reviews, only three of 36 included studies involved group practice (Radianti et al., 2020, Kyaw et al., 2019). Moreover, only one had a multiplayer option in which the users could look at and interact with the same pictures in neuroimaging (Shattuck, 2018). One multiplayer desktop solution had the option of interacting with other users to change users' attitudes towards poor people (Menzel et al., 2014). In another multiplayer solution, the users met synchronously in a virtual classroom using their desktop PCs to conduct a case study analysis (Claman, 2015). Their work was compared to that of an asynchronous group whose members worked on a discussion board. A review from 2018 featuring multiplayer virtual worlds included only 18 studies, all of them for desktop use (Liaw et al., 2018).

Nevertheless, use of VR for training groups in the ABCDE approach offers exciting possibilities. To be able to practice as a group in VR, online real-time multiplayer features are needed so that the group can be present and collaborate in the same environment (Liaw et al., 2018). Simulation-based activity is well suited for group learning and VR can provide effective simulation group learning (Kyaw et al., 2019, McGrath et al., 2018, Hughes et al., 2016). However, it is difficult to draw conclusions about the effects of different types of multiplayer VR applications because of the methodological limitations in past studies, and more research is required (Liaw et al., 2018, Kyaw et al., 2019).

2 Aims of the thesis

The overall aim of the work presented in this thesis was to contribute to the knowledge about the use of in-situ and VR simulation for learning the ABCDE approach.

This aim was operationalised into the following research objectives:

1. To describe changes in the performance of clinical actions by teams of healthcare professionals with different levels of experience of the ABCDE approach during repeated in-situ simulations with different cases (Paper I).
2. To investigate if individual (Paper II) and group-based (Paper III) self-practice in a real-time immersive and interactive VR application (the VirSam ABCDE VR application) gave a non-inferior learning outcome among first-year medical and nursing students compared to individual self-practice with traditional equipment for skill training.

3 Methods

To achieve the research objectives, an exploratory descriptive observational study (Paper I) and two RCTs (Papers II and III) nested within a four-armed RCT were conducted.

3.1 Ethics

The studies were approved by the Norwegian Centre for Research Data (reference number 535088 for Paper I and reference number 523810 for Paper II and III).

Approval to conduct the observational study (Paper I) was also sought and given by the units involved; the unit leaders were involved in the recruitment and partly in the conducting of the trial. All ordinary procedures at the units were followed for ethical reasons and to ensure staff and data security. The participants were informed both in writing and orally of their rights and the purpose of the study, including the participants' right to withdraw without providing a reason. Written consent was obtained from all participants.

Participation in the RCT study (Papers II and III) was linked to a teaching programme that was integrated into the curriculum of each study programme and approved by the course and/or study programme leaders. The participating students were informed both orally and in writing a week before and at the start of the teaching session that they would participate in a teaching session in which they would be randomised into different types of ABCDE practice. They were informed that they could consent to participate in the study at the end of the session to keep their focus on the teaching session and not on the study. The students consented by providing the data from the outcome measures.

3.2 The observational study (Paper I)

The observational study was conducted by collecting data about activities in a local project, related to a national campaign 'In safe hands 24-7', to build competency in the early detection of deterioration in patients (Norwegian Health Directorate, 2016). The objective for the local project was to try out in-situ simulations to practice systematic clinical observations using the

ABCDE approach in order to determine whether it was a feasible method for increasing competency. It was decided to focus on an elderly patient residing in a nursing home who followed the medical emergency pathway. The involved services were therefore the nursing home, the out-of-hours general practice, the hospital emergency department, the ambulance and the Emergency Medical Communication Centre. The local project also decided to repeat the in-situ simulation three times, using different cases, and to conceal the underlying diagnosis from the participants to ensure that the focus was on the ABCDE approach across cases and not in handling persons with a specific diagnosis.

This local project offered the opportunity to answer Aim 1 of this study about the quality of actions taken during in-situ simulations by different teams with different levels of experience in clinical observation. It therefore made sense to focus on the data from the nursing home, the out-of-hours general practice and the emergency department because these provided the desired diversity. The ambulance personnel were the most experienced participants but did not conduct systematic clinical observation themselves in the local project and there were thus no data on their performance. The blinded outcome assessors (see below) were not part of the local project but were included afterwards as part of the research endeavour.

3.2.1 Design

As the study aimed to learn more about what happens during repeated in-situ simulations, an observational design was chosen. Moreover, because as this was the first study of its type and no validated outcome measures were found, it was decided to conduct the study as an exploratory descriptive observational study. This description of the design was chosen to signal the nature of the study; it was not a definitive study but rather a first attempt at providing ‘hard’ quantified data (blinded assessment) of the quality of the clinical actions carried out during repeated in-situ simulations.

3.2.2 Participants

The participants were teams of health professionals consisting of ordinary staff from a nursing home, an out-of-hours general practice service and a hospital emergency department. They were recruited through the leaders of the units.

3.2.3 Instruction and in-situ simulations (interventions)

The teams participated in a two-hour introductory session held three weeks before the first of the three repeated in-situ simulations. The introductory session was conducted separately for each team and held at their own workplace. The session started with a lecture about systematically observing patients using the ABCDE approach and the participants were provided with written handouts that included an overview of the ABCDE method. This was followed by a lecture about simulation with a presentation of the phases – briefing, simulation and debriefing – explaining the hows and whys of each phase. In the last hour of the introductory session, the teams conducted a simulation with the briefing, simulation and debriefing phases. The clinical case was heart failure and the participants were instructed to focus on the ABCDE approach.

As described above, each of the repeated in-situ simulations included a briefing phase, a simulation phase and a debriefing phase (Ødegården et al., 2015).

1. Briefing phase. The team was informed about the learning goal, the ABCDE approach, and the resources and equipment available. The simulator manikins' facilities were demonstrated using the ABCDE approach, and the participants were invited to ask questions and try out the simulator's facilities.
2. Simulation phase. The simulation was conducted in as relevant a manner as possible, with no observers present except for the project team, consisting of one researcher who did the filming and the simulation facilitator. The scenario was carried out without interruptions, and the team was not given an opportunity to ask the project team questions related to the case. The simulation phase ended when the facilitator considered the simulation situation to be under control.

3. Debriefing phase. The scenario was systematically reviewed immediately after the simulation phase. The facilitator guided the participants through a systematic reflection on the simulation, to which all participants actively contributed.

Three different cases with similar clinical presentations but with different underlying diagnoses were used. The underlying diagnoses were pulmonary embolism, sepsis and heart failure; these were selected by the research team after suggestions from the recruited teams based on what they found to be relevant for their unit. The teams were not informed about the underlying diagnoses but told to keep their focus on the ABCDE approach.

3.2.4 Data collection

Data collection was performed through video recording of the simulations. The production of transcripts from the recordings was a tedious process, with three different persons involved to ensure that everything that was said and everything that was done were included in the transcript. The final detailed transcription covered 130 minutes of recording.

The clinical actions performed by the teams were the main unit of analysis because they represented the outcome of the clinical observations. Given that there was little use in making correct observations if they did not prompt correct actions, the descriptions of the clinical actions contained information about what was done and the quantity and form of administration, e.g. '5 mg of morphine is given i.v.'.

To present the transcripts to the four clinical experts who were hired to assess the simulations, a spreadsheet (Microsoft Excel) was made using the transcript and including the clinical actions and clinical values, as well as questions and a scoring system (Figure 5). The assessors were blinded to the specific learning objective, the diagnosis, the teams, the units, the order of the current simulation and to each other's assessments. They were instructed to score only the clinical actions that were clearly marked.

Figure 5. The spreadsheet used by the assessors with the transcript (yellow heading) and clinical actions (yellow highlighted cells), as well as questions with scoring instructions (orange heading and blue cells). To the far left, the clinical values and specified time are presented (light orange cells).

	A	B	C	D	E	F	G
1	**Simulator**	**vitalia**	**Linjenr.**	**Tilstede: Sykepleier 1 og 2 og hjelpepleier. Har tilgjengelig Morfin, nitroglyserin, iv væske og O2.**	**Er det et riktig valgt tiltak ut fra det som er situasjonen forut for tiltaket?** Rett/Feil/X (kan ikke avgjøres/ikke relevant)	**Er det valgt rett administrasjonsmetode på tiltaket?** Rett/Feil/X (kan ikke avgjøres/ikke relevant)	**Er tiltaket i samsvar med forutgående observasjoner?** Ja/Nei/X (kan ikk avgjøres/ikke relevant)
237			234	Spl 1 ser på monitoren og sier			
238			Tiltak 3	Det gis 0.4 mg Nitrospray under tungen til pasienten	Rett	Rett	Ja
239			235	" nå er bt 93/41.....			
240			236	...Skal vi henge opp væske eller?»			
241			237	Spl1 «det ligger inne en nål ja»			
242			238	Spl2 sier til pasienten «nå er det en ambulanse på vei»			
243			239	Pasienten svarer og spl2 småprater litt med han			
244			240	Spl1 går bort igjen til notatene sine og sier i tlf			
245			241	«han har hypertensjon og står på medisin».			
246			242	00.14.39			
247			243	Spl2 sier «jeg går og henter en maske jeg og bytter»			
248			244	Hjpl sier «jeg tok med maske, den ligger der»			
249	**ca. 15 min**		245	Spl 1 lytter i tlf og sier «ja ja og nå får han oksygen og han har fått nitro..			
250	BT	89/40	246	Ja ja..så ligger han med hevet rygg»			
251	PULSE	108	247	00.15.24			
252	RF	33	248	Spl 2 «nå tar jeg av deg nesebrillene så skal du få på deg en maske jan erik»			
253	TP	37,8	249	Spl 2 setter på maske uten reservoar og sier			
254	SAT	85	250	«da blir det lettere for deg å puste, da får du inn både nese og munn»			
255			251	Fasilitator spør hvor mye o2 han får nå?			
256			252	Spl2 sier «2 liter..»			
257			Tiltak 4	Det gis 2 liter O2 på maske uten reservoar	Feil	Feil	Nei
258			254	Spl 1 sier i tlf «2 liter sier hun....			
259			255	..skal vi sette på noe mer?....			
260			256	Den er på 85 da...»			

The clinical actions were assessed by the following questions:

1. Is it the correct choice of a clinical action based on its preceding situation? (yes/no/unknown)
2. Is the correct method of administration chosen? (yes/no/unknown)
3. Is the clinical action in accordance with the preceding observations? (yes/no/unknown)
4. What is your assessment of the choice of the clinical action? (1-10 scale where 1 is worst possible and 10 is best possible)
5. What is your assessment of the method(s) of administration? (1-10 scale where 1 is worst possible and 10 is best possible).

For each complete simulation, the overall outcome was assessed by four questions:

1. What is your overall assessment of the treatment of the patient in this simulation? (1-10 scale, where 1 is worst possible and 10 is best possible)
2. Are there any missing observations in the scenario? Yes/No. If Yeas, write with your own words which observations are obviously missing.
3. Are there any missing clinical actions in the scenario? Yes/No. If Yeas, write with your own words which clinical actions are obviously missing.
4. What is your short overall assessment of the treatment of the patient in this simulation? Present the assessment in your own words.

3.2.5 Analysis

Although it is possible to make comparisons across units when several units are involved, such a comparative study would require validated outcome measures and a large number of units. Thus, the comparison was conducted only within the units by comparing the repeated in-situ simulations of each team and the comparisons and interpretations of these were descriptive.

The written comments by the clinical experts to the open-ended questions were categorised according to the topic concerned. This analysis focused on identifying the overall topics within the team.

A quantitative analysis was conducted to evaluate the assessors' agreement (Cronbach's alpha) and their assessment of the quality of the clinical actions during each simulation. These latter outcomes are presented with mean and standard deviation. A statistical test was conducted to compare outcomes within each team, but due to the explorative nature and size of the study, they are not presented in detail.

3.3 The RCTs (Papers II and III)

These studies were the result of ongoing activity since 2015 to investigate the use of VR in healthcare education within a project called VirSam (in Norwegian 'VIRtuell SAMhandling', virtual cooperation).

