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Three-dimensional technology in healthcare education

-Experiences in practical nursing education

Mika Alhonkoski

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SARJA – SER. D OSA – TOM. 1906 | MEDICA – ODONTOLOGICA | TURKU 2025

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The originality of this publication has been checked in accordance with the University of Turku quality assurance system using the Turnitin Orginality Check service.

ISBN 978-952-02-0330-6 (PRINT)
ISBN 978-952-02-0331-3 (PDF)
ISSN 0355-9483 (Print)
ISSN 2343-3213 (Online)
Painosalama, Turku, Finland 2025

To my loved ones

UNIVERSITY OF TURKU
Faculty of Medicine
Department of Nursing Science
Nursing Science
MIKA ALHONKOSKI: Three-dimensional technology in healthcare education – experiences in practical nursing education
Doctoral Dissertation, 150 pp.
Doctoral Programme in Nursing Science
September 2025

ABSTRACT

The main purpose of this two-phased study was to analyse the pedagogical usage and outcomes of 3D technology in healthcare education at the level of vocational education and training. In this study 3D technology is defined as encompassing four components: 3D images, 3D environments, 3D holograms, and 3D printing.

PHASE I (2019-2022) aimed to develop an intervention using 3D technology in practical nursing education. This was implemented with a scoping review (n=31 articles) and mixed method study. The mixed method study was guided of theoretical framework of "Technological Pedagogical Content Knowledge". The data was collected from teachers using a survey (n=55) and semi-structured interviews (n=17). PHASE II (2022-2025) aimed to analyse the outcomes of using 3D technology among practical nursing students in first aid courses from the perspective of technology acceptance and learning outcomes. In total 59 (n=59) practical nursing students participated in the study. They were divided into the intervention group (n=32) and control group (n=27). Technology acceptance was studied with mixed method design guided by the "Technology Acceptance Model". This included a survey and focus group interviews. Learning outcomes were studied with a quasi-experimental design including a knowledge test (pre, post and follow-up) and skills test at the end of the first aid course.

As a result, the PHASE I found that 3D technology is a promising method in healthcare education with positive outcomes. The usage was dominantly with a 3D environment. Teachers emphasized the need to address several issues such as resources and collaboration when implementing 3D technology in teaching. In PHASE II the practical nursing students reported that the 3D technology was easy to use and useful. They felt more prepared to adapt new technologies in the future. Moreover, they learned better first aid knowledge and CPR-skills when the 3D technology was connected to the teaching.

As a conclusion, 3D technology can be seen as a promising method to utilize in vocational education and training among practical nursing students and it may enhance learning outcomes in first aid education and prepare students to adapt to new technologies easier in future.

KEYWORDS: 3D technology, healthcare education vocational education and training, practical nursing education

TURUN YLIOPISTO
Lääketieteellinen tiedekunta
Hoitotieteen laitos
Hoitotiede
Mika Alhonkoski: 3D-teknologia terveysalan koulutuksessa – kokemuksia lähihoitajakoulutuksesta
Väitöskirja, 150 s.
Hoitotieteen tohtoriohjelma
Syyskuu 2025

TIIVISTELMÄ

Tämän kaksivaiheisen tutkimuksen tarkoituksena oli analysoida 3D (kolmiulotteisen) -teknologian pedagogista hyödyntämistä sekä tuloksia terveysalan koulutuksessa. Tässä tutkimuksessa käsite 3D-teknologia määritellään sisältävän 3D-kuvat, 3D-ympäristön, 3D-hologrammit sekä 3D-tulostamisen.

Vaiheessa I (2019-2022) kehitettiin interventio 3D-teknologian hyödyntämisestä terveysalan ammatillisessa koulutuksessa. Vaihe sisälsi scoping katsauksen (n=31 artikkelia) sekä monimenetelmätutkimuksen, jossa teoreettisena viitekehyksenä käytettiin ”Technological Pedagogical Content Knowledge”-teoriaa. Monimenetelmätutkimuksessa aineisto kerättiin kyselyllä terveysalan opettajilta (n=55) ja haastattelemalla opettajia (n=17). Tulosten perusteella kehitettiin 3D-teknologiaa hyödyntävä interventio lähihoitajakoulutuksen ensiavun opetukseen. Vaiheessa II (2022-2025) arvioitiin intervention tuloksia kahdesta eri näkökulmasta: Teknologian hyväksyminen ja oppimistulokset. Arviointiin osallistui yhteensä 59 lähihoitajaopiskelijaa, jotka jaettiin interventioryhmään (n=32) ja kontrolliryhmään (n=27). Teknologian hyväksyntää tutkittiin monimenetelmätutkimuksella, johon kuului ”Technology acceptance Model”-teorian ohjaamat kyselyt sekä opiskelijoiden ryhmähaastattelut. Oppimistuloksia tutkittiin kvasikokeellisella menetelmällä testaamalla lähihoitajaopiskelijoiden tietoa pre-, post- ja seuranta-kyselyillä sekä elvytystaitojen osaamista ensiapuopinnon lopussa.

Vaiheen I tuloksena ilmeni, että 3D-teknologia on lupaava väline terveysalan koulutuksessa, johon liittyy useita positiivisia tuloksia ja josta korostivat monia eri asioita (esimerkiksi resurssit ja yhteistyö) implementoinnin tueksi. Vaiheessa II opiskelijat kuvasivat 3D-teknologiaa helppokäyttöiseksi ja hyödylliseksi. He kokivat olevansa intervention jälkeen valmiimpia hyödyntämään uusia teknologioita tulevaisuudessa kuin ennen interventiota. Opiskelijat oppivat myös paremmin hyödyntämällä 3D-teknologiaa. Opiskelijoiden oppimistulokset paranivat intervention myötä sekä ensiaputiedoissa että elvytystaidoissa.

3D-teknologia on menetelmä, jonka avulla on mahdollista parantaa oppimistuloksia ensiavun opetuksessa sekä valmistaa opiskelijoita kohtaamaan erilaisia teknologioita tulevaisuudessa.

ASIASANAT: 3D-teknologia, ammatillinen koulutus, lähihoitajakoulutus terveysalan koulutus

Table of contents

List of tables and figures

Tables

Figures

Abbreviations

3D	Three-dimensional
AR	Augmented reality
EQF	European Qualifications Framework
ER	Extended reality
EU	European Union
FNBE	Finnish National Board of Education
MR	Mixed reality
TAM	Technology Acceptance Model
TAM2	Extended Technology Acceptance Model
TPACK	Technological pedagogical content knowledge
USA	United States of America
UTU	University of Turku
VET	Vocational Education and Training
WHO	World Health Organization
VR	Virtual Reality

List of original publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:.

I Alhonkoski M., Salminen L., Pakarinen A. & Veermans M. 2021. 3D technology to support teaching and learning in healthcare education—a scoping review. International Journal of Educational Research, 105. Doi: https://doi.org/10.1016/j.ijer.2020.101699

II Alhonkoski M., Veermans M., Artukka K. & Salminen L. 2022. The perspectives of healthcare teachers on their technological pedagogical content knowledge of 3D technology: a mixed methods study. Computers, Informatics & Nursing, 40(11): 743-753.

III Alhonkoski M., Veermans M., Nurmi H., Kotonen S., Strandell-Laine C., Artukka K. & Salminen L. Practical nursing students' technology acceptance of three-dimensional technology—a mixed methods study with qualitative dominance. Manuscript.

IV Alhonkoski M., Veermans M., Nurmi H., Kotonen S., Strandell-Laine C., Artukka K. & Salminen L. 2025. Evaluation of learning outcomes among practical nursing students after using 3D technology in their studies. Computers, Informatics & Nursing, 0(0). Doi: 10.1097/CIN.0000000000001333

The summary also contains unpublished material.

1 Introduction

It is widely known that the nursing profession faces a huge need for professionals in upcoming years, and the lack of professional nurses has been estimated at several million nurses (Keating et al., 2021). At the same time a meaningful number of healthcare students reported that their motivations and goals to study did not include patient-centred nursing or nursing work at all, and a conspicuous part of the students are considering quitting their education (Bagenal, 2024). These aspects will challenge teachers to adequately teach the following generations using valid methods with sound learning outcomes and to deliver creative and motivating healthcare education (James et al., 2017).

Future nursing education will consist of innovative teaching and varying teaching strategies with the aim of valid, equitable and flexible learning possibilities for students (National League for Nursing, 2024). This goal for education is mentioned also by the World Health Organization (WHO) in the executive summary of the "State of the World's Nursing (2020)." This concerns theoretical as well as practical teaching and learning in nursing (Akram, 2018) and every educational level from higher education (Sumpter et al., 2022) to vocational education (Saglic & Aykac, 2018). What tools can help healthcare teachers to achieve the goal of innovation and how can teachers gain valid knowledge and competence in the use of these tools?

When describing the elements of future innovative nursing education, technological solutions are highlighted by several authors (see e.g. Sumpter et al., 2022; Booth et al., 2021). Using technology has been evaluated to be one solution for the workforce shortage and as a means to increase students' motivation to remain in education and work (Bagenal, 2024). This has been solidified in the statement from the International Council of Nursing (2023), where it states that new technology should be adapted more solidly in the nursing profession at the start of education. Locally in Finland, this has been realized in statements from the Ministry of Education and Culture (2023), where the rapid growth of the use of technology in education has been made a concrete goal until the year 2027. Additionally, the state-led initiative in Finland aims to integrate technological solutions—and even entire programs focused on technology-oriented professions, such as welfare technology—into healthcare education (Ministry of Education and Culture, 2022).

The concept of technology is broad, fragmented, and multifaceted, which presents a challenge in terms of understanding the various technologies and their usability from the perspectives of nursing and nursing education (Pepito & Locsin, 2019). In addition to understanding different technological concepts, healthcare educators must recognize that the use of technology is not self-explanatory; rather, it should serve as a tool to help nursing students achieve better learning outcomes and a more enriching learning experience (Gause et al., 2022). Moreover, the planned and structured use of technology in education can enhance nurses' ability to use and adapt to new technologies in their professional practice (Nes et al., 2021).

Several educational technology (e.g. e-learning) has been implemented in healthcare education, which may have led to confusion for teachers and students (Granić, 2022). Moreover, the rapid implementation of technology may have contributed to a situation in which teachers' and researchers' attitudes toward technology appear to be deterministic (Costa et al., 2019; Oliver, 2011). This means that the expectations concerning the usage of technology may be similar in each pedagogical context and that the adaptation follows an identical path (Costa et al., 2019). To avoid deterministic approaches, each technological solution should be understood within the context it belongs to (Ait Ali et al., 2023), and the use of theoretical frameworks should be evaluated when adapting technology to each pedagogical context (Costa et al., 2019).

From the perspective of health pedagogy, there is a discussion about how competent healthcare teachers are using new technology in a pedagogically meaningful way (Jobst et al., 2022a). According to research, healthcare teachers describe their competence from a positive perspective, and they feel confident about the possibilities that new technologies bring (Pajari et al., 2024; Ryhtä et al., 2020). The teachers have also had positive experiences of using and adapting new technology in healthcare education, which reflects a flexible attitude toward the usage of technology (Jobst et al., 2022b). At the same time healthcare teachers describe uncertainty and a structured need for continuing education and training with future technologies (Jobst et al., 2022b; Ryhtä et al., 2020), which needs to be considered by the institutions which produce healthcare education (Jobst et al., 2022a).

Three-dimensional (3D) technology, with its various applications, is considered a promising technological tool for use in education (Ardila et al., 2023). The concept of 3D technology has been reported to be confusing, when the hyponym of 3D technology "virtual reality" has been used to describe social media or learning-platforms which have no connection to 3D (Kardong-Edgren et al., 2019). The understanding of the content of 3D technology is typically associated with visualization and the interaction between the students and 3D objects (Geng, 2013) although 3D technology can also be connected to 3D printing (Javaid et al., 2022). Visualization (for example using 3D images or 3D environments) has been studied to stimulate the brain more actively and positively affect the users' memory and understanding (Amin et al., 2021), while the effectiveness of 3D printing is connected with concrete interaction with the object and experience of hands-on doing (Novak et al., 2021). 3D technology itself has been utilized in multiple areas, e.g. engineering, with promising outcomes including students' enhanced motivation and satisfaction towards learning (Hamash et al., 2024; Leung et al., 2022; Novak et al., 2021). It is notable that 3D technology has been implemented in pre-school level already, which may set pressure to use it at higher levels also (Aslan, 2023). Besides the different learning outcomes, 3D technology has been studied from the perspective of technology acceptance (Naik et al., 2024), which reflects the usage of structural theoretical frameworks in pedagogical planning and adaption.