Logo VirSam

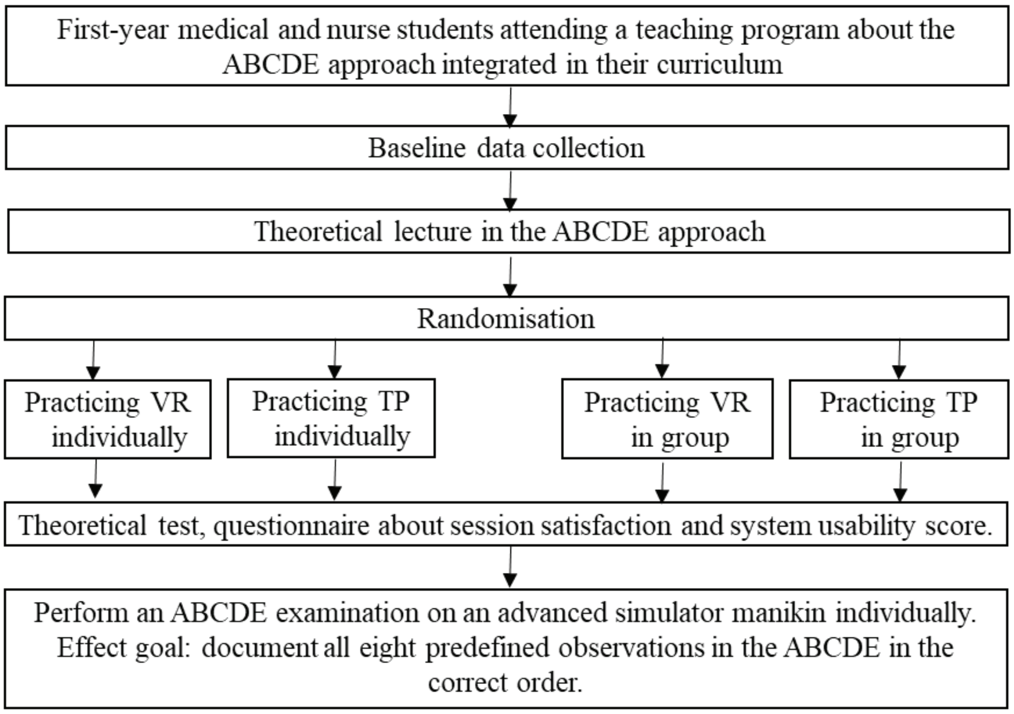
In VirSam, different activities have taken place, including the development of scenarios and facilities within the virtual world 'Second Life' for communication training and the development of VR applications for medical procedures (Snarby et al., 2019, Prasolova-Førland et al., 2018). A long-term goal of the VirSam project has been to provide evidence for the effects of VR sustainably integrated into ordinary healthcare education. This has been dependent on having easily available VR equipment and VR applications of an adequate standard that can be used without requiring extra involvement of teachers and technical staff.

With the availability of consumer versions of VR equipment (see the Introduction) and a growing competency in both the technical and pedagogical aspects of making VR applications for self-use, it has become possible to conduct large-scale effect studies. A considerable amount of time was spent on the development of the VR application used as the intervention in the RCTs, and data on this process have been collected but not yet published. The details of the development of the VR application are outside the scope of this thesis.

3.3.1 Design

Due to the focus on effects and the desire to produce definite answers, it was decided to conduct two open, non-inferior RCTs nested within a four-armed design. The flow of the study (i.e. the different 'actions' in the study and the teaching programme) is presented in Figure 6.

Figure 6. The flow of the two RCTs



It was decided to conduct the RCTs as non-inferior studies because VR has some disadvantages compared to real-life skill practice (Piaggio et al., 2012). Non-inferior studies are used when investigating whether a new intervention has an effect that is not worse, by more than a small, pre-specified amount, than an existing intervention, which then becomes the active control (Mallat, 2017).

It was clear from the outset that there would be two different RCTs in order to investigate individual and group self-practice independently. However, since the practical situation lent itself to it, the decision was made to nest the two different RCTs within a four-armed study. This did not affect the conduct of the two RCTs and gave the added possibility of making comparisons across them. In this thesis, only results from the two RCTs are reported; that is to say, the thesis does not cover or present data on comparisons across the two RCTs (this will be done later).

To draw conclusions about the feasibility of the use of the developed VR application in ordinary healthcare education, the design was adapted to fit that setting. This meant setting up the studies so that a large number of students could practice within a limited time with limited staff. In this case, it meant 220 students having to go through the teaching programme in 14 hours over two days with nine staff members, and 130 students in four hours during half a day with 18 staff members. Another factor to consider was the use of learning activities in the teaching programme as a study activity with another intention: The end of the teaching programme was answering theoretical questions about ABCDE and practicing on a manikin under time constraints. These activities were used for data collection in the RCTs.

3.3.2 Participants

The participants were first-year medical students taking part in a teaching programme on emergency medical care and nursing students taking part in a first-aid course or a course in practical nursing skills. The study took place on the three campus sites at the Norwegian University of Science and Technology (NTNU), Faculty of Medicine and Health Sciences, located in Trondheim, Ålesund and Gjøvik.

3.3.3 Interventions

There were two interventions: a VR application intervention and a traditional practice (TP) intervention. These are presented in Paper II and III, and some additional details on the VR application is provided here. In short, the TP consisted of practicing with traditional equipment; a digital blood pressure gauge, a digital oximeter, a digital ear thermometer, a clock, an overview of the ABCDE observations.

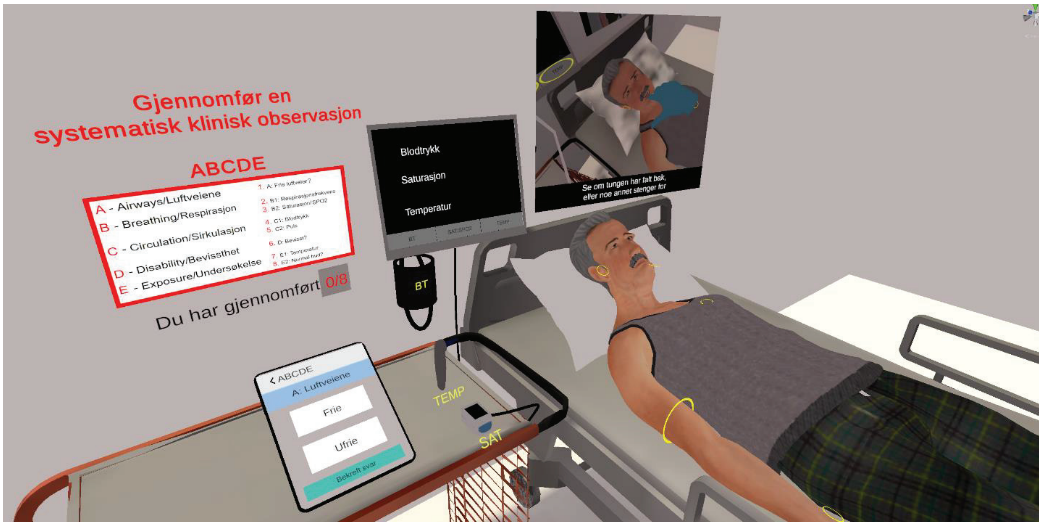
The VR application was developed in accordance with the guidelines for human-centred design for interactive systems which emphasises that the design be based upon an explicit understanding of users, tasks and environments (ISO, 2019). The overall design required deciding on the

ABCDE approach to be used (phase 1), specifying the requirements (phase 2) and developing the application in an interplay between the programmer, the domain experts and the end users (phase 3).

The development process of the specific VR application, which built on previous work in the VirSam project, started in February 2018 and ended in August 2019, with the main work carried out from December 2018 to May 2019. It was an iterative process featuring interviews with and application testing by health professionals, medical and healthcare teachers and students, as well as others with different backgrounds and experience. Affordances (Gibson, 2014), immersion (Cummings and Bailenson, 2016) and interactivity (Lombard and Ditton, 1997, Lee, 2009) were all emphasised. The application was developed for both individual and group practice.

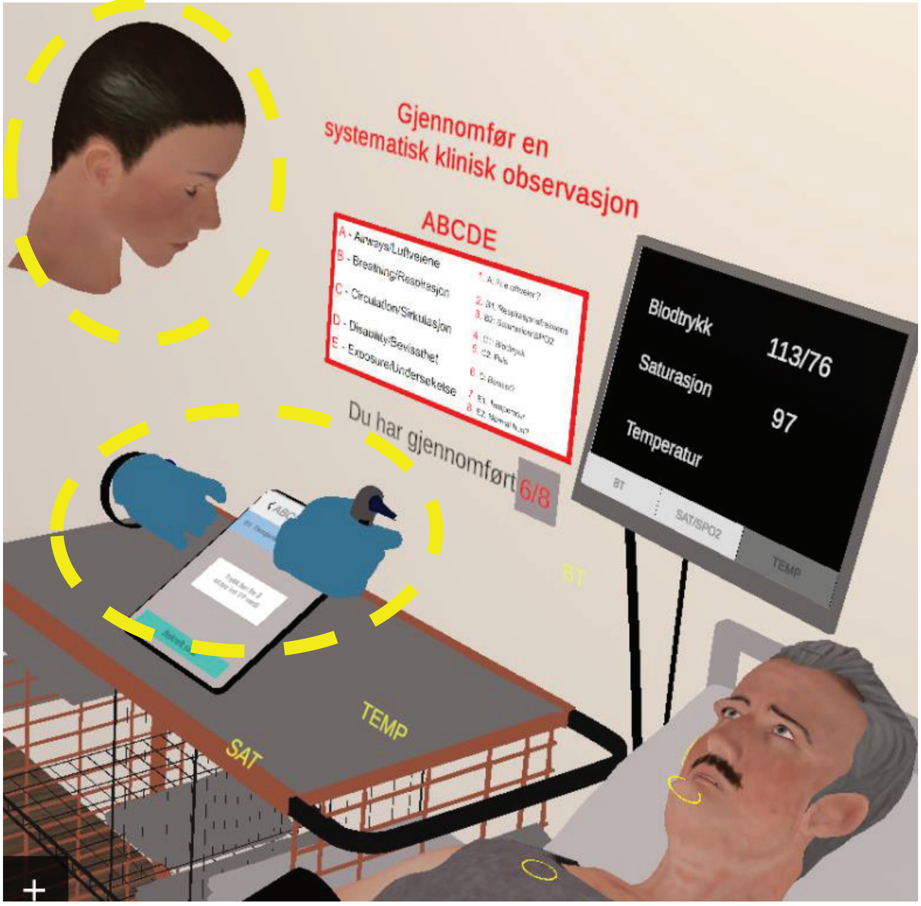
The virtual room created represented a generic patient room that could be found in a hospital or in an institution with a clinical examination room (Figure 7). It included an automated patient avatar lying on the bed with markings of where examinations could be done. The equipment available and the places where the player could interact with the equipment were marked with yellow circles. To support the players in practicing alone, they were provided with the ABCDE observations in their correct order (displayed on the wall to the left) and videos showing how to perform the observation (displayed on the wall to the right). On two pop-up screen (not shown here) they were also asked questions about the observations to be conducted and provided with feedback after completing a full ABCDE examination.

Figure 7. The equipment for a user standing at the right of the patient



When practicing as a group, the players needed to be able to see each other as avatars (virtual representations). After tests with full body avatars revealed technical problems, such as too great a reduction in the frames per second and challenges in programming the movement of the avatars to match the body movements captured by the head-mounted display and hand controllers, avatars were developed that had head and hands only (Figure 8). This solution was very well accepted by subsequent testers.

Figure 8. The look of the 'head and hand' avatar (marked with yellow dashed circles) as seen by another player.



3.3.4 Data collection

The outcome data were collected in two stages: a theoretical test directly after the practice session and then a practical test. The theoretical test comprised knowledge questions about the right order of the ABCDE and the eight observations and questions about the students' experiences of different aspects of the whole teaching session. It also included the System Usability Scale to measure the usability of the system during self-practice, graded on a curved grading scale (Lewis, 2018, Brooke, 1996). The practical test involved completing a full ABCDE examination on an advanced simulator (the 3G or ALS simulator, Laerdal Inc, Stavanger, Norway) with a time limit of five minutes. The students were instructed to write down their observations on a blank sheet of paper. The primary outcome was for all eight observations to be documented in the right order.

3.3.5 Analysis

A sample size calculation was conducted on the basis of previous research studies, leading to the choice of a non-inferior limit of 13 percentage points (Mpotos et al., 2014, Curran et al., 2015). A separate pilot study with students from a vocational high school to estimate the expected proportion who would carry out all observations in the right order (the primary outcome), which turned out to be 20%. With a power (1-B) of 80% and significance level (alpha) of 0.05, 118 students were needed in each group (Sealed Envelope Ltd, 2012).

The usual arguments that intention to treat (ITT) is the best approach in superior studies do not apply to non-inferior studies (Piaggio et al., 2012). The recommendation is to use per protocol analysis and ITT as a sensitivity analysis. However, as there was no deviation from the allocated groups and very few missing data points, one analysis was conducted, using all the available data. The analysis was conducted in a two-sample test of proportions for categorical variables and an independent samples t-test for continuous data. The absolute difference is presented.

4 Results

In this chapter, a summary of the main results from the three papers is presented. Results are presented in more detail in the respective papers. As the two RCTs were nested within a four-armed RCT, the recruitment, participants' descriptions and implementation are presented together. Selected outcome results, considered to be the most relevant for both RCTs, are presented separately for Papers II and III.

4.1 Paper I: Results

The aim of the explorative descriptive observational study was to describe changes in the performance of clinical actions by teams of healthcare professionals with different levels of experience during repeated in-situ simulations with different cases of systematic clinical observation of deteriorating patients.