In healthcare education, medical education has incorporated many elements of 3D technology, such as 3D images, 3D environments (e.g., virtual reality), 3D holograms, and 3D printing, particularly in the teaching and learning of anatomy, among other topics (Ardila et al., 2023; Jiang et al., 2022; Moro et al., 2020; Garcia et al., 2018). On the other hand, some areas of healthcare education (e.g. nursing education) may use 3D printing quite infrequently (Lioce et al., 2020). Overall, when describing healthcare education and the usage of 3D technology, the focus is on nursing education (Chen et al., 2020), while vocational education and training (VET), such as practical nursing education, takes a secondary role.

The main purpose of this two-phased study was to analyse the pedagogical usage and the outcomes of the 3D technology in healthcare education at the level of vocational education and training. To fulfil the main purpose, this study developed an intervention based on the knowledge revealed in PHASE I and analysed the outcomes of the intervention in PHASE II. Moreover, this study highlights that this research was implemented in vocational education and training (practical nursing education) and in that way, underlines the importance of evidence-based knowledge at that level also.

2 Review of the literature

First, in this chapter the theoretical approach to the use of technology in healthcare education is presented. Second, this chapter introduces the following main concepts of the study: 1) healthcare education 2) vocational education and training and practical nursing education, 3) three-dimensional technology. Third, this chapter presents the current literature on usage of technology in healthcare education.

2.1 Overview of the theoretical background in the use of technology for pedagogical purposes

While several technological solutions have been implemented in healthcare education, several theoretical frameworks have also been developed (Sackstein et al., 2023). This highlights the need for structured planning when new technology is to be adapted or accepted in education from the pedagogical perspective (Costa et al., 2019). This concerns teachers and students, who need to understand the pedagogical aims of the technology (Dočekal & Tulinská, 2015). Overall, the theoretical frameworks can be approached from both a competence perspective and an acceptance perspective, which is crucial to understand, especially when the educational context is highly practical, such as in nursing education (Locsin & Purnell, 2015). To fulfil a comprehensive approach this study aimed to implement different theories of technology usage with healthcare teachers and students.

From the perspective of competence in technology usage, two theoretical frameworks are mainly used in the pedagogical context: the Technological Pedagogical Content Knowledge (TPACK) framework, and the Substitution, Augmentation, Modification and Redefinition (SAMR) model. These theories are quite similar and pay heed to a skills-based approach to technology (Sindi Alivi, 2019). This study concerned TPACK as a more relevant theoretical framework and therefore it will be presented more precisely in the following chapter.

The adaptation or acceptance of technology itself can be seen through different theoretical perspectives (Sohn & Kwon, 2020). The first description has been presented in the Theory of Reasoned Action (TRA), which highlights the importance of an individual's own attitude towards technology (Thomas, 1983). This theory led to extensions such as the Theory of Planned Behavior (TPB) and the Decomposed

Theory of Planned Behavior (DTPB), which elaborated the adaptation and acceptance of technology to have more psychological dimensions (Momani et al., 2018). These theories describe the acceptance of technology at a general level, while the pedagogical need may not be the focal point (Sackstein et al., 2023). While examining the educational field, the most used theoretical framework is the Technology Acceptance Model (TAM) and its extensions (Granić, 2022; Davis, 1989). TAM will be presented more precisely in following chapter because it is one from two theoretical frameworks in this study.

2.1.1 Technological Pedagogical Content Knowledge (TPACK)

The Technological Pedagogical Content Knowledge (TPACK) framework is a theory, which focuses especially on combining different kinds of competences and the pedagogically relevant use of technology (Mishra & Koehler, 2006). According to the TPACK theory, if a teacher utilizes a technological solution in teaching and learning, the teacher should have competence in three different dimensions: 1) using the technology, 2) using technology in a pedagogically correct way and 3) using technology that suits the content that the teacher is teaching (Figure 1). To be more precise, it is not enough to just have good competence in each category, it is necessary to have the competence to unite these categories correctly (Mishra & Koehler, 2006).

TPACK can be described more precisely with the dimensions from the instrument called TPACK-deep, which is utilized in this study as well (Kabakci Yurdakul et al., 2012; Mishra & Koehler, 2006). This instrument focuses on the following dimensions: design, exertion, ethics and proficiency. These dimensions can be seen in all the original dimensions of the theory: 1) using the technology, 2) using technology in a pedagogically correct way and 3) using technology that suits the content that the teacher is teaching (Kabakci Yurdakul et al., 2012).

The design emphasizes the importance of planning when teachers implement technology in their teaching, highlighting the need to address key issues, such as evaluating teaching and learning with technology. In the ethics-dimension, the teachers must consider the legal issues and evaluate how the usage of technology may influence behavioural aspects, for example how the content of the technology may influence students' thinking. Finally, proficiency describes the issues that teachers need to consider to promote and develop the usage of technology. (Kabakci Yurdakul et al., 2012.) These dimensions are needed in healthcare education as well.

In the educational field the TPACK framework has been utilized and validated in varied contexts in language teaching (Wahyuni et al., 2024) and teaching cultural knowledge (Bae & Chong, 2024). One meaningful element is also that TPACK has been utilized among vocational education teachers (Nepembe & Simuja, 2023; Torggler et al., 2023), although the use of the TPACK in nursing education is minor (Ait Ali et al., 2023).

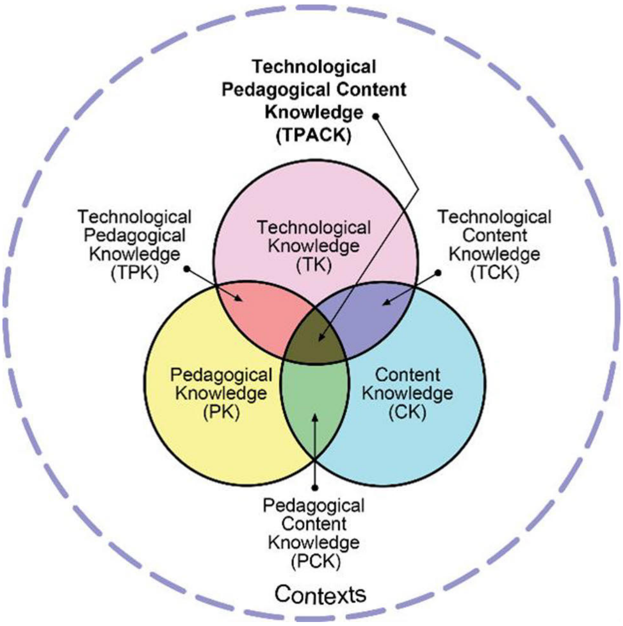

Figure 1. The TPACK-framework (also utilized in Paper Ⅰ).

2.1.2 The Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) is a theory that was originally developed by Davis (1989) to describe the elements of what a person needs to focus on when adapting new technology. These elements are the *perceived usefulness* and *perceived ease of use*. The perceived usefulness means one's feeling about the professional usefulness of certain technology. The perceived ease of use refers to the feeling of how easy a certain technology is to use and adapt to the work. These two elements are crucial for the willingness to adapt to new technology. (Davis, 1989.)

TAM was further developed by Venkatesh & Davis in 2000. The extended version of the original theory (called TAM2 from now on) interpreted the technology acceptance to include more elements of social processes of individuals. These elements in TAM2 reflect both cognitive (job-related) aspects –such as job relevance, result demonstrability, and output quality – and social influences such as subjective norm, image, and voluntariness. These factors shape the individual's perception of usefulness, which in turn influences their intention to use the technology. (Venkatesh & Davis, 2000.)

TAM and TAM2 have been validated in several educational contexts in computer science (Adouani & Khenissi, 2024), language learning (AlDakhil & AlFadda, 2022) and online teaching (Wingo et al., 2017). The theory has also been highlighted in nursing education, during virtual reality learning in a community course (Fontenot et al., 2024), online learning among public health nurses (Chen et al., 2008) and using smartphones in clinical settings (Lai et al., 2022).

2.1.3 The summary roles of the TPACK and TAM in this study

TPACK and TAM are both theoretical frameworks in this study. TPACK was evaluated as a relevant theoretical framework to study healthcare teachers' perspectives because of the skills-based approach (Mishra & Koehler, 2006). This was considered to support the healthcare teachers to connect the pedagogy, technology and professional demands in healthcare, such as understanding the concept of nursing (Locsin & Purnell, 2015). Therefore, TPACK's role was relevant, when this study focused on the healthcare teachers in sub study II (Paper II). For the examination of practical nursing students, this study evaluated TAM more relevant theoretical framework, because it does not emphasize pedagogical elements, but focuses on more concrete issues (for example usefulness or ease of use). Moreover, healthcare education includes several pedagogical elements from the social perspective, such as the importance of the nurse's own professional image (Venkatesh & Davis, 2000; Locsin & Purnell, 2015). These were the main reason for TAM being a theoretical framework in this study for the practical nursing students in sub study III (Paper III).

In summary, in this study TPACK was the theoretical framework used for the study of healthcare teachers, which focused on the pedagogical aspects of the usage of 3D technology (Paper II). TAM was the theoretical framework used in the study of practical nursing students to examine their technology acceptance after the usage of the 3D technology (Paper III).

2.2 Definition of the study concepts

2.2.1 Healthcare education

Healthcare education can be defined according to those professions that improve individuals' health and wellbeing (Word Health Organization, 2022). To be more precise healthcare education can be defined based on the professions it includes

(Frenk et al., 2022), such as whether or not it encompasses medical education (Mikkonen et al., 2019; Hackett & Proctor, 2016). In this study medical education was excluded, as its content is considered a relatively independent part of the educational landscape, differing significantly from other nursing-related education (Mickan & Coates, 2022). In addition to the definition of healthcare education, it is notable that the educational levels can differ from vocational education (e.g. practical nursing education) to higher education (e.g. registered nurses) (Salminen et al., 2010).

This study focuses on practical nursing education and the concept of healthcare education and utilizes the professional definition of the Finnish National Supervisory Authority for Welfare and Health (2020). Based on this definition, healthcare education can be viewed through the lens of specific professions that carry legal responsibilities and rights.

2.2.2 Vocational education and training and practical nursing education

Vocational education and training (VET) is a multi-dimensional educational system, with a wide variety of approaches to its implementation across Europe alone. (European Centre for Development of Vocational Training, 2022). There are various qualification frameworks and different ways to qualify from certain studies, reinforcing the fact that the contents of the qualifications are not directly comparable (European Centre for Development of Vocational Training, 2021). At the same time there is an existing lack of research in VET, which underlines the need for validated knowledge about learning outcomes (Toepper et al., 2022a).

In Finland, the VET system is guided by the Vocational Education and Training Act (2017) and the Finnish National Board of Education (FNBE), which sets the guidelines for vocational qualifications. VET stands for upper secondary education. In Finland the level of vocational education is level four according to the European Qualification Framework (EQF) (European Union, 2018). VET is usually very competence based, which refers to working life-oriented education. In vocational education there are also varied forms of education, for example apprenticeship training or further vocational qualifications (Vocational Education and Training Act, 2017).

The duration of vocational upper secondary education is usually 2-3 years and is worth 180 competence points. One competence point is equal to a minimum of 12 hours of students' work. All qualifications consist of qualification units, which may include both profession-specific studies and more general subjects, such as mathematics. After graduation, the student can also apply for higher education. (Finnish National Board of Education, 2021.)

Practical nursing education is one of the recognized qualifications within vocational education and training (VET). When students graduate as a practical nurse, it refers to a vocational upper secondary qualification. In Finland a practical nurse is a protected occupational title, which emphasizes the importance of graduation. The Finnish National Board of Education (2021) defines certain qualification requirements that each student must learn. During this study, the valid qualification requirements were from the year 2018.

The volume of practical nursing education in Finland is quite large for the size of the country and over 8,000 students enrol yearly in practical nursing education and around the same number of students graduate as licensed practical nurses (Education Statistics Finland, 2023). However, it is notable that the percentage of students who interrupt their studies is increasing, and over six percent of all students in vocation education and training have interrupted their studies (Statistics Finland, 2022).

During this study, practical nursing students' education consisted of two mutual qualifications units, which were mandatory for everyone. After these two qualification units, the practical nurse students' studies included one of eight competence areas. Every qualification unit included practical training in social and healthcare (Table 1). Practical nursing students' general subjects (for example mathematics) are worth 35 competence points (Finnish National Board of Education, 2021).

Table 1. Description of the mandatory qualification units and competence areas of practical nursing education (Finnish National Board of Education, 2021).

Mandatory qualification units		Competence area to choose from
Promoting growth and participation (25 competence points)		Competence area of nursing and care
		Competence area of care of the disabled
		Competence area of podiatric care
		Competence area of mental health and substance abuse work
Promoting wellbeing and functional capacity (30 competence points)		Competence area of care and rehabilitation for elderly people
		Competence area of basic life support
		Competence area of oral healthcare
		Competence area of children's and youth education and care

After all the studies have been completed, the National Supervisory Authority for Welfare and Health (2020) implements the registration as a licensed practical nurse.

The practical nurses work independently or assist other professionals, such as registered nurses, however, the core focus of the profession is on basic nursing and care, which is most evident in the care of elderly individuals (Roos, 2022). In nursing and care, the primary distinction difference between a practical and registered nurse often lies in their responsibilities related to medication administration (National Supervisory Authority for Welfare and Health, 2024). In Finland alone, the practical nursing profession is expected to face a significant workforce shortage in the future (Koponen, 2015), highlighting the growing pressure to provide high-quality practical nursing education (Lith, 2021). At the same time, like VET in general, there is an imbalance of targeted evidence-based knowledge concerning practical nurses and registered nurses (Goodare, 2017; Flinkman, 2014). For these reasons, the need for evidence-based knowledge about practical nurses and practical nursing education is evident (Roos et al., 2022).

2.2.3 Three-dimensional technology

In general, three-dimensional (3D) technology can be seen as immersive technology, for which the definition is challenging to describe unambiguously (Suh & Prophet, 2018). It can be a technological solution that provides high quantity or quality data to the user thereby stimulating the user's thinking (Namsoy et al., 2024). On the other hand, immersive technology can be defined as a user's immersive experience, while using the technology (Soliman et al., 2017). This experience is usually connected to various virtual realities (Suh & Prophet, 2018).

Similarly to the definition of immersive technology, the definition of 3D technology is unclear due to the multiple different kinds of technological solutions encompassed within the concept (Hackett & Proctor, 2016; Geng, 2013). In general, studies have been defined 3D technologies from the perspective of visualization and interaction (Geng, 2013), but also from the perspective of technology itself (Namsoy et al., 2024).

Basically, the definition of 3D technology can be seen as a technology, which utilizes monoscopic, stereoscopic or autostereoscopic methods to display the content. With a monoscopic display, the user can experience an object in three dimensions without using any specific technological tools (e.g. 3D-glasses), while these are needed for stereoscopic viewing. With the autostereoscopic method, the user can utilize multiple technological solutions to experience the object fully in three dimensions. Autostereoscopic methods include 3D printing (Hackett & Proctor, 2016; Geng, 2013.) This study defines the concept of 3D technology to include following technology: 3D image (Takimoto, 2023), 3D environments (Özkal & Kiliçer, 2022), 3D holograms (Sun et al., 2024) and 3D printing (Benham et al., 2024).

3D images are images that the user can see in three different dimensions, and the user may move the 3D image in different directions (Geng, 2013). The idea of a 3D hologram is basically the same, but the hologram is created using lasers (Yan et al., 2024).

3D environments include 360-degree environments, virtual reality (VR), augmented reality (AR), mixed reality (MR), extended reality (XR) and the metaverse. Moreover, more specifically VR means that user is partly or fully surrounded by the virtual environment, and the user can interact with the environment (Kilmon et al., 2010). AR means, that the user can utilize virtual elements in a real-life environment, for example the user can see some virtual elements in a real-life environment (Magi et al., 2023). MR utilizes elements from VR and AR (Kim et al., 2024). XR is kind of umbrella term, which covers VR, AR and MR for all kinds of reality (Davies et al., 2020), and metaverse stands for a virtual entity or platform which can include social communities which interact in the metaverse (Cho et al., 2024).

3D printing means that the user can print a concrete and individually designed object and touch and feel it (Javaid et al., 2022). To print, the user needs to have a 3D model, which in practice means a designed 3D image (Üçgül & Altıok, 2023).

In a pedagogical context, 3D technology has been studied in various fields in science, technology, engineering, arts and mathematics (STEAM) education (Staribratov & Manolova, 2024). Some studies have found that implementing 3D technology can be challenging because it has been unclear how and why the tools should be adapted to education (Thyssen & Meier, 2023), while in some cases, feelings of competence have been lacking (González-Martínez et al., 2019). This indicates a lack of structural planning, which a theoretical approach can offer (Thyssen & Meier, 2023). The usage of the 3D technology in education can be seen as purposeful, because of its promising outcomes in the education field (Staribratov & Manolova, 2024). More specifically, 3D technology has been studied as an effective tool for improving learning outcomes (Sun et al., 2024; Yammine & Violato, 2015), increasing satisfaction with learning (Üçgül & Altıok, 2023), and enhancing motivation in learning (Carrera et al., 2018).

This study utilizes the definition of 3D technology to include the following technology: 3D images, 3D environments, 3D holograms and 3D printing. Nevertheless, it is important to note that available resources can affect the ability to utilize this technology. For this reason, this study did not utilize 3D holograms in the intervention (Paper III and IV).

2.3 Literature about the 3D technology in healthcare education

2.3.1 Literature search

The purpose of the literature search was to describe relevant studies regarding the use of 3D technology in nursing education. Since 3D technology is commonly considered a component of immersive technologies, this literature review examines its use within the broader context of immersive technology. With this method, the literature review can present how 3D technology has been defined in pedagogical contexts where immersive technology has been utilized. Finally, this literature search aims to also describe the possible outcomes that are related to the technology used. The research questions for the literature search were following:

1. How have different kinds of immersive technologies been used in healthcare education?
2. How have different kinds of 3D technology been used in healthcare education?
3. What kinds of outcomes are related to the usage of 3D technology in healthcare education?

At the beginning, this study utilized the PICO-process to identify the inclusion and exclusion criteria (CDR, 2009). A Boolean operator was used in the literature search (Table 2).

Table 2. Inclusion and exclusion criteria.

PICO	Inclusion criteria	Exclusion criteria
P(opulation)	Following healthcare professions: practical nurse, registered nurse, osteopath, dental hygienist, dental technician, medical technologist, midwife, naprapathy, occupational therapist, optician, paramedic, physical therapist, podiatrist, prosthetist, public health nurse, radiographer or rehabilitation counsellor AND undergraduate student.	Students in continuing education or post grad students. Medical students.
I(ntervention)	Immersive technology and 3D technology	Technological tool, which has no relation to immersive or 3D technology.

C(ontext)	Healthcare education.	Other educational contexts. Patient education.
O(utcome)	Outcomes related to the learning	-

The search was implemented in four international databases: Eric (Ebsco), Cinahl (Ebsco), PubMed (Medline) and the Cochrane Library (Wiley). The search was limited to research articles, English language, and the availability of the abstract. There were no year limitations in this search.

The literature search was carried out in October-November 2024. After duplicates 658 articles were identified. First the headlines were screened. After this, the abstracts were screened. 576 articles were excluded, and the full text of 82 were screened. The excluded articles (n=576) concerned, for example patient education, immersive waterbirth, clinical immersion or cultural immersion. In the full text analysis 48 articles from 82 were excluded for the following reasons: the study included medical students (n=18), the study included clinical professionals or patients (n=12), the immersion was not connected to any technological intervention or solution (n=11), the context was not related to healthcare (n=4) or the study included another educational context (for example engineering) (n=3). The final data in this literature review included 34 articles.

The selected articles were analyzed using a narrative and thematic approach, because of its flexible structure (Sukhera, 2022). With a narrative analysis, the literature review could also assemble the literature first with descriptive content (e.g. basic knowledge about the articles) and then logically describe the elements concerning the research questions (Arksey & O'Malley, 2005).

The selected studies were from 15 different countries, with a predominant representation from the Republic of Korea (n=10). The studies were published in the period 2009-2024, although nearly all were published in or after the year 2020 (n=32) and several studies represented the newest information were published in the year 2024 (n=14). In empirical studies the participants were nursing students or nursing and midwifery students. One study included dental hygienist students as well. Overall, the most used designs were either quasi-experimental or experimental designs (n=10), cross-sectional surveys studies (n=9) or varying literature reviews (n=6). (Table 3.)

Table 3. Overview of selected studies.

Country	Reference
Republic of Korea (n=10)	Cho & Kim, 2024, Cho et al., 2024, Kim et al., 2024, Lee et al., 2024, Lee & Han, 2022, Moon et al., 2024, Park & Kim, 2022, Park et al., 2024, Yang & Oh, 2024, Yeun et al., 2020
USA (n=6)	Brown et al., 2023, Chike-Harris et al., 2020, Farra et al., 2018, Stewart et al., 2009, Willett et al., 2024, Woodworth, 2022
Australia (n=3)	Cant et al., 2022, Hanson et al., 2019, Hanson et al., 2020
England (n=2)	Logeswaran et al., 2021, Mather & McCarthy, 2021
Spain (n=2)	Cruz-Barrientos et al., 2024, García-Pazo et al., 2023
Brazil (n=2)	Domingues et al., 2022, Girão et al., 2021
Scotland (n=1)	Dall et al., 2020
Finland (n=1)	Mattsson et al., 2024
Canada (n=1)	Bally et al., 2024
Germany (n=1)	Pfeifer et al., 2024
Ireland (n=1)	Ryan et al., 2022
China (n=1)	Liu et al., 2024
Taiwan (n=1)	Yang et al., 2022
Italy (n=1)	Magi et al., 2023
Singapore (n=1)	Woon et al., 2021
Study design	**Reference**
Quasi-experimental or experimental studies (n=10)	Bally et al., 2024, Brown et al., 2023, Cho & Kim, 2024, Kim et al., 2024, Lee et al., 2024, H. Lee & Han, 2022, Mather & McCarthy, 2021, Moon et al., 2024, Yang & Oh, 2024, Woodworth, 2022
Cross-sectional survey studies (n=9)	García-Pazo et al., 2023, Girão et al., 2021, Chike-Harris et al., 2020, Cruz-Barrientos et al., 2024, Dall et al., 2020, Hanson et al., 2020, Park & Kim, 2022, Yang et al., 2022, Yeun et al., 2020
Mixed methods (n=3)	Farra et al., 2018, Hanson et al., 2019, Ryan et al., 2022
Qualitative interview studies (n=3)	Domingues et al., 2022, Liu et al., 2024, Mattsson et al., 2024
Literature review (n=6)	Cant et al., 2022, Cho et al., 2024, Logeswaran et al., 2021, Magi et al., 2023, Park et al., 2024, Woon et al., 2021,
Study report (n=3)	Pfeifer et al., 2024, Stewart et al., 2009, Willett et al., 2024

2.3.2 The usage of different immersive technologies in healthcare education

The usage of immersive technologies in healthcare education was multiple. Moreover, there was a clear dominance of different kinds of virtual immersive environments. These virtual immersive environments also included mixing these environments, for example virtual and augmented reality might be mixed. Other immersive technologies involved 360-degree images and videos, 3D images, telehealth and simulations tools, video-solutions and computer-based simulators (Table 4).

Table 4. Overview of different immersive technologies.

Immersive technology	Reference
Virtual reality, augmented reality, mixed reality, extended reality or metaverse (n=23)	Brown et al., 2023, Cant et al., 2022, Cho & Kim, 2024, Cho et al., 2024, Farra et al., 2018, García-Pazo et al., 2023, Girão et al., 2021, Kim et al., 2024, Lee et al., 2024, H. Lee & Han, 2022, Liu et al., 2024, Logeswaran et al., 2021, Magi et al., 2023, Mattsson et al., 2024, Moon et al., 2024, Park & Kim, 2022, Park et al., 2024, Pfeifer et al., 2024, Ryan et al., 2022, Stewart et al., 2009, Willett et al., 2024, Woon et al., 2021, Yang & Oh, 2024
360-degree image or video (n=3)	Pfeifer et al., 2024, Woodworth, 2022, Yang et al., 2022
3D images (n=3)	Hanson et al., 2019, Hanson et al., 2020, Dall et al., 2020
Telehealth-tools (e.g. videoconferencing) or telesimulation (webcam, microphone and computer screen) (n=3)	Bally, et al., 2024, Domingues et al., 2022, Chike-Harris et al., 2020
Different video-facilitations in simulations (n=2)	Mather & McCarthy, 2021, Yeun et al., 2020
Case-based computer simulator (n=1)	Cruz-Barrientos et al., 2024

In healthcare education, the usage of immersive technologies involved fully virtual simulations (Cruz-Barrientos et al., 2024; Cho & Kim, 2024; Brown et al., 2023). Immersive technologies were also used in the simulations to make the environment more realistic with emergency sounds and sights (Mather & McCarthy, 2021). In addition to their use in simulations, immersive technologies were also utilized for gaming (Dall et al., 2020), with lecturing (Bally et al., 2024) or in some part of the course for individual teaching tools or methods (Chike-Harris et al., 2020).