Each team was composed of three healthcare professionals who were colleagues and well known to each other. Each team was representative of the staff at its unit. None of the participants were familiar with simulations using an advanced simulator, but some had experienced simulations as part of their educational training.

The four clinical experts who assessed the outcomes commented on the overall lack of a systematic ABCDE approach in the teams from the nursing home and the out-of-hours general practice in all simulations. The comments for the team in the emergency department concerned errors in the choice of treatment.

The assessors showed good agreement (Koo and Li, 2016). They assessed 73 clinical observations; the interclass correlation coefficient between the assessors was 0.640 for the clinical action scores, 0.614 for the administration scores and 0.803 for the overall scores.

Across the teams, the overall average score given by the assessors was highest in the first simulation and second highest in the third simulation (Table 2). The team in the nursing home received low overall scores for all simulations, but in the last simulation showed markedly better scores on the clinical actions. However, the teams from the out-of-our general practice service and emergency department had no clear pattern in scores for clinical actions and thus no indication of improvement with repeated simulations.

Table 2. Assessment of the simulation overall and the performance of clinical actions in the three simulations for each of the teams in the participating units.

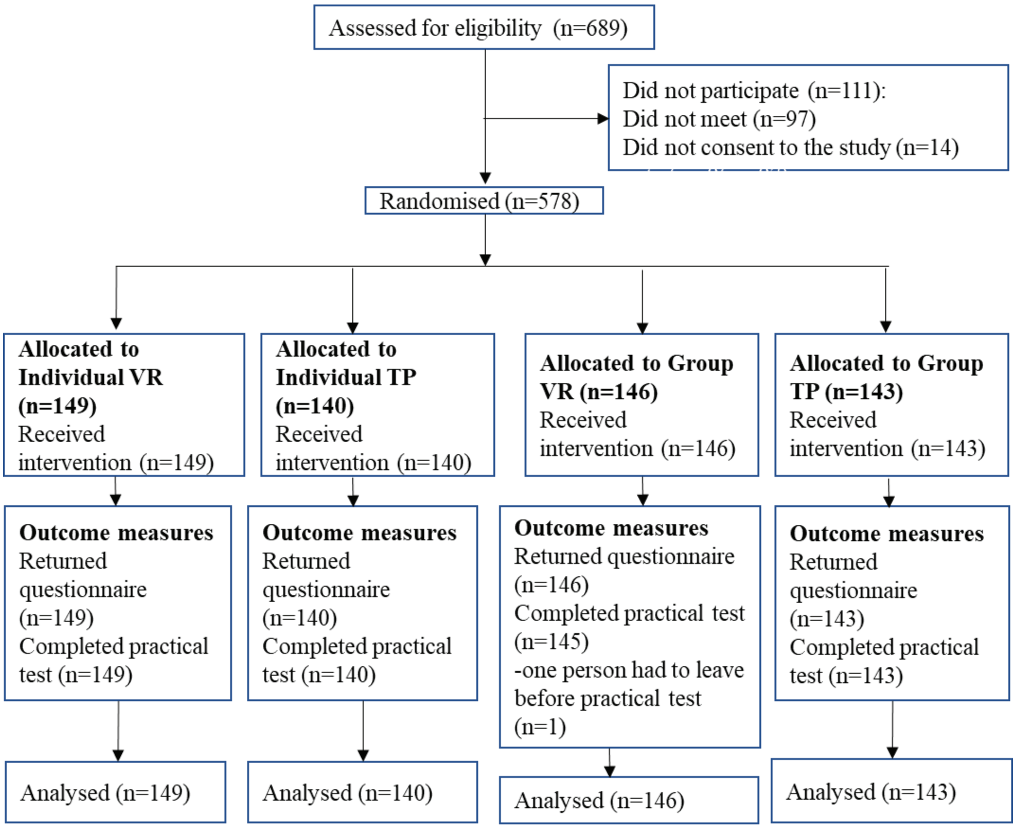
Unit and case	**Average overall score (SD) (range 1-10)**	**% of correct clinical actions (SD %-points)**
Nursing home		
-Pulmonary emboli	4.8 (1.3)	60% (13)
-Sepsis	3.3 (1.0)	50% (46)
-Heart failure	4.5 (2.1)	83% (14)
Out-of-hours GP		
-Pulmonary emboli	7.8 (2.6)	95% (11)
-Sepsis	4.8 (1.7)	69% (38)
-Heart failure	5.5 (1.3)	89% (19)
Emergency department		
-Pulmonary emboli	7.0 (1.2)	85% (24)
-Sepsis	6.3 (1.0)	76% (18)
-Heart failure	6.3 (0.5)	88% (18)

Thus, there were no consistent improvements in clinical actions from the three repeated in-situ simulations. The teams did not seem to adhere to the ABCDE approach throughout the simulations, which indicates that the teams were not able to apply their newly acquired experience of using the ABCDE approach from one case to another, different case.

4.2 Papers II and III: Participants and implementation of interventions

As described in the Methods section, the two RCTs were nested within a four-armed design. A total of 578 students were randomised to four groups with 289 participants in each of the RCTs (Figure 9).

Figure 9. Flow of participants (VR; virtual reality, TP; traditional practice).



The participants in Paper II had similar characteristics at baseline (Table 3), while there were some differences between the two groups in Paper III. Looking at the characteristics across all four groups, there are no indication of any pattern indicating problems with the randomisation. Thus, the differences observed are due to chance.

Table 3. Baseline characteristics of the participants in Papers II and III by group. The number and percentage for each variable may vary due to missing variables (N, %)

Baseline variables	**All (N=578)**	**Paper II - Individual**		**Paper III - Group**	
		Individual VR (N=149)	**Individual TP (N=140)**	**Group VR (N=146)**	**Group TP (N=143)**
Gender					
-Male	93 (16.7)	28 (20.3)	22 (15.8)	16 (11.5)	27 (19.1)
-Female	464 (83.3)	110 (79.7)	117 (84.2)	123 (88.5)	114 (80.9)
Age					
-Under 20 years	149 (26.8)	25 (18.1)	41 (29.5)	27 (19.4)	56 (39.7)
-20–24 years	345 (61.9)	96 (69.6)	83 (59.7)	90 (64.7)	76 (53.9)
-Over 25 years	63 (11.3)	17 (12.3)	15 (10.8)	22 (15.8)	9 (6.4)
Have you previously (number answering yes):					
-Been taught cardiopulmonary resuscitation (CPR)?	473 (84.9)	122 (88.4)	121 (87.1)	107 (77.0)	123 (87.2)
-Worked in healthcare?	310 (55.7)	80 (58.0)	77 (55.4)	79 (56.8)	74 (52.5)
-Been taught the ABCDE approach?	125 (22.4)	38 (27.5)	26 (18.7)	29 (20.9)	32 (22.7)
-Used a blood pressure gauge?	242 (43.4)	61 (44.2)	58 (41.7)	55 (39.6)	68 (48.2)
-Counted respiration frequency on someone else?	219 (39.3)	52 (37.7)	60 (43.2)	46 (33.1)	61 (43.3)
-Tried VR goggles?	160 (28.7)	39 (28.3)	33 (23.7)	38 (27.3)	50 (35.5)
-Trained using a simulator manikin?	224 (40.2)	48 (34.8)	64 (46.0)	52 (37.4)	60 (53.6)

There were no technical problems in the implementation of the intervention. The student-reported measure of implementation of the intervention, that is, the number of complete ABCDE examinations during the practice part, showed some differences in both studies (Table 4). In the individual study (Paper II), the proportion completing two or more full examinations was higher for those practicing VR (93.3% in VR vs. 62.9% in TP). In the group study (Paper III), more of those practicing with traditional equipment completed two or more full examinations (7.5% in VR vs. 25.2% in TP).

Table 4. Number of completed ABCDE examinations during the practice (N, %).

Number of completed ABCDE examinations during the practice session:	All N=578	Paper II - Individual		Paper III - Group	
		Individual VR N=149	Individual TP N=140	Group VR N=146	Group TP N=143
0	57 (10)	1 (1)	14 (10)	22 (15)	20 (14)
1	248 (43)	9 (6)	38 (27)	113 (77)	87 (61)
2	165 (29)	70 (47)	54 (39)	9 (6)	33 (23)
3 or more	108 (19)	69 (46)	34 (24)	2 (1)	3 (2)

4.3 Paper II: Results

The aim of this parallel group RCT was to investigate whether individual self-practice of the ABCDE approach in an immersive and interactive VR application gave non-inferior learning outcomes in first-year medical and nursing students compared to TP using traditional equipment.

The primary outcome, doing all observations in the correct order, showed the non-inferiority of the VR application (Table 5). Approximately one in four of all students performed all of the observations in the correct order, with 24.8% in individual VR compared with 27.1% in individual TP (absolute diff. 2.3 % points, one-sided 95%CI 0.0 to 10.8).

Nearly all the secondary outcomes were similar between the groups. For the 16 outcomes concerning the ABCDE approach, only one showed a difference between the groups (Table 4 in Paper II). On two of the six secondary outcomes concerning the students' experience, there was a difference (Table 5). More students in individual VR (82.6%) reported liking the way they practiced and thought that it was a good way to learn the ABCDE approach (85.1%) than did those using traditional equipment (36% and 48.2%, respectively).

Table 5. Selected outcome measures. Numbers are n (%) or mean (SD) with difference between the groups and 95% confidence interval (95%CI).

Outcome measure	**Individual VR N=149**	**Individual TP N=140**	**Absolute diff. in %-points (95%CI)**	**P-value**
The primary outcome				
-all eight observations documented in the correct ABCDE order (one sided-95% CI)	37 (24.8)	38 (27.1)	2.3 (0 to 10.8)	0.654
Secondary outcomes				
-Number of participants in the theoretical test who had all eight observations in correct ABCDE order	81 (54.4)	87 (62.1)	7.8 (-3.6 to 19.1)	0.180
-Number of participants who thought they had enough time to practice	48 (32.7)	56 (40.3)	7.6 (-3.5 to 18.8)	0.180
-Number of participants who thought the method was enjoyable	123 (82.6)	50 (36)	46.6 (36.5 to 56.6)	<0.001
-Number of participants who thought the training and practice were a good way to learn the ABCDE approach	126 (85.1)	67 (48.2)	36.9 (26.8 to 47.0)	<0.001
- System Usability Scale, range 0-100	Mean 79.7 SD (14.6)	Mean 73.7 SD (16.2)	6.0 (2.8 to 10.1)	<0.001

Individual VR scored high on the System Usability Scale. The System Usability Scale rating was equal to an A-, in the curved grading scale. Individual TP scored 73.7 on the the System Usability Scale, equal to a B- in the curved grading scale.

4.4 Paper III: Results

The aim of this parallel group RCT was to investigate whether group self-practice of the ABCDE approach in a *multiplayer,* immersive, interactive VR application produced a non-inferior learning outcome in first-year medical and nursing students compared to TP using traditional equipment.

The primary outcome, doing all the observations in the correct order, showed the non-inferiority of the VR application (Table 6). Approximately one in five of all students conducted all observations in the correct order, with 20% in group VR compared to 21% in group TP (absolute diff. 1% point, one-sided 95%CI 0.0 to 8.8).

Nearly all the secondary outcomes were similar between the groups. For the 16 outcomes concerning the ABCDE approach, only two of the 16 variables showed a difference between the groups (Table 4 in Paper III). On two of the six secondary outcomes concerning the students' experience, there was a difference. One of these showed that fewer students in group VR (11.1%) said they had enough time to practice than in group TP (26.4%) (Table 6).

Table 6. Selected outcome measures. Numbers are N (%) or mean (SD) with difference between the groups and 95% confidence interval (95%CI).

Outcomes measures	**Group VR N=146**	**Group TP N=143**	**Absolute diff. in % points (95%CI)**	**P-value**
Primary outcome				
-All eight observations documented in the correct ABCDE order (one sided 95% CI)	29 (20)	30 (21)	1 (0.0 to 8.8)	0.837
Secondary outcomes				
-Number of participants in the theoretical test who had all eight observations in correct ABCDE order	70 (47.9)	82 (57.3)	9.4 (-2.1 to 20.9)	0.100
-Number of participants who thought they had enough time to practice	16 (11.1)	37 (26.4)	15.3 (6.3 to 24.2)	<0.001
-Number of participants who thought the method was enjoyable	100 (69)	88 (62)	7.4 (-18.3 to 3.5)	0.186
-Number of participants who thought the training and practice were a good way to learn the ABCDE approach	104 (71.2)	93 (65)	6.2 (-17 to 4.5)	0.258
- System Usability Scale, range 0-100	Mean 72 SD (17.3)	Mean 74 SD (15)	2.4 (-6.1 to 1.4)	0.224

Group VR scored somewhat lower on the System Usability Scale, with a System Usability Scale rating equal to a C+, in the curved grading scale. Group TP scored 74 on the System Usability Scale, which equals a B- in the curved grading scale.

5 Methodological discussion

The methodological discussion starts with some considerations regarding reflexivity and continues with a discussion about the generalisability of the findings before the items in the Cochrane risk-of-bias assessment tool (RoB2) are used to structure the discussion of specific methodological issues regarding the three papers (Sterne et al., 2019).

5.1 Reflexivity

Reflexivity is intended to take the researchers' perceptions into account by considering the influence of the researchers on all aspects of the research process (Malterud, 2001). This involves them thinking about their background, perceptions and expectations throughout the whole research process.

My professional background is as a registered nurse. I have clinical practice mainly from the primary healthcare services, but I spent my first two years as a nurse in a neonatal hospital ward. For the last 10 years, after taking a master's degree in planning and leadership, I have worked with different projects in the municipality and the university related to human resource development.

In the project related to in-situ simulation (Paper I), the data were obtained from a project for which I was responsible before I started as a PhD candidate. My preconception, and I presume that of the others involved, was that repeated in-situ simulations would improve the clinical observation skills in the teams involved. Regardless, during the research project, I discussed with my main supervisor on many occasions the need to ensure that any interpretation of the clinical actions would be as unbiased as possible, including not being influenced by my own and others' preconceptions. It was decided early on to use multiple external assessors, and that they would need enough information to assess what was done during the simulations. One such discussion was whether to show the assessors video recordings because this could give them the most information. However, showing them the videos would increase the possibility of the assessors recognising features such as the setting. Therefore, it was decided to use transcripts, even if this required a lot of extra work.

Reflecting on this and other processes during the PhD period, I can see that I have changed my mindset from when I was running development projects so that I now think about biases, as exemplified above. This journey has taken me from being concerned about how to implement a project in order to make it work, to being concerned about how to plan and implement a project in order to ensure valid results that can be used by others. Thus, I have come to a deeper understanding of the definition of research: 'A systematic investigation, including research development, testing, and evaluation, designed to develop or contribute to generalizable knowledge' (US Federal Register, 2018).

I have also changed my view on what it means to provide generalisable knowledge. In short, it has been a journey during which I have come to appreciate facts and objective knowledge, understood as what can be documented by unbiased measurements. My master's thesis was a case study about planning processes in a two-level organised municipality, designed as a qualitative study with a theoretical approach. There, I used a more theoretical approach, presenting the theories in the Introduction and using them to argue for the methodological choices and to discuss the findings. Although I investigated theories as part of the work for this thesis, I have spent more time searching for and reading empirical studies. As is evident from this part of the thesis and the individual papers, I have placed an emphasis on presenting the results from empirical studies in the Introduction and have used these and methodological guidelines (Schulz et al., 2010, Sterne et al., 2019) to inform the methodological choices. I have also mainly discussed the findings using results from other empirical studies.

This change also became evident in a recent discussion. Someone told me to remember to mention the work of Karl Popper (Ackermann, 1976) and write about falsification and verification since I have conducted RCTs. I would normally have agreed that this is something that would benefit the discussion, as I agree that this is a foundation for some of the thinking behind RCTs. However, I now find it more important to describe what has been found in other studies and how high-quality studies have been executed, to provide in detail the methods I have used and to ensure that the empirical findings are sound and clearly presented.

So, one of my main reflections in hindsight is that I have become more aware of where I stand in relation to positivist and constructivist approaches (Guba, 1990). It is fair to say that, as a researcher, I am closer to the positivist position, as is evident from the focus and the way I have presented the work in this thesis. Nonetheless, I think that there are several phenomena that are dependent on our perception of the world and thus subjectively or socially constructed.

This brings me to the approaches used to challenge my own expectations and preconceptions during this PhD work. Reading the works of many researchers has been recommended to help ensure reflexivity (Malterud, 2001). This has been the main approach for me, although it has also included discussions with supervisors and work colleagues. I have also presented preliminary work to obtain feedback and be challenged. There was also the realisation that there is a large variation in how things are done. In RCTs, there are strict procedures to follow and framework and assessment tools to help prevent bias (Machin and Fayers, 2010, Schulz et al., 2010). Still, this does not ensure quality, as evidenced by the fact that few trials are assessed as having a low risk of bias (Dechartres et al., 2017). This is one example of situations that have given rise to periods in which I repeatedly questioned the correctness of the choices I had to make during the research. Although this was unpleasant at the time, in hindsight I can see that these were the moments when I really challenged my own understanding and thus increased my reflexivity, in parallel to increasing my competency.

5.2 Generalisability

Generalisability depends on two fundamental questions (Kukull and Ganguli, 2012). First, are the results of the study true or just an artefact of the way the study was designed or conducted? Second, are the study results likely to apply, generally or specifically, in other study settings or samples?

In the observation study (Paper I), all relevant units in a conveniently chosen municipality were asked to participate and they decided for themselves whether to do so. In addition, the participants in the different teams were self-recruited within the units, meaning that the employees most interested in learning were the ones most likely to have volunteered to participate. Furthermore, because there were few participants, generalisability in the usual sense was weak. However, this study was an explorative study that investigated changes within the same units over time (Singh, 2007). Thus, it was designed to learn more about what goes on during in-situ simulations, and not, for example, to provide knowledge about whether staff at nursing homes in general benefit from repeated in-situ simulations.

In the two RCTs (Papers II and III), the aim was to determine definitively whether practicing with VR was inferior to practicing with traditional equipment for novice medical and nursing students. The issue is therefore whether the sample of students and the setting were representative beyond the university in which the study was conducted. Most of the learning objectives and content in nursing and medical education in Norway are based on international requirements or guidelines. Learning clinical observation is obviously a common theme across both fields. When this is taught in the curriculum, the format can vary, but there is no reason to believe that there is substantial variation in the expected learning outcomes and overall approaches. Thus, although the study was set in the beginning of the students' first year, it is likely that the findings can be generalised to settings where the subject matter is taught later in the curriculum.

With regard to the student sample, this has been described in the papers to make it easier to compare with other settings. What is more likely to influence the generalisability, however, is the admission requirement or, more precisely, the grades needed for admission. The requirements and grades needed for the four medical schools are similar in Norway, and the grades needed are among the highest for all university educations. This is similar to many other countries, and it can be expected that the findings will apply to medical schools that recruit from among those with the best grades.

Although the RCTs were conducted in one university, they included nursing students from three different nursing programmes with different grades needed for admission. The reason for this was that the university had undergone a recent merger and had expanded to new campuses, but the process of making one joint nursing programme had not been completed at the time of the study. Thus, the sample of nursing participants represents some variation in nursing programmes, intake grades and locations. This variation implies that the findings can be generalised to a broader range of settings than if the study had been conducted within just one nursing programme.

5.3 Specific methodological considerations

5.3.1 Bias arising from the randomisation process

The randomisation process consists of two parts (Higgins et al., 2019): the chance generation of an allocation sequence that specifies how participants will be assigned to interventions (allocation sequence generation) and the actual allocation of the participants to interventions (allocation sequence concealment). This section will deal only with Papers II and III because there was no randomisation in Paper I.

When the randomisation took place, only the number of students expected to participate in the teaching programme was known. To ensure random allocation sequence generation, the RAND() function in Excel was used. This is considered to be an adequate random number generator that is widely used, and no bias was expected.

When it comes to allocation sequence concealment, the risk of bias must be judged on the basis of the procedures followed. Due to practicalities, the actual allocation had to take place at the start of the teaching session. Thus, the allocation sequence generated, which was printed on identity (ID) stickers, had to be concealed until the actual allocation took place. For this, the common approach of using identical opaque plastic bags was used, and the person doing the allocation had to select from among multiple bags. To prevent the person doing the allocation from influencing the allocation when one bag was opened, the ID stickers were placed on the table before the students entered the room. The allocator did not know the students coming, could not influence the order in which the students entered the room and was thus unable to systematically influence the allocation.

Another possibility of bias in this process would have arisen from students switching ID stickers with fellow students. To prevent this, the staff told the students to wear their ID sticker, using a safety pin, immediately after they were seated.

The final argument for a low risk of bias for the randomisation process is that the baseline characteristics of the groups did not suggest a problem with the randomisation process.

5.3.2 Bias due to deviations from intended interventions

Deviations from the intended interventions include such issues as additional interventions and non-adherence by trial participants to their assigned intervention (Higgins et al., 2019).

In the repeated in-situ study (Paper I), the intervention consisting of an introduction and three simulation sessions were strictly organised. This left no room for the participants to deviate.

The participants in the RCTs (Papers II and III) were aware of their assigned intervention during the trial after the common introductory session, when they were told the type of practice they should attend. To avoid non-adherence, such as switching groups, the students were physical grouped when they were told their allocation. The groups were then followed to their place of practice, where the staff present controlled the ID stickers.

During the practice, there was no option for additional interventions because there were staff present who observed the students. The staff present knew which intervention the students had been selected for, but they had written instructions that told them what they could do and say and they had no practical opportunity to provide any additional interventions for the students. To avoid deviations during the interventions, most of the same staff were used in all the interventions during the trial. The staff were also trained in different scenarios that could arise to ensure that everybody did things as similarly as possible in all the interventions. Briefings were held throughout to discuss how things went and to reinforce the instructions. Because there were no known deviations from the intended interventions, the risk of bias in this domain is considered to be low.

5.3.3 Bias due to missing outcome data

Bias due to missing outcome data involves missing measurements and biases introduced by procedures used to account for the missing outcome data (Higgins et al., 2019).

The outcome data in the observational study (Paper I) were recorded by video and transcribed. Thus, data could be missing if the transcript did not fully represent the video recordings, and the video recordings did not fully represent what actually happened. Care was therefore taken in both areas, and it is unlikely that there were missing data that influenced the assessment. There were no missing data in the assessors' scorings.

In the RCTs (Papers II and III), the missingness of different variables (in practice from the questionnaires) were less than 5%, and for most variables close to 0%. The missing was judged to be random and equally distributed between the arms. Furthermore, due to this, no manipulation of the data was done; for example, there was no imputation. In this domain, too, the risk of bias in the RCTs is considered to be low.

5.3.4 Bias in measurement of outcomes

Errors in measurement of outcomes can be due to errors in the measurements themselves or in how they are recorded (Higgins et al., 2019).

The method of measuring the outcome was highly standardised, both in the observational study (Paper I) and the RCTs (Papers II and III). In the RCTs, all students took the same practical test and answered the same questionnaire, and the measures and classifications were applied equally for all participants. Any errors, although unlikely, would thus have been equally distributed across the arms. The risk of bias is therefore low in this domain.

In the observational study, the clinical actions from all the simulations were assessed by the same questions. The assessors did not know which teams they were scoring or the order of the simulations. There was thus a low risk of bias.

5.3.5 Bias in the selection of the reported results

Bias in the selection of the reported result can happen if the researchers choose not to publish some of the results or select results based on the direction of the results (Higgins et al., 2019).

In both the observational study (Paper I) and the RCTs (Papers II and III), all available results were presented. In the RCTs, these results were analysed as planned before the data was produced and all numbers presented were assessed from direct observation. Thus, there was a low risk of bias for selected results.

In the observational study, the plan for analyses was made after the data had been produced, since the video recordings were part of a local development project and the research project implemented afterwards; this introduces a risk of bias. However, the transformation of the video recordings into the transcript was carried out after the plan for the analysis was made.

5.3.6 Overall bias

In light of the above bias review and the recommendations in RoB2 (Sterne et al., 2019), the RCTs (Papers II and III) are considered to be at low risk of bias.

Due to the nature of the observational study (Paper I) and the issues discussed above, the overall risk of bias for this study is considered to be high.

6 Discussion of findings

6.1 Summary of findings

The main finding in this thesis was that there was no consistent improvement from three repeated in-situ simulations with different cases, most likely due to the teams not adhering to the ABCDE approach throughout the simulations (Paper I). This indicates that the teams were unable to apply their newly acquired experience of using the ABCDE approach from one case to another, different case. It was also found that self-practicing the ABCDE approach in VR was non-inferior to self-practice with traditional equipment, whether this was done alone (Paper II) or in a group (Paper III). The students practicing VR alone were most satisfied with the method of practice.

6.2 What is the best method for learning the ABCDE approach?

This thesis concerns the use of in-situ and VR simulations to learn the ABCDE approach. At the core of the thesis is the determination of the best method for learning the ABCDE approach.

6.2.1 Setting and learning approaches

First, it has to be acknowledged that the setting and the learners play an important part. There is an obvious difference between teaching the ABCDE approach to experienced healthcare professionals working in an emergency department, who are used to handling deteriorating patients, and first-year students starting to learn about the normal body. Looking at the literature on the effect of interventions relevant to learning the ABCDE approach, previous studies have been conducted in varying settings with different learners. In a meta-analysis on simulation and managing deterioration among nurse students (Orique and Phillips, 2017), the range of settings has included advanced-practice nursing students in simulation labs, registered nurses in emergency departments and student nurses in skill labs, among others.