Immersive technologies in healthcare education have been implemented with the use of a number of theoretical frameworks. The utilized theoretical frameworks involved: Kolb's experiential learning theory (Cho & Kim, 2024; Yang & Oh, 2024; Willett et al., 2024; Domingues et al., 2022), Jeffrey's Simulation Theory (Kim et al., 2024; Brown et al., 2023), Layered Learning Theory (Moon et al., 2024), Ericsson's educational theory of deliberate practice (Brown et al., 2023) and the Nursing Education Simulation Framework (Willett et al., 2024). In this case, it is notable that TPACK or TAM were not utilized in the articles that were included in this literature search. The immersive technologies were used mostly as a part of some form of simulation pedagogy (Cant et al., 2022).

2.3.3 The usage of 3D technology in healthcare education

Under half of the studies (n=15) in this literature review reported 3D technology as an immersive technology in healthcare education. In these studies, the definition of immersive technology was clearly defined as 3D technology (Geng, 2013). The use of 3D technology was associated with virtual immersive environments, specifically virtual reality, augmented reality and mixed reality (Brown et al., 2023), as well as 360-degree environments (Yang et al., 2022), or 3D images (Dall et al., 2020) (Table 5).

Table 5. The usage of 3D technologies.

Usage of 3D technology	References
Virtual reality, augmented reality, mixed reality (n=11)	Willett et al., 2024, Park et al., 2024, Mattsson et al., 2024, Moon et al., 2024, Brown et al., 2023, Magi et al., 2023, Ryan et al., 2022, Park & Kim, 2022, Woon et al., 2021, Farra et al., 2018, Stewart et al., 2009
3D images (n=3)	Hanson et al., 2019, Hanson et al., 2020, Dall et al., 2020
360-degree images (n=1)	Yang et al., 2022

The implementation of 3D technology in healthcare education also included the utilization of theoretical frameworks. Firstly, the implementation concerned simulation pedagogy (Moon et al., 2024; Willett et al., 2024; Brown et al., 2023). Moon et al. (2024) utilized Layered Learning Theory in the simulation of coronary artery disease patient treatment. Secondly, Willet et al. (2024) utilized Kolb's experiential learning theory with the cycle of learning and the Nursing Education Simulation Framework to discuss and describe different simulation cases, in which 3D technology was found to be useful. Thirdly, Brown et al. (2023), implemented simulation pedagogy in a nursing students' curriculum utilising Jeffreys' Simulation Theory. Similarly to the immersive technologies, there were no articles that would have described the utilization of TAM or TPACK.

2.3.4 The outcomes related to the usage of 3D technology in healthcare education

This study found that 3D technology was connected to both positive learning outcomes as well as enhanced emotional outcomes in healthcare education. Regarding improved learning outcomes in healthcare education, a link was found to various types of 3D virtual environments (virtual reality, augmented reality and mixed reality), 3D images and 360-degree images. Improved emotional outcomes in healthcare education were related to different types of 3D virtual environments (virtual reality, augmented reality and mixed reality) and 3D images (Table 6).

Table 6. Improved outcomes, that were related to 3D technology.

Learning outcome	**References**
Knowledge (n=3)	Hanson et al., 2019, Moon et al., 2024, Woon et al., 2024
Self-efficacy (n=1)	Moon et al., 2024
Clinical-skills (n=1)	Hanson et al., 2020
Self-confidence (n=1)	Moon et al., 2024
Emotional outcome	**References**
Satisfaction (n=3)	Hanson et al., 2020, Park & Kim, 2022, Ryan et al., 2022
Positive experience (n=5)	Brown et al., 2023, Ryan et al., 2022, Dall et al., 2020, Farra et al., 2018, Stewart et al., 2009
Self-reported feeling of learning (n=1)	Farra et al., 2018
Feelings of empathy (n=1)	Mattsson et al., 2024

2.3.5 Conclusion of the literature review

As a conclusion of this literature review, there many immersive technologies used in healthcare education. Although the studies focused solely on nursing and/or midwifery education, it appears that immersive technology has strong potential for use in teaching and learning in healthcare education. This can be seen in the use of 3D technology (Hanson et al., 2019). Alongside the growing number of studies on 3D technology, various types of virtual environments demonstrated a strong prevalence. This refers to a one-sided understanding of the technology and awakens the question about research into other 3D technologies; 3D images, 3D holograms and 3D printing. Finally, an interesting observation was the scarcity of theoretical frameworks in studies involving 3D technology, reflecting the same lack of structural planning noted by Thyssen and Meier (2023) in their study.

According to this literature review, the concept of 3D technology faces challenges in terms its definition. There were studies, that used terms such as “virtual worlds”, “virtual patients”, and “virtual simulations” without defining the technology as 3D technology (Cant et al., 2022; Logeswaran et al., 2021; Stewart et al., 2009). The same issue was noticed also for terms such as “virtual reality”, “augmented reality”, “mixed reality”, “extended reality" and “metaverse.” There is of course the possibility that these technologies are not 3D, but the contents (for example using certain types of display technology) of the articles refer strongly to the usage of 3D technology. This conclusion highlights the same issue raised by Kardong-Edgren et al. (2019) regarding the use of unclear definitions of virtual reality across varying contexts. If the definition of 3D technology is taken for granted, future research may be too unclear to implement, or the validation could face a lot of questions.

The general conclusion of this literature review finds that future research should be focused on a detailed definition of 3D technology. Moreover, there is a lack of research examining 3D technology as a distinct entity within healthcare education. No studies included more than one type of 3D technology, which may limit healthcare educators’ perspectives on the potential applications and uses of 3D technology in teaching and learning. Finally, the literature review highlights the need for research at the level of VET. For these reasons, this research aims to explore the use of 3D technology including various technological solutions in vocational education for practical nursing. This is particularly relevant, as practical nurses are expected to use different technologies in their professional practice, and early exposure during their studies may facilitate future adaptation to such technologies.

3 Purpose of the study and research questions

In this chapter, the study purpose was presented. The main purpose of this two-phased study was to analyse the pedagogical usage of 3D technology in healthcare education at the level of vocational education and training and the learning outcomes. Based on this knowledge, an intervention involving the use of 3D technology in healthcare education was developed and implemented (Figure 2).

The purpose of PHASE I was to analyse the pedagogical use of 3D technology in healthcare education at the level of vocational education and training and develop and implement an intervention of the 3D technology for students in healthcare education. PHASE I included two sub studies. The research questions of this phase were:

1. What kinds of pedagogical contexts and outcomes are related to the use of 3D technology in healthcare education? (Paper I)
2. How do healthcare teachers self-assess the use of 3D technology in healthcare education? (Paper II)

The purpose of the PHASE II was to analyze the outcomes (technology acceptance and learning outcomes) of an intervention in healthcare education for practical nursing students. PHASE II included two sub studies. The research questions of this phase were:

1. How do practical nursing students' self-asses their technology acceptance after using 3D technology in healthcare education? (Paper III)
2. What kinds of learning outcomes are related to the use of 3D technology in healthcare education? (Paper IV)

The overall goal was to produce new knowledge about the use of 3D technology in healthcare education, enabling educators to evaluate its pedagogical potential to enhance teaching and learning in the field.

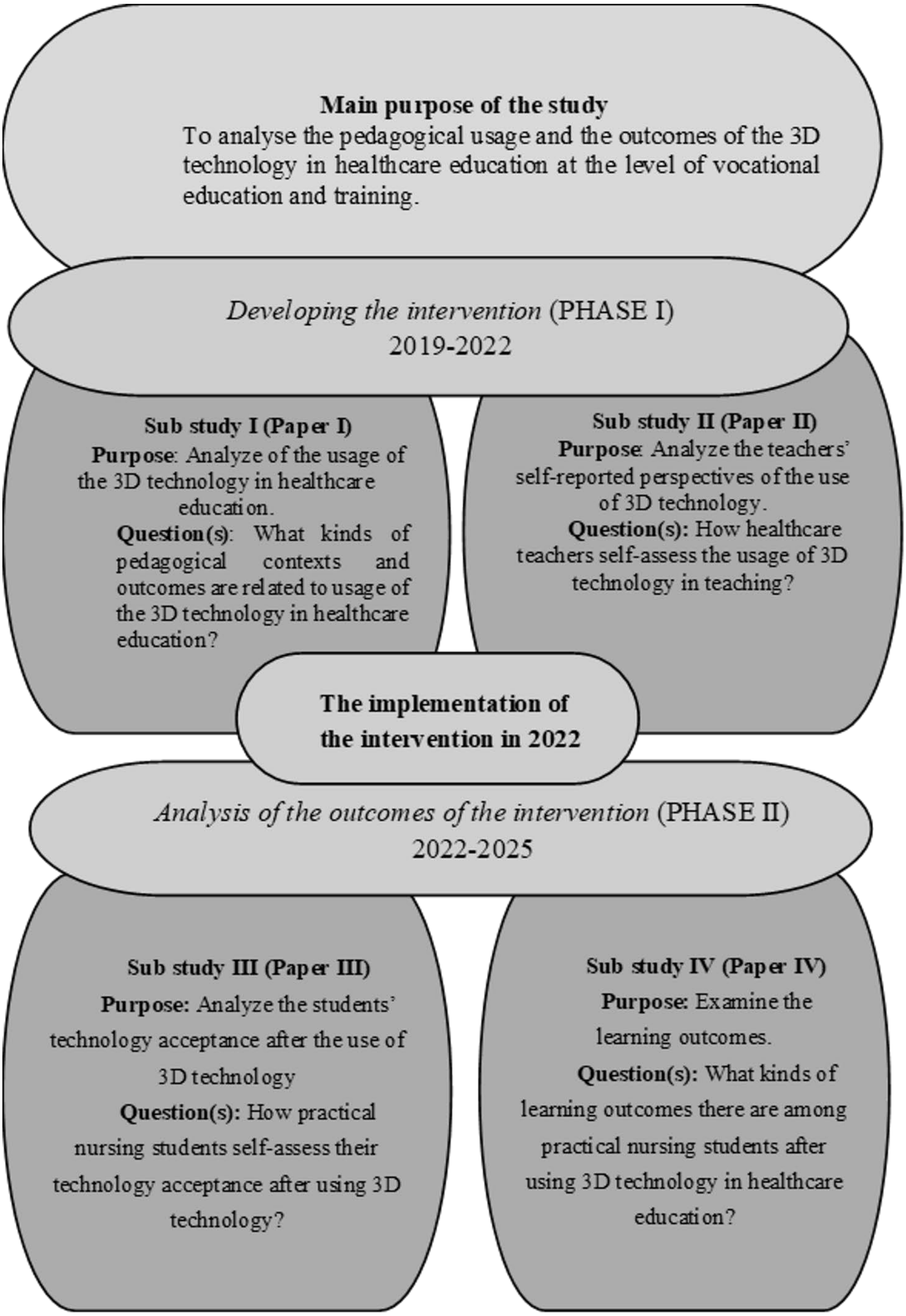

Figure 2. The overview of the purposes of the study.

4 Materials and methods

This chapter presents the materials and methods used in the study, including the study design, setting and samples, data collection, data analysis, and ethical considerations. Multiple methods and designs were used in the different phases of the study. An overview of the design and methods used can be found in Table 7.

Table 7. Overview of the designs and methods used across the study.