We have not managed to find many studies from primary care settings, but there are guidelines on how to use the ABCDE approach for nurses in non-emergency settings (Mayo, 2017, Smith and Bowden, 2017). One example from specialist care, showing an improvement, was a full-scale simulation-based course delivered in a hospital ward using the more experienced staff as instructors and adjusted to local needs (Fuhrmann et al., 2009). There are also more generic approaches with a similar intention but conducted locally by using a train-the-trainer approach (Orfaly et al., 2005), used in campaigns to improve patient safety, for example (Norwegian Health Directorate, 2016, WHO, 2011).

The learning approaches also differ. There is a difference between a created VR, handling a simulator manikin in simulation and real-life experience. In the meta-analyses mentioned (Orique and Phillips, 2017), the range of approaches included in-situ simulation, high-fidelity simulation, medium-fidelity simulation, web-based educational programmes, case-scenario simulation and more. They did not conclude whether any of these approaches gave a better outcome. No studies using VR to learn the ABCDE approach were found, but a study using a serious game approach measured the ability to perform the ABCDE examination as an outcome (Dankbaar et al., 2017). The approach in the serious game was for the user to select between choices related to the virtual standardised patient's expressed condition, using a desktop mouse and keyboard to point at the equipment or treatment to initiate a clinical action.

6.2.2 Amount of practice

The amount of practice is known to influence the outcome (Tabangin et al., 2018, Norman et al., 2012). The amount was quite different in the studies in this thesis, with a one-hour learning session in the RCTs (Papers II and III, with 20 minutes of actual practice) to a six-hour intervention in the in-situ simulations (Paper I). In one systematic review investigating the effectiveness of education in recognition and management of deteriorating patients, the interventions ranged from 25 minutes to 45 hours (Connell et al., 2016). The study concluded that high-fidelity simulation demonstrated effectiveness when delivered in brief sessions lasting only 40 minutes. Studies with a short intervention duration show that during the 40 minutes of practice, six students practiced on the same simulator in turn (Crofts et al., 2006, Crofts et al., 2007). There was pre-training before the practice, which consisted of watching a video of the simulation to be practiced.

Paper I considered the reasons for a lack of consistent improvement after three repeated in-situ simulations, and this will also be discussed further below, but looking at the amount of practice the participants had (six hours), given the findings in the review, some improvement might have been expected. The practice period in the RCTs lasted only half as long as the time that yielded an improvement in the review (Connell et al., 2016). The entire learning session in the RCTs took one hour. Moreover, the study with the shortest intervention time in the systematic review, where registered nurses practiced Simulated Training for Enhancing Patient Safety (STEPS) for 18 to 25 minutes, had a debriefing part, the length of which is not specified in the article (Sittner et al., 2009). One framework for simulation design (Jeffries, 2005) suggests spending an equal time on briefing, simulation and debriefing, which amounts to 20 minutes of actual practice in a one-hour session like that in the RCTs.

6.2.3 Repetitions

Practice can vary between sustained periods of repetition or repetitions at intervals. One study found that time-distributed repetitions helped learners to retain their skills better than one sustained period of practice (Andersen et al., 2016a). Other studies have shown that repeated practice in the same session yields a positive learning outcome (Bluestone et al., 2013, Singleton et al., 2018, Kim et al., 2016b). Repetitions are regarded as highly important in simulations (Issenberg et al., 2005).

Both the observation study (Paper I) and the RCTs (Papers II and II) were designed for repeated training, although in different ways. Just as it was expected that the amount of training would give results (Paper I), so too was it expected that repetition each week for three weeks would contribute to improvement, which it did not. In the RCTs, repetition was expected to take place during the 20-minute practice period. It was found that those practicing individually managed more repetitions (Paper II) than those practicing in groups did (Paper III). The obvious reason is that those practicing in groups had to wait their turn. Nonetheless, there was a difference between those practicing individually in VR (who did more complete ABCDE examinations during the practice) and those using traditional equipment (Paper II), which may have been because the students found the VR more engaging and fun, motivating them to repeat the practice. Nevertheless, it led to no difference in outcome.

6.2.4 Getting the chance to practice

Even if the design of a teaching programme to learn the ABCDE approach ensures a sufficient amount of practice and the possibility of repetition, it is not the same as every individual participant getting the (same) chance to practice. Many simulation programmes are based on groups of learners, in which they are sometimes given different roles due to limitations in available time and equipment (Tolsgaard et al., 2015, Rode et al., 2016). A typical example might see 10 learners participating, two of whom are given the task of practicing while the remaining eight are observers or given other roles. The non-practicing roles can also be important for learning through observational learning, according to (Bandura, 2002).

Even if the roles are rotated in a simulation, it is likely that not all participants will get to do the actual practice. This challenge is also known from the VR literature, which found that it is important that every participant has something to do; if not, they are likely to lose focus (Creutzfeldt et al., 2016). In the VR application for those practicing as a group in the RCT, digital question boards appeared for the users who were not engaged in the ABCDE examination. The boards appeared every time the user in the active position started on a new observation, in order to catch the attention of the others and engage them in the ongoing examination. However, whether this had an effect is not known.

6.2.5 What is the best learning method?

Coming back to the question of the best method to learn the ABCDE approach, what can be said? In light of the discussion above, the answer is partly ‘it depends’. There are several approaches in different settings with different learners that all seem to give at least some kind of positive outcome.

To move beyond this general statement, which is unlikely to be helpful for those planning to implement a learning activity, there is a need for more studies comparing different interventions with the same setting and learners.

6.3 Cognitive load when learning the ABCDE approach

The observation study (Paper I) considered whether cognitive load (van Merrienboer and Sweller, 2010) could be one of the reasons for the teams' failure to improve during repeated simulations. When deciding on and developing the VR application tested in the RCTs, this was a driving factor for many of the choices made. Cognitive load theory is based on 'a cognitive architecture that consists of a limited working memory with partly independent processing units for visual and auditory information, which interacts with an unlimited long-term memory' (Paas et al., 2003).

There are theory and design principles for healthcare and medical simulations to avoid cognitive load. These take into account three interrelated components of the working memory: the intrinsic, germane and extraneous loads (Fraser et al., 2015, Meguerdichian et al., 2016). These will be used to structure the discussion of cognitive load in learning the ABCDE approach.

6.3.1 Intrinsic load

Intrinsic load comprises the demands on working memory caused by the intrinsic nature of the learning task (Fraser et al., 2015). This is related to the learning objective(s), which can range from simple to complex and thereby require varying amounts of intrinsic cognitive load (van Merrienboer and Sweller, 2010). If there are many and complex learning objectives for one learning activity, it is obviously more demanding for the students. In both the study on in-situ simulations (Paper I) and the RCTs (Papers II and III), the main learning objective was the ability to perform the ABCDE approach. This can at a quick glance seem to be a simple learning objective.

However, to master the ABCDE approach, several other minor learning objectives have to be mastered, such as the ability to remember the algorithm and the observations to be done and to perform the hands-on skills like taking blood pressure. In learners with knowledge about normal clinical values, it also includes recognising deviations and knowing what actions to take (Disher et al., 2014). In other studies on learning the ABCDE approach, it seems that the learning outcome, though frequently not stated explicitly, is the general one of learning to apply the ABCDE approach (Stayt et al., 2015). However, there is some variation in the type of ABCDE approach to be learned, such as basic (Thim et al., 2012) or advanced (Vaughan and Parry, 2016). Even so, it seems that most studies, including those in this thesis, take it for granted that the learning outcome is at the right level. Future studies could benefit from considering this, because the ABCDE approach can be a complex learning object with a potential high intrinsic load.

6.3.2 The germane load

The germane load is the required cognitive resources needed to process the intrinsic load, or the learning goal (Fraser et al., 2015); if you are given a learning objective, how much does it take to grasp what it involves? This includes elements related to previous tasks or knowledge (van Merrienboer and Sweller, 2010), such as knowing how to take blood pressure. If you have no idea what the learning outcome is about, you obviously require a higher germane load to make sense of it. The germane load can be optimised by making sure that the learner is able to link the present learning outcome to something familiar. One way of doing so is to provide a self-explanatory prompt that facilitates understanding; in this case, for example, the mnemonic ABCDE (Liaw et al., 2015).

In the in-situ study (Paper I), the participating healthcare professionals had some pre-learned knowledge and skills, such as the ability to perform clinical observations and knowledge about normal clinical values and the actions to take when clinical values deviate from the norm. Thus, the germane load was not expected to be high. In the RCTs (Papers II and III), the novice medical and nursing students were likely to lack previously learned clinical knowledge and skills. Therefore, care was taken to explain why they should learn the ABCDE approach, highlighting that it is a generic skill needed across settings. It was hoped that, by doing so, they would find this an exciting learning experience and focus more on that than on their unfamiliarity with the learning outcome. Given the rather high satisfaction with the teaching session (Papers II and III), this seems in general to have succeeded. Still, it is likely that the germane cognitive load was on the higher side for the students in the RCTs, as is the case with most new learning activities (Issenberg et al., 2005).

6.3.3 Extraneous load

The extraneous cognitive load comprises the external or unwanted aspects that adversely affect the cognitive process of learning (Fraser et al., 2015). One simple and easily identifiable example is any external factor drawing the learners' attention away from the learning activities, such as technical issues or unfamiliarity with simulation technology (Dankbaar et al., 2016). A more pedagogically challenging example is identifying those activities that are not needed to reach the core learning outcome, such as dealing with a relative of the patient at the same time as performing the ABCDE on the patient: Is that a necessary feature if the ABCDE is the main or only learning outcome (Spruit et al., 2016)? Extraneous load can be reduced by simplifying the approach (van Merrienboer and Sweller, 2010) and adjusting it to the level of the user (Issenberg et al., 2005).

In the in-situ simulations (Paper I), it is likely, as stated in the paper, that the use of different cases contributed to the lack of quality in the clinical actions. This was a deliberate choice because the learning outcome was about the generic use of the ABCDE approach, highlighted by others as important and as providing test results that are more valid (Liaw et al., 2011b). If the teams were not confident enough to follow the routine, however, it seems obvious that it would be better to divide the learning activity in two: 1) learning the ABCDE drill and then 2) learning to use the approach for different cases. A similar way of thinking was used in a study on in-situ simulations for learning to manage five high-risk low-frequency situations (Singleton et al., 2018), in which the participants first got to explore and practice on each of the 22 different tasks involved.

6.3.4 Optimising the cognitive load

The process of trying to understand the findings from the repeated in-situ simulations (Paper I), was very influential in developing both the VR application and the design of the TP used in the RCTs (Papers II and III). It was clear that the learning outcome should be to learn the ABCDE algorithm (i.e. the order of the observations to be performed). Three examples among many simplifications were to have relatively few observations (easier to remember the order), use the clinical values of a healthy person (avoiding judgement of the values) and use electronic devices (without needing to learn the specifics of the equipment). In a study on serious games, the researchers concluded that having high fidelity (many features) in the game produced too high a cognitive load (Dankbaar et al., 2016).

As discussed above and as research has shown, cognitive load plays a part in the learning process. Looking at the studies in this thesis, it seems fair to conclude that the cognitive load was too high in the repeated in-situ simulations, given what was observed and the comments from the blinded assessors (Paper I). The core problem was the learning outcome of being able to apply the ABCDE approach across different cases. This meant that the intrinsic cognitive load was too high, which had the consequence of too high extraneous cognitive load because the teams had to focus on too many things during the simulation. With regard to the RCTs, it is more difficult to determine whether the cognitive load was too high or too low. It is tempting to state that the level was appropriate, but it is difficult to be sure because the load was not measured. One proxy form of documentation could be the proportion of those who successfully achieved the learning outcome (one in four to one in five). Success equated to a grade A on the A–F scale (F = failure) and a success rate of +20% is on the higher side.

6.4 Feedback in simulations

Feedback is frequently highlighted as being central to the learning process (Issenberg et al., 2005, Stone and Heen, 2015). Feedback can be conceptualised as information provided by someone or something on aspects of one’s performance or understanding and is one of the most effective drivers of learning (Hattie and Timperley, 2007). The intention with feedback is to reduce the discrepancy between the current performance and the desired goal. Feedback, in addition to repeated practice, is regarded as the most important element in simulation (Issenberg et al., 2005), where it is often part of the debriefing session. Not surprisingly, in the three studies in this thesis, feedback was a central element.

In the repeated in-situ simulation study (Paper I), the conventional format for simulation was used. Each simulation started with a briefing for preparation, then the actual simulation took place, followed by a debriefing. Since no consistent improvement was found in the study, it must be concluded that the feedback (debriefing) sessions did not have a clear impact on the performance of the clinical actions during the simulations. Other studies on repeated simulations that report positive outcomes adopted a slightly different approach to feedback (Singleton et al., 2018, Bluestone et al., 2013, Kim et al., 2016b). In one study, 22 different tasks related to five high-risk, low-frequency situations were practiced (Singleton et al., 2018). The participants received feedback on their performance after each task. In contrast to the study presented in Paper I, however, after the feedback they practiced the same scenario again until they were able to complete the tasks within a set time limit. Only then did they move onto the next task.

This focus on practicing until mastery requires the quality of feedback to be optimal. However, because so much time has to be spent on the actual practice to master it, the feedback must be limited in time and thus to the point. It also suggests the need for a facilitator or expert to give the feedback. In a review discussing influential factors in learning and performance of skills (Wulf et al., 2010), the researchers found that positive feedback gave better learning and performance outcomes than did neutral feedback and feedback commenting on what went wrong. They concluded that feedback has an important role in motivation and enhancing self-efficacy. They also argued that feedback needed to target the learning outcome, and should be informative and motivating. Another review of 109 articles found feedback to be the single most important feature in simulation-based learning with regard to the goal of effective learning (Issenberg et al., 2005). The authors also argued that the source of the feedback is less important than its presence.

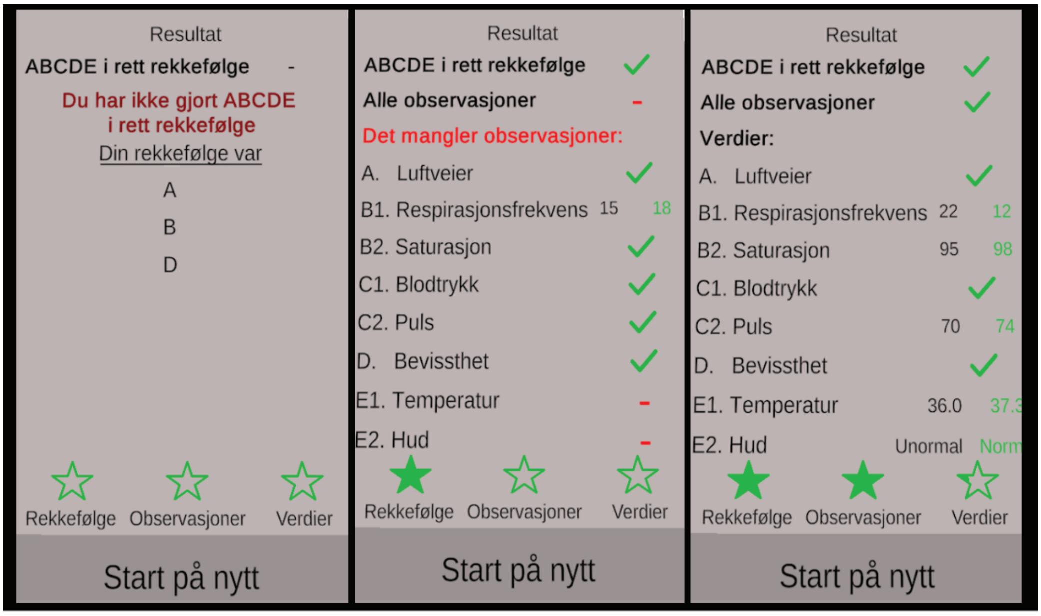
In the development of the VR application, an effort was made to identify the right type of feedback, which balanced the learning outcome, the time needed to understand the feedback and the trustworthiness of the feedback, while at the same time pointing to what needed to be focused on in the next practice (Table 7).

Table 7. Examples of features of the feedback tablet of the VirSam ABCDE VR application.

Area	**What was done**
Learning outcome	Present the results of the practice in order of the priorities of the learning outcome, showing 1) if the order of the observations was correct, 2) which observations were performed/omitted and 3) if the clinical values observed were correct.
Time needed to understand feedback	Present one item at the time. Clearly mark as correct or incorrect. Summarise with three stars the three areas on which feedback was given (see above).
What to focus on in the next practice	Mark in red if the order of the observations was not correct (main learning outcome). Show with numbers but without highlighting both the correct clinical values and the documented clinical values that were incorrect.

In the studies referenced in this thesis that described the features of VR applications, no similar feedback feature was identified. However, in VR games for entertainment, scoreboards are a common form of feedback and were partly utilised in the VirSam ABCDE VR application (Figure 10).

Figure 10. The feedback tablet displayed in the VirSam ABCDE VR application. The left column shows an example with all missing observations, and wrong order of the ABCDE. The middle shows some missing observations, but right ABCDE order. The right column shows all the learning goals have been achieved but some values have been measured incorrectly.



There are several advantages from group learning (Wulf et al., 2010, Räder et al., 2014), including the possibility for peer feedback from other group members. In the RCT where the students practiced in groups (Paper III), the intention was that the students would give each other peer support and feedback during the practice. This was not measured, but it was observed that groups ranged in feedback from total silence to almost constant conversation. In the in-situ simulations (Paper I), there was feedback after the simulations but little feedback on each other's performance during the simulations. It is likely that the power of peer feedback could have been exploited more fully in both studies if it had been given more focus, especially in the instruction but also partly in the design. One way of doing this could have been to assign one of the group members to observe and give feedback, a practice frequently used (Rode et al., 2016).

The fact that the interventions in the RCTs, both VR and TP, was self-practice also deserves some comment. It is, of course, more resource-demanding to have an expert or tutor present but it is likely that they could have helped with feedback that would have reduced the discrepancy between the current performance and the desired goal (Hattie and Timperley, 2007). Still, one of the reasons why simulation is used less often than desired (Akaike et al., 2012, Krogh et al., 2014) is their cost, which includes the cost of facilitators. Thus, on balance, it is at least fair to investigate the effect of self-practice approaches.

6.5 VR in healthcare education

The most novel part of this thesis is its use of VR as a tool for learning. This last section will therefore discuss the use of VR in healthcare education for students and professionals. To start with the main conclusion, the work presented in this thesis and several other studies have shown that VR can be used in education and can produce the same learning outcomes as other types of teaching (Kyaw et al., 2019, Khan et al., 2018). However, there are nuances that should be taken into consideration.

Even if VR is not a new technology, VR equipment and programmes are not yet integrated into healthcare and medical education. This is because affordable and good-quality VR equipment that allows for both full immersion and interaction only became available in consumer versions in 2016. There is also a lack of VR programmes for education. Furthermore, there are different ways to use VR, such as 3D desktop solutions (Prinz et al., 2005) that can be interactive (Shattuck, 2018); immersive and interactive VR, where the user is represented in a scenario in the first person and can take actions (Harrington et al., 2018); and non-immersive but interactive VR, with the user presented in the third person (Farra et al., 2018). This makes it difficult for educators to know where and how to invest.

The most developed area for VR in healthcare education is that of virtual patients (Consorti et al., 2012, Peddle et al., 2016), where there are several commercial products available. These are typically desktop solutions in which the learner can provide input (e.g. ask questions or select tests) and the responses are pre-programmed. Such solutions are good for clinical reasoning (Peddle et al., 2016), but not for practicing clinical skills. To practice clinical skills, it must be possible to interact with the environment. A recent review indicates that this possibility, which was used for the VR application in the RCTs (Papers II and III), is more effective than less interactive solutions are (Kyaw et al., 2019). The importance of the level of immersion is less clear, however. It is generally held that the level of immersion in VR is important for learning (Dede, 2009, Slater and Wilbur, 1997) but no difference in outcome has been found between immersive and non-immersive interventions (Smith et al., 2018). In a recent review (Radianti et al., 2020) on the design elements and lessons learned regarding immersion in VR, it was found that the most advanced applications are those for teaching procedural knowledge. These have the largest number of design elements and are therefore complex to develop and need more VR experience to apply. This is likely why there are few immersive and interactive applications in education to date. Another review has called for further research to evaluate the effectiveness of immersive and interactive forms of VR (Kyaw et al., 2019).

Even if VR has become more commonly used (Statista, 2020), only a small proportion of the younger population have tried it (one in four of the students in the RCTs) and far fewer have such equipment themselves. This means that learning how to use VR also has to be taken into consideration. Several studies have reported that it is important to include time for inexperienced users to practice with VR equipment before starting a simulation (Menzel et al., 2014, Caylor et al., 2015, Tiffany and Hoglund, 2014). When developing the VR application used in the RCTs (Papers II and III), at least an equal amount of time was spent ensuring that inexperienced users could practice. One problem that persisted was getting the inexperienced users to put on the VR equipment quickly. In the tests preceding the RCTs, the written instructions with pictures to demonstrate how to put on the equipment were sufficient for inexperienced VR users but because of time constraints in the RCTs it was decided to also instruct the participants orally on how to do this, and the staff present helped those who did not immediately grasp how to put on the equipment. Thus, when having many students using VR solutions, attention to the fundamentals of its use needs to be factored in.

Among the greatest benefits of VR simulation are the accessibility to and possibilities of repeated practice (Silveira and Cogo, 2017, Pottle, 2019, Liaw et al., 2018). It can give learners access to virtual situations and equipment that they would not otherwise have. Moreover, importantly, they can use it for self-practice due to the possibility of programming support into a VR application. One review of self-regulated learning in simulation found this to be a powerful approach, especially when integrated into the curriculum (Brydges et al., 2015).

This points to a final aspect of the use of VR in healthcare education. The use of VR solutions, either scheduled or self-regulated, should be integrated into study programmes along with the other learning activities.

6.6 Conclusion

This thesis has investigated the use of in-situ and VR simulation in learning the ABCDE approach. It has contributed new knowledge about the features of repeated in-situ simulations when practicing the ABCDE approach on different cases of deteriorating patients by teams of healthcare professionals with different levels of experience, and about the effects of self-practice using fully immersive and interactive VR to learn the ABCDE approach.

More studies are needed to objectively document the learning process in repeated in-situ simulations. The VirSam ABCDE VR application can be used for training novice medical and nursing students in the fundamentals of the ABCDE approach.

7 Implications for practice and future research

The main implications for practice are given in the section on VR in healthcare education. It is also worth highlighting the need to encourage educators to at least explore VR as an educational tool. It is not a panacea but educators should try it out in order to learn about its advantages and disadvantages.

When it comes to future research, the lack of any consistent improvement from repeated in-situ simulations raises questions that need to be answered. Studies that have used a similar methodology to study changes in the quality of clinical actions during simulations could not be found in the literature. Thus, even though this is only one minor study, given that the findings are anomalous and unexpected, further investigation is warranted.

Moreover, although the RCTs on the effect of practicing VR were well conducted and had a large and sufficient sample size, they are the first of their type. Thus, replications by other research groups are warranted.

Furthermore, with the current rapid technological development of VR, new solutions and applications with new possibilities are likely to emerge at an increasing rate. This means that at least some of the research on VR solutions dating back several years will be obsolete, and studies using the new solutions will be needed.

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Paper I

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RESEARCH ARTICLE Open Access

Is individual practice in an immersive and interactive virtual reality application non-inferior to practicing with traditional equipment in learning systematic clinical observation? A randomized controlled trial

Helen Berg* and Aslak Steinsbekk

Abstract

Background: The aim was to investigate if individual self-practice of the ABCDE approach (Airways, Breathing, Circulation, Disability, Exposure) in an immersive and interactive virtual reality (VR) application gave non-inferior learning outcome compared to using traditional equipment (TP) in first year medical and nursing students.

Methods: A non-inferior parallel group randomized controlled trial. The study was linked to a regular teaching program conducted in August and September 2019. All students participated in a 15-min ABCDE introduction session, before they self-practiced the ABCDE approach for 20 min in either a fully immersive and interactive VR application using hand controllers with some haptic feedback (Individual VR) or with blood pressure gauge, ear-thermometer and oximeter (Individual TP). The primary outcome was the number of students who documented all the eight predefined observations in the ABCDE approach in the correct order in a practical test on an advanced simulator manikin with a time limit of 5 min, done immediately after the self-practice. The predefined one-sided non-inferiority limit was 13% points.

Results: Of all eligible students, 84% participated in the study and randomly allocated to VR (*n* = 149) or TP (*n* = 140). The primary outcome showed non-inferiority of the VR application with 24.8% in individual VR doing all observations in correct order compared to 27.1% TP (absolute difference 2.3% points, one sided 95% CI 2.3 to 10.8). The secondary outcomes were similar between the groups, but more students in VR reported liking the way they practiced (absolute difference 46% points, 95% CI 36.5 to 56.6) and that it was a good way to learn (36.9% points, 95% CI 26.8 to 47). VR also scored high on the System Usability Scale (mean difference 6.4% points, 95% CI 2.8–10.1).

Conclusions: Individual self-practicing the ABCDE approach in VR was non-inferior to individual self-practicing with traditional equipment.

Keywords: Virtual reality, ABCDE approach, Individual self-practice, Simulation, Clinical skills, Immersive, Interactive virtual reality, ABCDE approach, Individual self-practice, Simulation, Clinical skills, Immersive, Interactive

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Background

Systematic clinical observation is an essential skill to ensure patient safety and recognize deterioration in the patient [1]. The Airways-, Breathing-, Circulation, Disability-, Exposure- approach (ABCDE approach) is the internationally recommended and widely used approach for this purpose [1–3]. There is a need for implementing the ABCDE approach in undergraduate medical training [4]. According to systematic reviews, the best way to learn the ABCDE approach is through simulation-based training [5–7]. They have found both high-fidelity and low-fidelity simulations with actors, advanced and simple manikin simulators and interactive e-learning courses to be effective.