Phase	Paper (time)	Study design	Sample	Data collection (Instrument)	Data analysis
Ⅰ Developing the intervention	Ⅰ (2019-2020)	Scoping review	31 articles	Literature search	Narrative and thematic approach
	Ⅱ (2021-2022)	Mixed method Theoretical framework of TPACK	Healthcare teachers in individual interviews (n=17) and a survey (n=55)	Individual interview TPACK-deep	Deductive thematic Descriptive statistics, Cronbach's alpha, Shapiro Wilk test, Tukey's HSD test, Tukey-Kramer adjustment, 2-smaple t-test
Ⅱ Analysis of the outcomes	Ⅲ (2022-2024)	Mixed method Theoretical framework of TAM	Practical nursing students (n=32)	Focus group interviews TAM2 (pre, post)	Content analysis Descriptive statistics, Cronbach's alpha, Shapiro Wilk test, Paired Sample T-Test, Wilcoxon Signed-Ranks
	Ⅳ (2022-2024)	Quasi-experimental framework	Practical nursing students (n=59)	Knowledge test (pre, post, follow up) Observation tool (post)	Descriptive statistics, Shapiro Wilk test, Press and Cook's D statistics, The repeated measure analysis, Mann-Whitney U test, Logistic regression
Summary of the result	Summary		All the findings relating previous studies		

4.1 Study design, setting and sample

PHASE Ⅰ, *The development of the intervention*

The purpose of PHASE I was to analyse the pedagogical usage of 3D technology in healthcare education at the level of vocational education and training and develop and implement an intervention involving 3D technology for students in healthcare education. This phase included two different sub studies: sub study I (Paper I) and sub study II (Paper II).

The first sub study aimed to describe the pedagogical contexts and possible outcomes of using 3D technology in healthcare education. Because of the new and rare nature of the concept (3D technology), it was important to include a wide scope from the relevant literature to fulfil the aims of the study. Because of this, the study was conducted with a scoping review focusing on the pedagogical contexts and outcomes related to usage of the 3D technology in healthcare education.

The scoping review design was implemented in the year 2019-2020. The framework for the review was based on Arksey & O'Malley's (2005) framework for scoping reviews. The inclusion and exclusion criteria were created with PICO to identify a clear structure for the research (CDR, 2009). The literature search was targeted only at healthcare education, excluding medical education. The articles also had to include a clear description of 3D technology, because of the existing conflicts over the use of the concept (Kardong-Edgren et al., 2019). In total 427 articles were identified and a sample of 31 articles met the final inclusion criteria. (Paper I.)

The second sub study aimed to analyse the self-reported perspectives of healthcare teachers about their technological pedagogical content knowledge concerning 3D technology (Mishra & Kohler, 2006). This study was implemented using a mixed methods design in 2021 and it included a survey and semi-structured individual interviews. The TPACK approach was used as the theoretical framework of the study, which created a pedagogical structure for the study (Mishra & Kohler, 2006).

Before the data collection, ethical permission was granted from the Ethics Committee for Human Sciences at the University of Turku (21/2020). The data was collected from healthcare teachers working in practical nursing education from 11 vocational institutes in Finland. Each vocational institution named the contact person who organized information about the study for the teachers. The contact person also sent the link to the survey and organized the participation in the interviews. In total 357 teachers were invited to participate in the study, 55 answered the survey, and 17 of those participated in the semi-structured interviews. The same researcher implemented each interview. (Paper II.)

PHASE Ⅱ, *The analysis of the outcomes of the intervention*

The purpose of PHASE II was to analyse the outcomes (technology acceptance and learning outcomes) of an intervention in healthcare education for practical nursing students. This phase included two different sub studies: sub study III (Paper III) and sub study IV (Paper IV).

The third sub study (Paper III) aimed to analyse the technology acceptance of practical nursing students on a first aid course after using 3D technology. This sub study was implemented using a mixed methods design within the theoretical framework of the Technology Acceptance Model (TAM) (Venkatesh & Davis, 2000).

The fourth sub study aimed to examine the learning outcomes of practical nursing students after using 3D technology during a first aid course. This sub study was implemented with a quasi-experimental design (Paper IV).

Both studies were implemented at the same vocational institute of practical nursing education. The vocational institute was chosen because of its wide educational influence in Finland. The students of the intervention group (sub study IV) were the same students who participated in sub study III which assessed their technology acceptance. The students were in their own groups to guarantee a familiar environment to study in and because their curricula were planned according to the vocational institute's regulations. Both studies were implemented during first aid courses, which lasted altogether 16 hours per group (two consecutive days). The content of the first aid course (according to the curriculum) was the same for each group and followed the national skills requirements (Finnish National Board of Education, 2021). Due to the absence of two practical nursing students (n=2), the final sample size was 30. All practical nursing students received first aid courses involving the use of the following 3D technology: 3D images, a 3D environment and 3D printing To be included in the third and fourth studies, participants had to meet the following criteria: (1) be first-year practical nursing students, and (2) have volunteered to participate.

The third sub study (Paper III) was implemented with a total sample of 32 (N=32) practical nursing students from two different groups (n=13 and n=19). The mixed methods design included a pre- and post-survey and a focus group interview after one month from the end of the first aid course (Table 8).

In the fourth sub study a total sample of 59 (N=59) practical nursing students were invited to the study. The participants were divided into two intervention groups (n = 13 and n = 19) and two control groups (n = 11 and n = 16). For the analysis phase, these were combined into a single intervention group (n = 32) and a single control group (n = 27). The learning outcomes were determined using a knowledge test and cardiopulmonary resuscitation (CPR) skills test (Table 8). Six practical nursing students (n = 6) opted out of the CPR skills test, resulting in final sample sizes of 59 participants for the survey (n = 59) and 53 for the CPR skills test (n = 53). Those students, who did not participate in the CPR skills test did not have announce any reason for declining. The reason for declining the test may be connected to the potential stress caused by the test, even though the skills test was planned to be as free as possible. The practical nursing students in the intervention group were the same students as in the third sub study (Paper III). There were no randomizations in this study. The students in the intervention group received teaching with the intervention (3D technology) and the students in the control group received teaching in the traditional way (basically lecturing and using PowerPoint-slides). The amount of first aid training was the same for the students in the intervention and control group (Paper IV).

4.2 Description of the intervention

The chosen focus for the intervention was a first aid course, for the following reasons: 1) it is a structured course with clear learning aims, and 2) it includes both theoretical and skills-based (competence) learning aims (Table 8).

Table 8. Description of the aims and the content of the first aid course.

Learning aims of the first aid course (Finnish National Board of Education, 2021)	
First day (eight hours of teaching): Learn: 1) how to react in first aid situations, 2) how to work in traffic incidents, 3) how to give first aid to an unconscious person, 4) how to resuscitate a patient	*Second day (eight hours of teaching):* Learn: 1) how to stop bleeding, 2) how to give first aid in different sudden attacks, 3) how to give first aid for strains and bone fractures

The intervention in this study involved the use of 3D technology in practical nursing education during the first aid course, which was implemented twice during PHASE II due to the small number of practical nursing students in one group (Table 10). During that same period data from the control group was collected. The intervention was based according to the results of PHASE I, where the usage and outcomes of 3D technology were examined (Table 9).

Table 9. Intervention implementation and data collection.

2022				
January	**February**	**March**	**April**	**May**
First implementation of the intervention (two consecutive days).	Focus group interviews (sub study Ⅲ).		Second implementation of the intervention (two consecutive days).	Focus group interviews (sub study Ⅲ).
TAM2-survey (sub study Ⅲ) Before the course and at the end of the course.	Follow-up knowledge test (sub study Ⅳ).		TAM2-survey (sub study Ⅲ) Before the course and at the end of the course.	Follow-up knowledge test (sub study Ⅳ).
Knowledge test (sub study Ⅳ) Before the course and at the end of the course.			Knowledge test (sub study Ⅳ) Before the course and at the end of the course.	
CPR skills test (sub study Ⅳ) At the end of the course.			CPR-skill test (sub study Ⅳ) At the end of the course.	

The final content of the used intervention was modified to match the learning programme of the vocational institute. The concrete 3D tools used in the intervention were: 3D images, a 3D environment, and 3D printing. The use of these 3D tools was planned separately for each learning aim of the first aid course. In line with established scientific practice, the intervention is detailed using the TIDieR checklist (Figure 3), as recommended by Hoffmann et al. (2014).

Using 3D technology to teach first aid in practical nursing education

1)Why, 2) What, 3) Who, 4) Where and 5) How much entirely

The intervention was given to practical nursing students to improve learning outcomes.

During the intervention, the practical nursing students used 3D images, 3D environments and 3D printing and the intervention was implemented for all subjects as part of the first aid course's content.

All technologies were the property of practical nursing students' own institute.

The duration of the first aid course was 16 hours (two consecutive days).

6) How much and 7) How it was tailored

3D images: Sudden attacks. Students utilized a television, which was capable of displaying interactive 3D images of human organs. While utilizing this the students discussed the topic with guiding questions. The total duration was three hours.

3D environment (360° environment with mobile devices): Wound care and accidents in traffic. Varying 360° environments were created, which students used with mobile devices. While utilizing them, the students discussed about the topic with guiding questions. The total duration was three hours (including two hours of practice).

3D environment (360° environment with glasses and hand controls): Resuscitation, shock and unconsciousness. Students interacted with different cases in a 3D environment. After interaction, they discussed the cases with each other. The total duration was five hours (including three hours of practice).

3D environment (augmented reality): Heart attack. The students examined the heart anatomy with glasses and determined the reason for a heart attack. The total duration was two hours.

3D printing: bone fractures and strains. The researcher 3D printed several objects with fractures (for example a radius with a fracture). The students discussed the fracture and the correct first aid for it. They also used an active 3D printer, which was printing objects during the students' discussions. The total duration was three hours.

8) Modification and 9) How well

All students, who received the intervention, received it without modification.
The intervention was evaluated in terms of knowledge (pre, post and follow-up) and skills (post).

Figure 3. Content of intervention according to the TIDieR checklist (Hoffmann et al., 2014) (modified from Paper IV).

4.3 Data collection

PHASE I, *The development of the intervention*

The data collection in PHASE I was conducted using the following methods: 1) a literature search (sub study I), and 2) a survey and individual interview (sub study II).

In the first sub study, the search was conducted in seven different scientific databases: Cinahl (Ebsco), Pubmed (Medline), Eric (Ebsco), APA PsychInfo (Ebsco), Cochrane Library (Wiley), Teacher Reference Center (Ebsco) and Education Research Complete (Ebsco). The only limit beside the inclusion and exclusion criteria was that the literature had to be written in English.

All records were evaluated by two independent researchers according to the inclusion and exclusion criteria made with PICO (CDR, 2009). The search terms were developed in collaboration with the university's information specialist, with the aim of capturing a broad scope of undergraduate healthcare education—excluding medical education (Paper I).

In the second sub study, the survey was implemented with a TPACK-deep questionnaire, which is a 5-point Likert scale instrument with together 33 statements in the four following categories: design, exertion, ethics, and proficiency (Kabakci Yurdakul et al., 2012). Before implementation, permission to utilize the questionnaire was sought by the publisher and the questionnaire was back-translated into Finnish (Sousa & Rojjanasrirat, 2011). Four open-ended questions were added to the instrument, which described the usage of 3D technology in general. Two additional background questions were asked: the participants' years of teaching experience and whether they had used 3D technology (yes or no). Before implementation, the questionnaire was pre-tested with seven teachers in a different vocational institute. According to the feedback some re-wording was made to make the questionnaire more understandable. In the actual data collection, 55 teachers out of 357 answered (a 15% response rate) the questionnaire via a ©Webropol link they received from the organization (©Webropol, 2021, University of Turku, Finland). The teachers also answered to open-ended questions and finally there were totally 68 different written answers. In addition to the questionnaire, there were 68 open-ended answers from healthcare teachers. There was no sociodemographic data (age or gender) collected, because it was evaluated irrelevant for this study. The researcher sent two reminder emails. (Paper II.)

Besides the survey in second sub study, semi-structured individual interviews (n=17) were implemented with the aim to focus on teachers' perspectives of TPACK concerning using 3D technology in their own teaching. The four dimensions of TPACK deep (design, exertion, ethics, and proficiency) guided the interviews

(Kabakci Yurdakul et al., 2012), which were implemented either face-to-face (n=2) or with Zoom-tool (n=15). Teachers were also asked general questions about using 3D technology in their teaching (for example benefits and challenges). All interviews were recorded with voice (not picture in Zoom-tool) and written in Word format soon after the interviews (Paper II).

PHASE Ⅱ, *The analysis of the outcomes of the intervention*

The data collection in PHASE II was conducted using the following methods: 1) a TAM2-survey and focus group interviews (sub study III), and 2) a knowledge test and observation tool (sub study IV) (Table 9).

In the third sub study, the survey was conducted with practical nursing students (n=32) before (pre) and at the end (post) of a first aid course. The aim of the survey was to assess the possible change in students' technology acceptance after they had used 3D technology during their first aid courses. The survey was implemented with an extended Technology Acceptance Model (TAM2)-questionnaire. TAM2 is a Likert-scale (1=strongly disagree to 7=strongly agree) instrument, divided into the following nine categories: "intention to use", "perceived usefulness", "perceived ease of use", "subjective norm", "voluntariness", "image", "job relevance", "output quality" and "result demonstrability" (Venkatesh & Davis, 2000). Before implementation, the permission to use the instrument was sought from the licenced publisher and back-translated into Finnish (Sousa & Rojjanasrirat, 2011). The translated instrument was pre-tested among 15 (n=15) practical nursing students its clarity and understandability. According to the pre-testing, a few sentences were re-worded. In the actual data collection, the students answered the questionnaires with a personal code and paper and pencil. The final survey's data included 30 (n=30) pre-answers and 28 (n=28) post-answers. (Paper III.)

The focus group interviews in third sub study were conducted one month after the first aid course among 30 (n=30) practical nursing students. The aim of the focus group interviews was to deepen the understanding of the students' technology acceptance after they had used 3D technology during their first aid course. The students were divided in five focus groups with five to seven students in each group. The Technology Acceptance Model (Venkatesh & Davis, 2000) guided the interviews covering the following scales: perceived usefulness, perceived ease of use, and job relevance. All interviews were recorded and written in Word format soon after the interviews (Paper III).

In the fourth sub study a knowledge-test was conducted about first aid content , which was based on the content of the international first aid, resuscitation and education guidelines (2020). The test included 30 questions, six choices to answer with one correct answer. The value of a correct answer was 1 and the value of an incorrect answer was 0. The practical nursing students in the intervention and control groups answered the knowledge test before the first aid course (pre), when the course ended (post) and one month after the first aid course (follow-up). The number of answers at each time point are shown in Table 10. (Paper IV.)

Table 10. The number of the students taking the knowledge test.

Time point of the knowledge test	Students (n=) in intervention groups	Students (n=) in control groups
Pre	32	27
Post	30	24
Follow-up	30	24

The observation tool in sub study IV included observations and data from the CPR-manikin. Each practical nurse student (N=53) divided into intervention groups (n=29) and control groups (n=24) performed a two-minute CPR-test with a manikin. Each student made the test at the end of the first aid course. The observation tool was created according to the international guidelines for resuscitation (Olasveengen et al., 2021) and included a certain protocol that students need to follow in a certain order. The observation tool consisted of ten performances that students either managed correctly or incorrectly (for example "the student tries to wake the victim: yes or no). Six performances were observed by the researcher and four performances were based on the CPR-manikin's data (for example the student releases the chest 100% after each compression: yes or no). The value of a correct performance was 1 and the value of an incorrect performance was 0.There were no pass or fail limits (Paper IV.)

4.4 Data analysis

PHASE Ⅰ, *The development of the intervention*

The data in the first sub study was analyzed according to the framework developed by Arksey & O'Malley (2005) for scoping reviews. The final sample of 31 (n=31) articles were screened carefully. Narrative and thematic approaches were used to data analysis. Firstly, the narrative approach was utilized and the publications' general information was organized: the study design, country, the type of article and the educational perspective. Secondly, the thematic approach was utilized and all articles were categorized into categories that described: what 3D technology was used, what the pedagogical contexts were, and what the outcomes were of using 3D technology in healthcare education. (Paper I.)

The data in the second sub study was analyzed in two different ways. The data from the survey was analyzed with a statistical analysis and the data from semi-structured individual interviews were analyzed using a deductive thematic analysis (Paper II).

The survey data was analyzed using SAS Enterprise Guide 7.1 statistical software. The data (n=55) was analyzed according to the TPACK framework's four categories (design, exertion, ethics, and proficiency) with two background variables (experience in years and usage of 3D technology/yes or no). First, the TPACK-deep framework's reliability was analyzed with Cronbach's alpha and its confidence interval together with inter-item correlations. Secondly, the experience in years used as a background variable was regrouped, because of the small number of answers in some of the experience groups. The final experience groups were the following: 0-5 years, 5-10 years and over 10 years. The normality of the background variables was analyzed with a plot review and from significant key statistical figures including the p-value of a Shapiro-Wilk test for normality. The analysis to explain the dependent sum variable created from the TPACK-deep answers was made one by one against the background variables. To analyse the relation between the TPACK-deep responses and the teacher's experience, an analysis of variance procedure (ANOVA) was utilized with a Tukey's HSD test and Tukey-Kramer adjustment. Beside this, the relation between the response of TPACK-deep and the usage of 3D technology was analysed with a 2-sample t-test.

According to the analysis of each response in the TPACK-deep framework, for each category the calculated reliabilities were 0.84 or higher (Cronbach's alpha). The confidence intervals were also high enough, and the same as the correlations between categories' items. This showed that the instrument was reliable enough and the items within it had relatively high internal consistency. Afterwards, the total scores for each questionnaire category were calculated and converted into mean values. This was used to create the sum variable. Finally, analysing the normality of variables a plot review and significant key statistical figures, including the p-value of a Shapiro-Wilk test, were utilized. This showed that all variables in each category were normally distributed.
(Paper II.)

In Paper II, the semi-structured individual interviews and open-ended responses were combined and analyzed deductively using a thematic analysis, based on the TPACK framework (Mishra & Koehler, 2006) and its categories: design, exertion, ethics, and proficiency. The thematic analysis followed a process that included five stages: compilation, disassembly, reassembly, interpretation, and conclusion. In the compilation stage, the voice-recorded data was transcribed into a written format, before the actual coding happened in the disassembly stage. Coding started by creating meaning units according to the TPACK framework. After that the data was coded according to the TPACK's categories of: design, exertion, ethics and proficiency. In the reassembly phase, the themes and subthemes were created deductively according to similarities between the categories. In the interpretation phase, the researcher made a thematic map, which aimed to justify the relations between the themes and subthemes in the TPACK categories. Finally, in the conclusion phase, themes and subthemes finalised and the researcher viewed the analysis as an entity. In this phase direct quotes from the data were also added to the text (Castleberry & Nolen, 2018; Erlingsson & Brysiewicz, 2017).

PHASE Ⅱ, *The analysis of the outcomes of the intervention*

The data analysis in sub study III was conducted with statistical methods (TAM2-survey) and with a content analysis guided by the TAM framework. The quantitative data analysis was made with SAS Enterprise Guide 7.1 statistical software. First, it is notable that the analysis methods were chosen to be suitable for small amounts of data (McDermott, 2023). The Cronbach's alpha and its confidence interval (including the inter-item correlations) were utilized to analyse the internal consistency of the items. Secondly, the plot review and significant key statistical figures, including the p-value of the Shapiro-Wilk test for normality, were utilized to analyse the normality of the difference between pre- and post-survey means. Finally, each category was analysed one by one with either Paired Sample T-Test or Wilcoxon Signed-Ranks Test to determine possible statistically significant differences between the pre- and post surveys. During the analysis, one item in the 'result demonstrability' category was removed due to its significant negative impact on the Cronbach's alpha. After deleting it, the Cronbach's alfa referred better internal consistency (from 0.52 to 0.79). (Paper III.)

For the analysis, a sum variable was calculated as the mean of the category items' overall sum concerning the timepoints as pre and post. Then the normality of the difference between these 2 timepoints were studied. The following categories showed normally distributed data, making them suitable for analysis using a paired sample t-test: 'perceived ease of use,' 'image,' 'job relevance,' 'output quality,' and 'result demonstrability.' In other categories, the data was not normally distributed, and a nonparametric Wilcoxon Signed-Ranks Test was used in the analysis. Normality was inferred from a plot review and from significant key statistical figures, including the p-value of the Shapiro-Wilk test for normality with a significance level of 0.05. (Paper III.)

The qualitative analysis of study from Paper III was made with a content analysis according to the guidance of the Technology Acceptance Model (Venkatesh &

Davis, 2000). The phases of the data analysis process involved: preparation, organisation, and reporting. Firstly, in the preparation phase, the meaning units were created according to the following TAM categories: perceived usefulness, perceived ease of use, and job relevance. These categories were chosen, because they may reflect more content in practical nursing students' minds, while they don't have so much working experience in the context of healthcare. The contents of these categories were the meaning units, which formed the base of the data coding. Secondly, in the preparation phase, the meaning units were collected as a matrix of categories for the actual coding. With this matrix, the researcher verified the connection between the codes and the categories from the TAM framework. After this categories and the subcategories were created, Thirdly, in the reporting phase, all phases and parts of the analysis were checked before the final reporting. (Lindgren et al., 2020; Assarroudi et al., 2018.)

The analysis for sub study IV was conducted using the SAS Enterprise Guide 7.1 statistical software. The data from the knowledge test and observation tool (CPR-skills) were analyzed separately and the two intervention groups and control groups were combined as one. The final number of participants was 59 (N=59): 32 in the intervention group (n=32) and 27 in the control group (n=27).

The analysis of the knowledge test included the sum of 30 questions. The variables in the final analysis consisted of the group (intervention groups and control group), three timepoints (pre, post and follow up), and the interaction between the timepoints and groups. A repeated mixed model was implemented to analyse statistically significant differences. At the beginning, six outliers (n=6) were identified from the data, which significantly influenced the analysis. These outliers were identified through the residual normality check of the original repeated measures mixed model (Shapiro-Wilk test) and influence diagnostics (Press's and Cook's D statistics), prior to the decision to exclude them from the analysis. The outliers were all in the control group, which finalized the participants to 21 students in the control group (n=21). After this a plot review and significant key statistical figures, including the p-value of the Shapiro-Wilk test, were utilized for testing the normality of the data. (Paper IV.)

A repeated measure analysis was conducted to determine possible statistically significant differences in the mean overall score relating to different timepoints. There was also some missing data, which was assumed to be missing at random (MAR). By comparing the Akaike Information Criteria (AIC) for different covariance structure options for the model, the smallest AIC value was found with an unstructured covariance structure, which was therefore used in the repeated measures mixed model. (Paper IV.)

At the beginning of CPR-analysis, the same outliers (n=6) were deleted from the data which were deleted from the survey data. The final data included 29 students in the intervention group (n=29) and 18 students in the control group (n=18). The data was not normally distributed (according to a plot review and the Shapiro-Wilk p-value), which led to utilizing a non-parametric Mann-Whitney U test to compare the groups' rank sum. Finally, 10 logistic regressions were performed to compare the results between the intervention group and control group. (Paper IV.)

4.5 Ethical considerations

All phases followed good ethical guidelines and scientifical practices. Research processes were based on the Declaration of Helsinki, general data protection regulations and the Finnish Advisory Board on Research Integrity with Human Subjects (Finnish National Board of Research Integrity TENK, 2023; GDPR, 2016; World Medical Association, 2013).

PHASE Ⅰ, *The development of the intervention*

The first sub study followed the structured framework of scoping review (Arksey & O'Malley, 2005). Two independent researchers (M.A. and A.P.) screened the data separately and used transparent PICO-criteria for including and excluding the literature. All issues that were controversial, were solved with discussion together. The whole literature screening process was described according to the PRISMA-guidelines. (Paper I.)

Ethical approval for the second sub study interviews was obtained from the Ethics Committee for Human Sciences at the University of Turku, Humanities and Social Sciences Division [21/2020]. The approval to utilize the TPACK-instrument was obtained from the copyright's owner. Research permits were sought from each vocational institute (n=11) separately and after obtaining the research permits, the first emails for participation were sent. The research information included informed consent, instructions for completing the TPACK-deep survey via a provided link, and contact details for participants interested in taking part in the interview (Paper II).

Most of the interviews (n=15) were via the Zoom-tool and the rest (n=2) were face-to-face. All the interviews were recorded. To minimize identification possibilities (voice, dialect expressions, expressions that may refer to the individual institute) the interviews were written in Word format.

All data was stored in the server of University of Turku. The process followed the content of the ethical approval. The data from PHASE I is not open for public usage.

PHASE Ⅱ, *The analysis of the outcomes of the intervention*

The ethical approval for PHASE II was obtained from the Ethics Committee for Human Sciences at the University of Turku, Humanities and Social Sciences Division [34/2020]. The approval to utilize the TAM2-instrument was obtained from the copyright owner by email. First, the research permit was sought from one vocational institute. Additionally, due to the underage population, the information was also requested to be passed on to the parents. The voluntariness of the participation was emphasized. The participants signed informed consent forms. The drop-out were linked to the students' unwillingness to participate the study.