However, practical aspects challenge the quantity of simulation training. This includes the demand for high density of qualified staff, that the equipment is expensive and fragile and the activity is not available for students without arrangements [8, 9]. Furthermore, medical and healthcare students have limited opportunity to practice such skills in their clinical placements, due to lack of supervision and relevant practicing situations [10]. One possible solution to increase the opportunity for more practice is the use of virtual reality (VR) which can give the students the possibility to self-practice simulation [11]. VR may also benefit to reduce the use of critical resources like lecturers, time, cost and traveling [12].

Virtual reality with the use of head mounted goggles, is an immersive three-dimensional (3D) environment were the user is completely occluded from reality. The user can interact with the virtual environment through hand controllers [13]. Research on the effect of different types of VR applications have been collected in several meta-analyses and reviews, and these show that VR have similar effect as other forms of training like lecturing, web-based programs, video films, simulation etc. [14–18].

Thus, there can be a potential for using VR to learn the ABCDE approach. However, we have not found any publications where the ABCDE approach for systematic clinical observation is practiced in a fully immersive and interactive virtual environment. We only found two experimental studies investigating the effect of serious game where the ABCDE skills were one of the outcome measures, and these found the results to be similar as other training [19, 20].

The aim of this study was to investigate if individual self-practice of the ABCDE approach in an immersive and interactive virtual reality application (the VirSam ABCDE application) gave a non-inferior learning outcome compared to individual self-practicing with traditional equipment for skill training in first year medical and nursing students.

Method

Study design

This was a non-inferior parallel group open randomized controlled trial. The reason for choosing a non-inferiority design was the disadvantages of VR compared to real life skill practice. The study was part of a larger trial, where it was recruited students to another RCT simultaneously.

The trial was conducted in August and September 2019. The study was approved by the Norwegian Centre for Research Data (NSD, reference number 535088).

Participants and recruitment

The inclusion criteria were first year medical and nursing students that had started their study no later than 2 months before this study was conducted.

The recruitment was linked to teaching programs which was integrated into the curriculum of each study program. The students were informed that they should participate in a teaching session where they would be randomized to different types of practicing the ABCDE approach. The students were informed that they would be asked to participate in this study by sharing data from the teaching session. They were asked at the end of the session to keep the focus on having the students participating in the teaching session (and not the study). Those who attended the session was eligible for the study and those who shared their data were included.

Randomization and allocation

To randomize students, separate randomization lists were made for each batch using the RAND() function in Excel. The lists were printed as identity-stickers with an ID number and the type of practice the students were to participate in. These were sealed in identical opaque plastic bags which were mixed and randomly selected. The stickers were placed on the desk in ascending order according to the ID number. The allocation was done by asking each student entering the classroom to sequentially seat themselves at the lowest available ID number. When the introduction part was over, the students were informed where to go for their practice according to the allocation code on their sticker.

Interventions

The whole teaching session took approximately one hour for each student; 15-min introduction, 20-min individual practice and approximately 15-min testing. The rest was time for moving between rooms or waiting for the practical test. The time for introduction and practicing is the standard of the time used in a brief and simulation phase [21, 22] in simulation training.

The focus throughout the teaching session was the importance of keeping to the ABCDE order, the eight observations to be done (Table 1) and documentation of the observations. The content used, the observations chosen and equipment provided (a digital blood pressure gauge, a digital oximeter, a digital ear thermometer, a clock, an overview of the ABCDE observations) was based on recommendations in guidelines and studies [1, 2] and in dialogue with those responsible for the curriculum at the study programs.

All participants took part in the introduction session where they were informed briefly about the teaching and the study. They had a six minutes lecture on the ABCDE approach and watched a seven minutes video made by the authors, demonstrating how to do the ABCDE examination on an advanced simulator manikin (The introduction video [23]).

The participants allocated to individual self-practice in VR was instructed how to take on the VR equipment (Oculus Rift S or Oculus Quest head mounted device and hand controllers) by one instructor helping 3 students. The instructor did not provide any further help except if there were technical problems with the VR equipment or the software. The VR application (the VirSam ABCDE application) was developed specifically for this study by the authors, with hired help for programming (Unity 2018.3.0f2) (Table 2, and video of the VR-features [24]). The application has a tutorial on how to use the VR hand-controllers, and an ABCDE practicing part (Table 1). In the practicing part, all observations are done on a virtual patient using virtual versions of the provided equipment. Instructions on how to do the observations is given as a silent subtitled film. Feedback on performance is automatically generated after completion of all observations.

The participants allocated to individual self-practice with traditional equipment was instructed what to do and how to use the equipment by one instructor helping 3 to 6 students. They got a printed sheet with pictures of the equipment along with simple instructions for its technical use. The instructors did not provide any further help except if there were failure with the equipment.

The minimum of help in both the groups was to reflect a self-training situation.

Data collection

The participants completed a baseline questionnaire when they entered the introduction session.

The outcome data was collected through a questionnaire and a practical test after the practicing part. First, they answered a questionnaire on the right order of the ABCDE and the eight observations, and on their experiences with the different parts of the whole teaching session. There was no time limit, but the majority used approximately 6 min. Afterwards they did a full ABCDE examination on an advanced simulator (the 3G or ALS simulator, Laerdal Inc., Stavanger, Norway) with clinical values of a healthy person. The same equipment as described above was available at the bedside table. The participants were informed that they got maximum 5 min to perform the examination, at which point they were interrupted. One staff member was present to give instruction and assist with technical issues like operating the monitor to show the values from blood pressure, saturation and temperature if the students did these observations. If the staff observed that the students struggled with the technical issues without requesting help, they helped. Otherwise they did not interact with the student, they were instructed to only answer "do as you think is best" if the student asked anything. The staff was blinded to the student's allocation.

To validate the scoring of the participants documentation of their ABCDE observations from the practical test, the authors (HB and AS) independently scored subsamples in an iterative process. These scorings and the criteria for scoring was refined until consensus. Then HB and AS independently coded the answers from 30 randomly selected students and subsequently found some data punching errors and a few incompatible answers. It was therefore decided to enter all data twice by two independent persons. HB and a third person hired for the purpose scored all the answers independently

Table 1 The information the students got regarding which eight observation to do and the order they should be done in

ABCDE algorithm	Observations
A- airways	1: observe if the airways are free -document
B- breathing	2: count the respiration frequency (The number breaths per minute, one breath = inbreath + outbreath) -document
	3: get the oxygen saturation using a digital oximeter -document
C- circulation	4: get the blood pressure using a digital blood pressure gauge -document
	5: count pulse (the number of heart beats per minute) -document
D- disability	6: observe if the patient is conscious -document
E- exposure	7: get the temperature using a digital ear thermometer -document
	8: observe if the skin is normal -document

Table 2 Features in the practice part of the VR application (the VirSam ABCDE application)

VR-features	Explanation
Immersion	Be presented in a 3D virtual room modelled from an equipped observation room and having 360-degree vision.
Interaction	Virtual hands to pick up and move things and to get haptic response.
Virtual patient (VP)	A healthy older male person lying on the bed half dressed, having visual response (eye blinking, head movement, open and close mouth, chest movement), haptic response (breath, pulse on the wrist), and changing clinical value responses to use of digital equipment (BP, temperature, O2 saturation). No vocal response.
Haptic feedback	Vibration in the hand controllers when feeling the pulse (each heart beat) on the wrist, and when placing the hand on the chest (each respiratory intake).
Audio feedback	Inflation sounds from blood pressure gauge and "bip" from ear thermometer when measures ready (5 s)
Wristwatch	On left hand. Classic design showing real-time including seconds.
Patient monitor	Monitor with touch screen buttons to get clinical values (BP, temperature, O2 saturation).
Documentation tablet	Tablet with touch screen buttons for responses, including numeric pad for entering clinical values and choice between predefined options.
Instructions	A silent subtitle video running on a wall mounted screen showing how to do the observations, and a poster on the wall with the ABCDE observations.
Feedback	When the user select that all documentations are done, a scoreboard appears with detailed feedback and a summary maximum of three stars, covering order of observations, whether all observations were done and if the values from the observations were correct.

and checked for accordance. They were blinded to the allocation in this process.

Implementation of the intervention

To monitor the implementation of the intervention, the technical problems encountered during the self-practice was recorded. The students were also asked how many times they completed full ABCDE examinations during the practice session (0, 1, 2, 3 times or more).

Outcome measures

The primary outcome was the number of students who documented all eight ABCDE observations in the correct order on the practical test (yes/no). When there were two observations required for one step in the algorithm (B, C, E), it was scored as correct regardless of the order the observations were documented.

One group of secondary outcomes concerned the ABCDE approach:

- Number of participants who arranged the eight observations in the right order. The order in the questionnaire was in the same random order for all students [1–8]. This was coded equal to the primary outcome.
- Number of participants who arranged the ABCDE letters, presented with their Norwegian names which does not correspond to the same letters, in the right order (yes/no). The order in the questionnaire was in the same random order for all students (DBAEC).
- Number of participants who had all eight observations documented, but ABCDE in the wrong order in the practical test.
- Number of participants who did not complete all eight observations in the practical test.
- Number of participants who did not complete all eight observations but had the right ABCDE order on the documented observations in the practical test.
- Number of participants who wrote both the type of observation and the correct type of result on all the documented observations in the practical test.
- Number of participants who wrote both the type of observation and the correct type of result on the each of the eight individual observations in the practical test.
- The average number of observations documented in the practical test.
- The average number of observations documented in the correct order counted from A (Airways) in the practical test.

The other group of secondary outcomes concerned the student's experiences with the teaching session and where asked on the questionnaire. The questions were scored on a Likert Scale where 1 was very strong disagreement and 5 was very strong agreement. The scale was dichotomized, with 4 and 5 coded as agreement:

- Did you get enough training on the ABCDE approach before starting to practice?
- Did the video help you learn what observations to do?

– Did you have enough time to practice?
– Did you like this way to practice?
– Do you think this training and practice was a good way to learn the ABCDE approach?
– Do you feel confident to conduct an ABCDE examination?

They also completed the System Usability Scale (SUS) as a measure of the usability of the system they used during the self-practice. The answers to the ten questions were transformed into one single score according Brooke [25] and given a grade from the curved grading scale (CGS) [26].

Statistics

Data for the sample size calculation came from previous studies testing clinical learning outcomes, indicating that a 10–15% points non-inferiority limit is fair [27, 28], and it was decided on a limit of 13% points. We conducted a pilot with 18 health worker students in their second year at a vocational high school who had some experience in systematic clinical observation. Twenty percent of these students got everything correct on the primary outcome. We expected a similar outcome arguing that the university students in our study had less practical experience, but more experience in studying to master new tasks. With an expected outcome in both groups of 20% correct answers, with a non-inferiority limit of 13%, a power (1-B) of 80% and significance level (alpha) of 0.05, 118 students was needed in each group. The calculation was done using the web calculator for non-inferior trials provided by Sealed Envelope [29, 30].

Baseline variables are presented with descriptive statistics. As there was no deviation from the allocated groups and hardly any missing data, only analysis of available data was done. It was used independent sample t-tests for continuous variables (SPSS v. 26, IBM Inc) and tests of proportions using two-sample test of proportions for the categorical variables (StataMP 16, Stata Inc). Results are presented as an absolute difference. For the primary outcome the one-sided 95% confidence interval (95% CI) is reported according to the one-sided non-inferiority limit. To make the presentation more conventional, the secondary outcomes are reported with two-sided 95% CI.

Results

Recruitment and baseline characteristics

Overall 689 first year medical and nursing students were eligible in the larger study and 289 participated in this study (another 289 participated in another RCT). They were

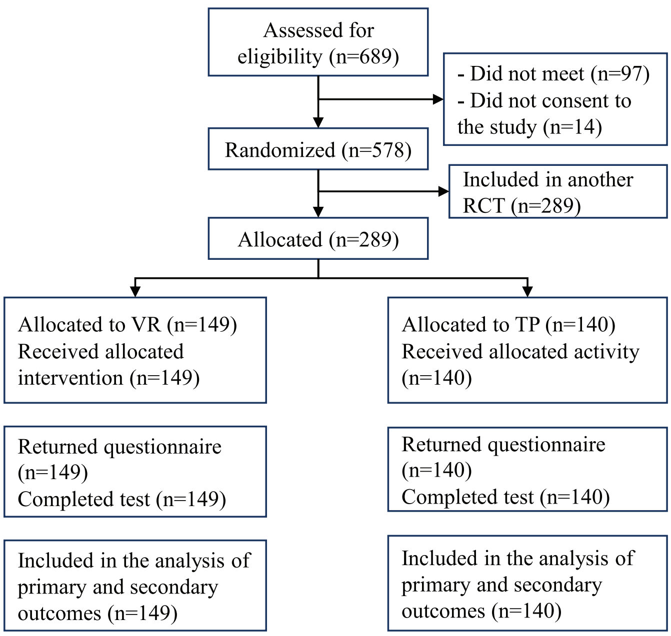

Fig. 1 Flow of participants (VR; virtual reality, TP; traditional practice)

randomized with 149 to individual self-practice in virtual reality (Individual VR) and with 140 to individual self-practice with traditional equipment (Individual TP) (Fig. 1).