The data collection for sub study III included a survey (TAM2) and focus group interviews. The survey was conducted by pen and paper. The researcher collected all surveys and stored them in a secure place before converting them into an electronic format. After the conversion, the paper surveys were destroyed immediately in the university. The focus group interviews were recorded. To minimize identification possibilities (voice, dialect expressions, expression that may refer to the individual institute) the interviews were written in Word format (Paper III).

The data collection for sub study IV included a knowledge test and an observation tool, which the researcher used while observing the resuscitations. Knowledge tests were conducted by pen and paper. The researcher collected all the papers and stored them in a secure place before converting them into an electronic format. After the conversion, the paper tests were destroyed (Paper IV).

All the data for PHASE II was stored in the server of the University of Turku. The process adhered to the approved ethical guidelines. The data from Phase II are not publicly available.

5 Results

5.1 The development of the intervention

The purpose of the PHASE I was to analyse the pedagogical usage of the 3D technology in healthcare education at the level of vocational education and training and to develop and implement an pedagogical intervention utilising 3D technology for students in healthcare education.

The pedagogical usage and outcomes related to the usage of the 3D technology in healthcare education

In sub study I (scoping review, Paper I) the final sample included 31 articles (limits: must be in English). The articles were written mostly in the USA (n=10) and had multiple designs with quasi-experimental dominance (n=8). The all articles were published from years 2011 to 2019. The study contexts were multiple and involved: nursing-, midwifery-, community health nursing- and physiotherapist undergraduate education. All studies were divided into following categories: 3D imaging, 3D environments, 3D holograms, and 3D printing. Most of the studies concerned 3D environments (n=19) and only one study (n=1) involved 3D printing (Paper I).

The outcomes related to the usage of 3D technology were divided into learning outcomes and outcomes that supported learning. According to the learning outcomes, there were eight studies in the data that reported statistically significant improvements in learning in CPR and fire safety skills (Rossler et al., 2019; Boada et al., 2015), and in students' anatomical and pharmacological knowledge (Hanson et al., 2019; Rutty et al., 2019). 3D technology also enhanced the students' own perception of their learning (Rutty et al., 2019) and heightened their empathic emotional responses (Everson et al., 2015). (Paper I.)

The outcomes that supported learning were divided into user experience (e.g. satisfaction), motivation, attitudes (e.g. self-confidence to learn), and emotions (Hanson et al., 2019; Rutty et al., 2019; Chang & Lai, 2018;Vaughn et al., 2016). (Paper I.)

Healthcare teachers’ self-assessed perspectives of the usage of the 3D technology in healthcare education

In the sub study II survey (TPACK-deep), a quarter (24%) of teachers (n=13) had used 3D technology in their teaching, indicating that most of the teachers did not have experience of using 3D technology in healthcare education. The teachers, who had utilized 3D technology in their teaching valued their technological, pedagogical content knowledge more highly (exertion p=0.021 and 2) proficiency p=0.004), than those, who had not utilized 3D technology in their teaching (Paper II).

In the qualitative part of sub study II, 17 (n=17) teachers participated in the interviews. The survey answers (n=68) to open-ended questions were combined with the interviews in a thematic analysis. After the analysis each TPACK category (design, exertion, ethic and proficiency) included themes and subthemes that described the healthcare teachers’ perspectives of their technological and pedagogical content knowledge of 3D technology. (Paper II.)

In the design category the themes included: *resources*, *teachers’ individual attributes,* and a *student analysis*. Teachers underlined that they need to be honest about the amount of time that will be spent using 3D technology, at least the first time. This concerned the fact that planning the content of healthcare education also needs a lot of resources. Another important element was the understanding of the actual 3D technology, and understanding the technological level of the students, so that they would be willing to use 3D technology. The teachers reported that the utilization of 3D technology must be carefully planned. (Paper II.)

In the exertion category the themes included: *implemented 3D technologies, added value on a personal level,* and *student-oriented use.* In this theme, the teachers limited the usage of 3D technology to 3D images and 3D environments (including 360- degree environment, virtual reality and augmented reality). (Paper II.)

In the ethics category, the themes included: *content sensitivity*, *pressure to utilise 3D technology*, and *convenience for students.* The importance of legal issues, such as data protection, were at the core of the teachers’ descriptions. They noticed that teachers need to evaluate whether using 3D technology demands the students to make a personal account and provide individual information for certain programs. Each student should also have the fair possibility to use 3D technology (the number of devices). Additionally, from the teachers’ perspective, the content of the 3D technology must be carefully selected to ensure it is not too sensitive for students. (Paper II.)

In the proficiency category, the themes included: a *co-operative environment,* and *the working community’s attributes*. The teachers’ leading perspective was that co-operation in the future could vary a lot when it comes to 3D technology. Additionally, co-operation would be beneficial with a person who focuses just on the use of the technology. In this way, healthcare teachers could focus on pedagogical issues. Another element was that the use of 3D technology needs the support of working place and community. The usage must be supported and also, the atmosphere of the institute must be open and creative-rich. (Paper II.)

Summary of the of the development of the intervention in PHASE I

First, the main result of the pedagogical contexts and outcomes related to the usage of the 3D technology in healthcare education can be summarized as follows: *According to the literature there are several 3D technologies used in several pedagogical contexts in healthcare education with positive outcomes related to these 3D technologies.* Second, the main result of the healthcare teachers' self-assessed perspectives of the usage of the 3D technology in healthcare education can be summarized as follows: *Healthcare teachers emphasized the importance of several themes which concerned critical perspectives on the usage of the 3D technology in healthcare education.* According to these main results (Figure 5), the intervention was developed to include multiple technological solutions, but to fulfil the pedagogical aims in implementation, i.e. the implementation process followed the perspectives of healthcare teachers.

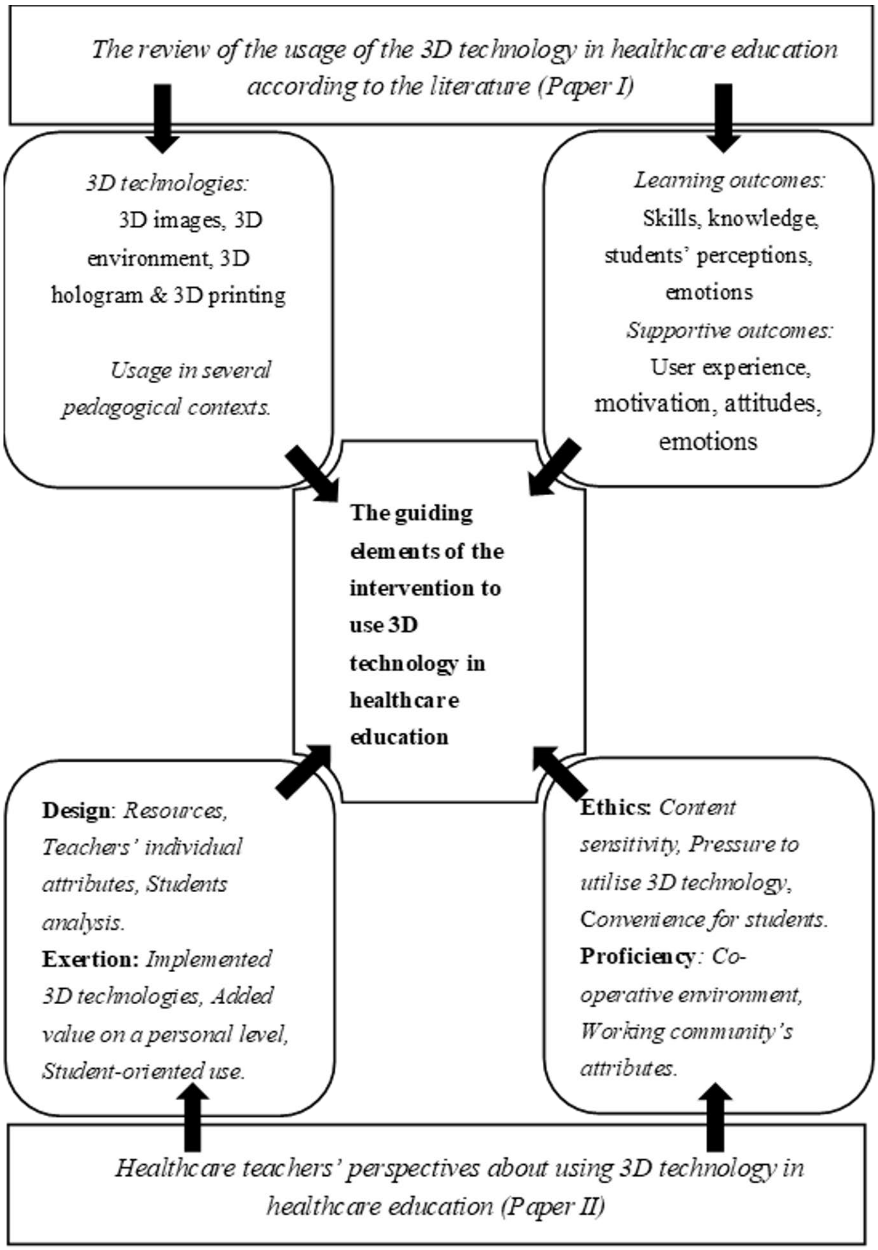

Figure 4. The main elements of the intervention (Papers Ⅰ and Ⅱ).

5.2 The outcomes of the intervention

The purpose of PHASE II was to analyze the outcomes (technology acceptance and learning outcomes) of the intervention in healthcare education among practical nursing students. After the implementation of the 3D technology the following elements were examined among practical nursing students: 1) technology acceptance (sub study III), and 2) learning outcomes (sub study IV).

Practical nursing students' self-assessed technology acceptance after using 3D technology in their education

The third sub study includes quantitative and qualitative results concerning the practical nursing student' technology acceptance. The survey was conducted pre (n=30) and post (n=28) of a first aid course. According to the survey results, the practical nurse students' technology acceptance increased after using 3D technology with a statistical significance in the following TAM2 categories: first, with a paired T-test 1) perceived ease of use ($p<0.001$), 2) output quality ($p=0.030$), 3) result demonstrability ($p<0.001$); and secondly, with Wilcoxon Signed-Ranks for 1) the intention to use ($p=0.004$), 2) perceived usefulness ($p=0.017$), and 3) voluntariness ($p=0.042$) (Paper III).

The following categories were created to describe the technology acceptance in nursing after the 3D technology use from the data of focus groups interviews: *(1) usefulness for education, (2) usefulness for care work, (3) benefits for the individual role, (4) preparedness for future technological solutions,* and *(5) challenges with technological solutions.* The practical nursing students highlighted the usefulness of 3D technology in understanding the issues. This attribute may be useful in education and in the future profession with patients when 3D technology may help to learn about difficult elements concerning aspects such as certain illnesses. According to the students' ideas, 3D technology may be beneficial when caring for patients with dementia because 3D technology can activate memories in an effective way. The students felt that early usage of 3D technology in vocational education would prepare them to face different technologies in their future working life in nursing. The students associated this preparedness with the expectation that their higher technological competence would lead to more diverse roles in their profession. Besides the above, the practical nursing students noticed that 3D technology can be difficult to use, or the use may pose challenges such as dizziness or nausea. In this case, the use of 3D technology was not beneficial for enhancing technology acceptance. (Paper III.)

The learning outcomes related to the usage of the 3D technology in healthcare education

In sub study IV, the practical nursing students' learning outcomes were related to the knowledge (pre, post and follow up) of first aid in general and to CPR-skills (post). As a result of this study, the practical nursing students' knowledge and skills both underwent statistically significant improvements in the intervention group compared to the control group. First, the knowledge scores showed a statistically significant change in relation to the post and follow-up timepoints ($p<0.0001$) and the interaction between the timepoint and group ($p=0.0380$). Second, according to the Bonferroni adjusted p-value, the follow-up timepoint shows that the intervention groups' knowledge scores were statistically significant higher values than the control groups' scores ($p=0.0408$). (Paper IV.)

According to the possible changes in the CRP skill-scores, it was firstly noticed that the mean and median were higher in the intervention group compared to the control group. Secondly, after analysing the Shapiro-Wilk p-value, it was noticed that rank sum of intervention group was significantly higher than the equivalent value of the control group ($p=0.0004$). Finally, the CRP scores were analysed separately for each performance. After the logistic regression of each performance, the scores of the intervention groups were significantly higher than the control groups' scores for the following performances: 1) calling for emergency assistance ($p=0.0028$), 2) opening the airway of the victim correctly ($p=0.0489$), 3) checking for possible breathing correctly ($p=0.0016$), and 4) achieving the correct depth during chest compression ($p=0.0107$). (Paper IV.)