There were 227 (78.5%) females and the majority was from 20 to 24 years old (Table 3). A total of 243 (87.7%) of the participants reported to have been taught cardiopulmonary resuscitation (CPR) previously. There were 33 (11.9%) participants reported to have conducted a systematic clinical observation before, and 64 (23.1%) of the participants reported to have been taught the ABCDE approach previously. Some had experience in using VR (72 (26%)) or simulator manikin (112 (40.4%)).

Those in individual TP was somewhat younger (Table 3). A larger proportion in VR had been taught the ABCDE approach but fewer had used a simulator manikin. On balance, the groups were similar at baseline (Table 3).

Implementation of intervention

The intervention in both groups was implemented as planned, without any major technical or other type of practical problems. It was only recorded that VR-goggles had to be restarted three times because of lost tracking of hand-controller.

A larger proportion of the students practicing in the VR application reported completing the full ABCDE examination two times or more during the practice session (absolute difference 30.4% points, 95% CI 21.5 to 39.4).

Primary outcome

A total of 37 (24.8%) participants in VR and 38 (27.1%) in TP had all eight observations documented in the correct ABCDE order. The absolute difference was 2.3% points, the one-sided 95% CI upper level was 10.8% which was within the limit of 13% points and thus demonstrate the non-inferiority of VR practice (Fig. 2).

Secondary outcomes

Except for one outcome, the secondary outcomes concerning the ABCDE approach showed similar results which further strengthened the non-inferiority of VR practice (Table 4). The secondary outcome in the questionnaire, which was similar to the primary outcome, having all observations in the correct order, showed an absolute difference of 7.8% points (95%CI − 3.6 to 19.1) in favor of TP. For the other outcomes, it varied whether the small differences favored VR or TP. The outcome which showed a difference was the reporting of Respiratory frequency where students in VR did better (97.3% correct in VR vs 89.3% in TP, absolute difference 8% points, 95% CI 2.3 to 13.8).

Table 3 Baseline characteristics of the participants. The *n* for each variable can vary due to missing, *n* (%)

Baseline variables	All (***N*** = 289)	VR group (***N*** = 140)	TP group (***N*** = 149)
Gender			
-Male	50 (17.3)	28 (20.3)	22 (15.8)
-Female	227 (78.5)	110 (79.7)	117 (84.2)
Age			
-Under 20 year	66 (23.8)	25 (18.1)	41 (29.5)
-20–24 year	179 (64.6)	96 (69.6)	83 (59.7)
-Over 25 year	32 (11.6)	17 (12.3)	15 (10.8)
Study program			
-Medicine	69 (23.9)	36 (24.2)	33 (23.6)
-Nursing	220 (76.1)	113 (75.8)	107 (76.4)
Have you previously (number answering yes):			
-Worked in health care	157 (56.7)	80 (58.0)	77 (55.4)
-Been taught cardiopulmonary resuscitation (CPR)	243 (87.7)	122 (88.4)	121 (87.1)
-Conducted systematic clinical observation	33 (11.9)	18 (13.0)	15 (10.8)
-Been taught the ABCDE-approach	64 (23.1)	38 (27.5)	26 (18.7)
-Used a blood pressure gauge	119 (43.0)	61 (44.2)	58 (41.7)
-Counted respiration frequency on someone else	112 (40.4)	52 (37.7)	60 (43.2)
-Tried virtual reality googles	72 (26.0)	39 (28.3)	33 (23.7)
-Trained using a simulator manikin	112 (40.4)	48 (34.8)	64 (46.0)

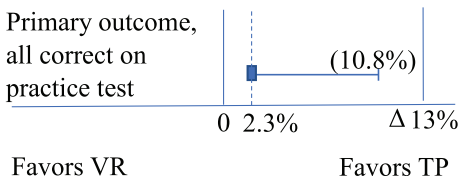

Fig. 2 Primary outcome

For the secondary outcomes concerning the experiences with the teaching session, there was a difference on the satisfaction with the type of practice (Table 5). Students practicing VR scored higher on liking the type of practice (82.6% vs. 36%, absolute difference 46.6% points, 95% CI 36.5 to 56.6) and on the training and practice were a good way to learn the ABCDE approach (85.1% vs. 48.2%, absolute difference 36.9% points, 95% CI 26.8 to 47.0) (Table 5). Furthermore, the outcome on the SUS favored VR with a mean SUS score of 79.7, corresponding to Grade A-, and 73.3, Grade B-, in TP (absolute difference 6.4% points, 95% CI 2.8 to 10.1).

Discussion

Self-practicing the ABCDE approach individually in VR using the VirSam ABCDE application gave a non-inferior learning outcome compared to individual self-practicing with traditional equipment. Most of the other outcomes gave similar results in both groups, but those practicing in VR was more satisfied and scored the usability higher.

The main strength of this study is the design and the high proportion of students participating, making the results generalizable to similar first year medical and nursing students. The study also included the required number of students from the sample size calculation. There were no major methodological limitations except for the lack of blinding due to the nature of the study. The study tested only one type of VR application, had short follow up time and an larger effect could be expected with more time to practice and/or repetition as it is known that repeated practice is the best way to retain knowledge and skills [31, 32]. Another limitation is that there was no systematical measure on environmental impact in this study, which could have been warranted given the investigation of VR which is a relative new

Table 4 Secondary outcomes measures concerning the ABCDE approach. Numbers are *n* (%) or mean (SD) with difference between the groups and 95% confidence interval (95%CI)

Outcome measure	Individual VR ***N*** = 149	Individual TP ***N*** = 140	Absolute diff. % points (95% CI)	***P***-value
Number of participants that in the questionnaire had:				
- all eight observations in correct ABCDE order	81 (54.4)	87 (62.1)	7.8 (−3.6 to 19.1)	0.180
- ABCDE in the right order	136 (91.3)	127 (90.7)	0.6 (−7.2 to 6.0)	0.868
Number of participants in the practical test who:				
- had all eight observations documented, but ABCDE in wrong order	6 (4.0)	5 (3.6)	0.5 (−4.9 to 4.0)	0.840
- did not complete all eight observations	106 (71.1)	97 (69.3)	1.9 (−12.4 to 8.7)	0.730
- did not complete all eight observations, but had the right ABCDE order on the documented observations	55 (36.9)	56 (40.0)	3.1 (−8.1 to 14.3)	0.590
- wrote both the type of observation and the result of the observation	89 (59.7)	86 (61.4)	1.7 (−9.6 to 13.0)	0.768
Number of participants in practical test with correct observation of (independent of order):				
- Airways	145 (97.3)	135 (96.4)	0.9 (−4.9 to 3.1)	0.664
- Respiratory frequency	145 (97.3)	125 (89.3)	8.0 (2.3 to13.8)	0.006
- Saturation	141 (94.6)	135 (96.4)	1.8 (−3.0 to 6.5)	0.461
- Blood Pressure	144 (96.6)	137 (97.9)	1.2 (−2.5 to 5.0)	0.530
- Pulse	118 (79.2)	121 (86.4)	7.2 (−1.4 to 15.9)	0.104
- Disability	93 (62.4)	84 (60.0)	2.4 (−13.7 to 8.8)	0.674
- Temperature	84 (56.4)	82 (58.6)	2.2 (−9.2 to 13.6)	0.706
- Skin	77 (51.7)	64 (45.7)	6.0 (−17.5 to 5.5)	0.311
Average number of observations documented from practical test	Mean 6.3 SD (1.5)	Mean 6.4 SD (1.4)	Mean diff. 0.05 95%CI (−0.382 to 0.285)	0.775
Average number of observations documented in the right order from A (Airways) in practical test	Mean 5.1 SD (2.5)	Mean 5.2 SD (2.3)	Mean diff. 0.07 95%CI (− 0.623 to 0.478)	0.796

Table 5 Secondary outcomes measures concerning the students experiences with the teaching session. Numbers are *n* (%) or mean (SD) with difference between the groups and 95% confidence interval (95%CI)

Outcome measure	Individual VR ***N*** = 149	Individual TP ***N*** = 140	Absolute diff. % points (95%CI)	***P***-value
Number of participants who thought:				
- they got enough training about ABCDE before starting practicing	36 (24.2)	29 (20.7)	3.4 (−13.1 to 6.2)	0.483
- they learned what observations to do trough the introduction video	83 (55.7)	81 (57.9)	2.2 (−9.3 to 13.6)	0.712
- they had enough time to practice	48 (32.7)	56 (40.3)	7.6 (−3.5 to 18.8)	0.180
- the way to practice was likable	123 (82.6)	50 (36)	46.6 (36.5 to 56.6)	< 0.001
- the training and practice were a good way to learn the ABCDE approach	126 (85.1)	67 (48.2)	36.9 (26.8 to 47.0)	< 0.001
- they were confident to conduct an ABCDE examination	43 (28.9)	37 (26.4)	2.4 (−12.7 to 7.9)	0.644
System usability scale (SUS, range 0–100)	Mean 79.7 SD (14.6)	Mean 73.7 SD (16.2)	Mean diff. 6.0 95% CI (2.8 to 10.1)	< 0.001

type of equipment. On balance we do not see that the environmental impact of VR compared to traditional real-life practice (e.g. travel needed for face-to-face practice) is likely to be different, given relative low cost and the same type of resources needed for accomplishment of the interventions in this study.

The study confirmed the a priori assumption that VR would give a non-inferior learning outcome due to VR having some disadvantages compared to practicing in real life. Only a few earlier randomized controlled trials with a non-inferior assumption was found [33–35], and they got a similar result as the current study. Other randomized controlled trials without a non-inferior assumption have found the use of VR to give similar learning outcome as the comparison intervention [16, 36, 37]. However, there are some recent meta-analysis that have found VR to be superior, e.g. comparing VR simulator to box trainer for minimally invasive procedures [15] and in improving postintervention knowledge and skills [18]. Thus, the current study, due to its size and rigor, lends strong support to the assumption that VR at least gives a non-inferior learning outcome.

The students evaluated the usability of the VR application, as documented by the System Usability Scale (SUS), to be better than practicing with traditional equipment. The VR application got a SUS rating equal to a A-, which is in the 85–89 percentile [26]. This is encouraging as there are earlier studies showing that VR can give users motion sickness, that technical problems like software failure can happened and that the effort of learning to use VR can be distracting to learning new skills [20, 38]. Furthermore, the high usability scores confirm our observation that there were no technical problems. But more importantly, it is a clear indication that the features of the VirSam ABCDE application developed for this study was well chosen and implemented.

The main features of the VirSam ABCDE application are immersion and interactivity, which have been found important for creating engagement and satisfaction in VR [19, 39]. Most studies on the effect of VR evaluated in clinical- and healthcare reviews and meta-analyses have used either fully immersive [33, 34] or interactive [36] solutions. Thus, there are few studies on the effect of applications that are both immersive and interactive. This was one of the reasons that the application used in this study was self-developed, no application was found that was both fully immersive and interactive and focusing on the ABCDE approach.

Due to the non-inferiority on learning outcomes and superiority on satisfaction and usability, the application can be recommended for use in education of healthcare professionals. Nevertheless, the application has some restrictions. It was emphasized that the level of the ABCDE learning objective should be adapted to novices, and that the VR application should be easy use. Thus, it is likely not to be relevant for personnel experienced in using the ABCDE approach nor in training for the more advanced ABCDE observations.

Conclusions

Self-practicing the ABCDE approach in VR gave a non-inferior learning outcome compared to self-practicing with traditional equipment in first year medical and nursing students, and the students were more satisfied with using VR. VR solutions that is immersive and interactive can be used as a practical and engaging way to learn the fundamentals of the ABCDE approach.

Abbreviations
ABCDE: Airways, Breathing, Circulation, Disability, Exposure; VR: Virtual Reality; TP: Traditional Practice; SUS: System Usability Scale; CGS: Curved Grading Scale; CI: Confidence Interval; SD: Standard Deviation; 3D: Three-Dimensional; CPR: Cardiopulmonary Resuscitation

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Not applicable.

Authors' contributions
HB and AS contributed equal in all parts of the study. Both authors read and approved the final manuscript.

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Availability of data and materials
The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
All ordinary procedures were followed to ensure ethics and data security. The participants were informed both in writing and orally of their rights and the purpose of the study and consent by sharing their data. The study was approved by the Norwegian Centre for Research Data (NSD, reference number 535088).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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