Summary of the analysis of the outcomes of the intervention in PHASE Ⅱ

First, the main result of the practical nursing students' self-assessed technology acceptance after using 3D technology in healthcare education can be summarized as follows: *The practical nursing students noticed that using 3D technology during their first aid course can create multiple promising elements contributing to their technology acceptance. These elements may reduce the barriers to adopting new technology in their working life.* Second, the main result of the learning outcomes related to the usage of the 3D technology in healthcare education can be summarized as follows: *Using 3D technology may increase practical nursing students' knowledge of first aid and increase the quality of their CPR-skills.* According to these main results, the implementation of the intervention was pedagogically effective and positively increased the technology acceptance and learning outcomes of the practical nursing students. A more precise description of the outcomes of the intervention can be seen in Figure 6.

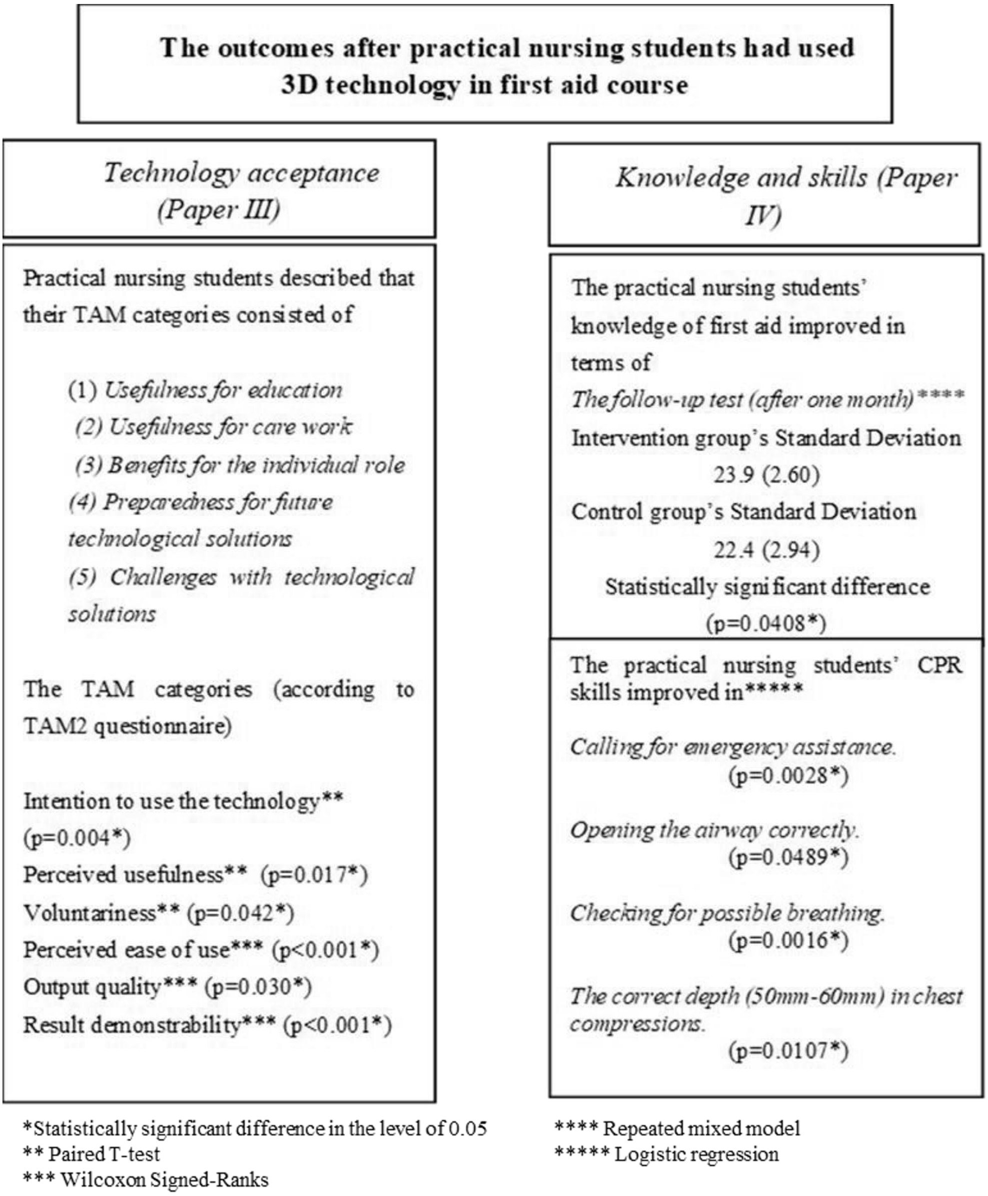

Figure 5. The main results of the outcomes of the intervention (Papers Ⅲ and Ⅳ).

6 Discussion

This chapter includes a discussion about the main results of this study and a description of the validity, reliability and trustworthiness of the phases of the study. Finally, implications and suggestions for the further research are provided. More detailed discussions are presented in the Papers I-IV.

6.1 Discussion of the development of the intervention (Phase I)

The pedagogical usage and outcomes related to the usage of the 3D technology in healthcare education

According to the results of sub study I (Paper I), the concept of 3D technology is connected to promising learning outcomes and outcomes that support the learning. 3D technology also enhanced several aspects of learning, such as skills and knowledge, which have already been addressed in studies related to medical education (Triepels et al., 2020). The other element, besides the learning outcomes, was that according to the results, 3D technology may be connected to better motivation and satisfaction with the teaching and learning in healthcare education. The importance of educational motivation is highly known, although the definition of motivation is multisided (Rafii et al., 2019; Yilmaz et al., 2016). Other studies (Carrera et al., 2018), as well as this study, have not defined learning motivation especially, but at least some kind of positive connection may exist. Nevertheless, it should be considered that 3D technology may have a positive impact on students' experiences during their initial use (Liaw et al., 2021). This was not reported clearly in the results of this scoping review.

From a pedagogical perspective, the use of 3D technology was seen as offering several technological possibilities, such as 3D imaging and 3D printing. Moreover, the results emphasize, that the pedagogical usefulness does not only concern different virtual environments, as has been the focus of other studies (Park et al., 2024). However, it is notable that there may be a gap in the pedagogical utilization of some technologies, e.g. 3D printing, between medical (Shah & Chong, 2018) and healthcare education, while this study included only one study concerning the usage of 3D printing in healthcare education (Rutty et al., 2019). The results of this study underline the importance of visualization in the pedagogical use of 3D technology, which occurred in anatomy teaching. This result supports other studies' results concerned medical education (Richards, 2023) and results concerning the positive effect of 3D technology on memory in general (Amin et al., 2021). This study utilized the concept of 3D technology among healthcare teachers in vocational education and practical nursing students, which also highlights the pedagogical versatility of 3D technology, although all the studies in the scoping review concerned higher education, for example nursing education.

Healthcare teachers' self-assessed perspectives of the usage of the 3D technology in healthcare education

In the second sub study (Paper II), healthcare teachers in vocational education described their competence in the use of technology in teaching and learning to be generally good, which is supported by existing research (Jobst et al., 2022a). Overall, the teachers, who had utilized 3D technology in their teaching and learning, reported higher values in terms of TPACK categories (*exertion* and *proficiency*), which may reflect that the usage of 3D technology can positively affect their experience of digital competence. Developing this experience of enhanced competence and awareness of different technologies has been noted as meaningful, as it allows teachers to better capture students' attention (Costello et al., 2014). It is worth mentioning, that in this study, the usage of the 3D technology was minor and 3D printing had not been utilized at all.

Healthcare teachers' views on the usage of the 3D technology were positive, while they mentioned pedagogical usefulness in terms of enhancing learning outcomes, as well as providing motivation and variety in different lessons with 3D technology (*design & exertion*). In addition to the actual competence, the teachers in this study reported the importance of having the right, open and flexible attitude, when it comes to trying 3D technology (*design*). The same result has been published also by Kulju et al., 2024, who underline the importance of a multi methods approach in improving the digital competence of healthcare teachers. Moreover, the healthcare teachers in this study reported that using 3D technology could enhance their personal sense of purpose in the workplace, due to their increased competence in integrating technology into their teaching (proficiency). This result may support the perspective, that there is no "one-size-fits-all" approach to teaching teachers how to adapt technologies, but the actual process of learning can consist of multiple methods and technologies (Foulger et al., 2017).

The findings of this study confirm that healthcare teachers and vocational institutions must carry out flexible co-operation and structural pedagogical planning when 3D technology is implemented in education (*proficiency & design*). The healthcare teachers need support, but also they need knowledge about the usability of 3D technology for different topics, but also about the sensitive elements and challenges, for example dizziness (*ethics*). This is not a totally new finding, as several studies have highlighted the need of planning (Lee & Chang, 2020), teacher training (Kulju et al., 2024), and co-operation (Backfisch et al., 2021) when new technology is implemented in teaching. The novelty of this study is that it targets these findings for implementing 3D technology in teaching.

Summary of the PHASE Ⅰ

In summary (Papers I and II), this study finds that healthcare teachers in vocational education understand 3D technology from a narrow point of view, which was solidified in the dominance of 3D environments. This was also underlined in scoping review, where only one study concerned 3D printing. Moreover, the similarities between the literature and healthcare teachers' perspectives highlighted the promising benefits of using 3D technology in teaching and learning within healthcare education. It is worth mentioning, that despite the positive aspects, the healthcare teachers did not describe the adaption of the 3D technology as an easy process. They emphasized the structured process of implementation and rejected the institutional mandate to use 3D technology, summarizing the need for pedagogical guidance when incorporating 3D technology into healthcare education in vocational education and training. These results do not signify the effect of 3D technology in healthcare education but the results enable the healthcare teachers and vocational institutes to evaluate the possibility to use the 3D technology in healthcare education. Nevertheless, the results of PHASE I justify developing the pedagogical intervention carried out in this study, which consists of multiple 3D technology, and which can all be seen as promising in terms of promoting the learning experience of practical nursing students in healthcare education. Despite the promises, the results of this phase clearly also present the need for structural pedagogical planning of the usage of 3D technology in healthcare education (for example in terms of ease of use and usefulness), which may influence the adoption process of technology.

6.2 The discussion of the of the outcomes of the intervention (Phase II)

Practical nursing students' self-assessed technology acceptance after using 3D technology in healthcare education

To date, technology acceptance has been studied in healthcare education, for example, among nursing students using 3D environments (Chow et al., 2012) and medical students using 3D printing (Olatunji et al., 2023), while this study focuses on vocational-level practical nursing students. The general result of the third sub study (Paper III) supports the results from nursing and medical education: using 3D technology may have a positive effect on elements of technology acceptance in the form of the students' ability to adapt to technology, be more self-confident about technology or understand the benefits of using technology (Olatunji et al., 2023; Chow et al., 2012). In this study, practical nursing students reported that using 3D technology in their first aid course had several benefits from educational, professional and individual perspectives. It is also important to understand, that these descriptions of the students do not concern the context of first aid, but the wider working field of practical nursing.

Firstly, the survey (TAM2) in sub study III showed that the usage of 3D technology may have a significant connection to students' thoughts about how easy or useful they feel 3D technology is. Moreover, these findings were supported by the qualitative data, where students described that the ease of use may lead to higher feelings of self-confidence and motivation to use 3D technology and further, prepare them better for future nursing work. It is important to understand that the practical nursing students also reported the opposite experience of usefulness and easiness, as some of them experienced challenges such as dizziness and nausea with 3D technology. These are meaningful elements, because healthcare teachers may need to use other tools for the students who experience these problems. The challenges of 3D technology are not a new result, while studies have reported nausea in the use of 3D technology (Chang et al., 2020). In these situations, the 3D technology does enhance the students' technology acceptance and may not be a justified method to utilize.

Secondly, the practical nursing students indicated that the use of 3D technology would be beneficial in nursing and care work among patients, such as elderly patients. The actual benefits would be that they would have more ideas for engaging patients (with 3D environments or 3D printers) and more time to spend with them. This result is justified by Booth et al. (2021b) and Starkweather et al. (2019), who state that the educational use of new technology will be the basis of future nursing work, although the used technology is not directly related clinical nursing. This means that the education should indicate different technological possibilities to prepare students for changing nursing contexts (Booth et al., 2021b; Krick et al., 2019). Additionally, in this study the practical nursing students connected the educational usage of 3D technology to more multiple and broader work-possibilities in the future, because of their increased technology acceptance, while they were studying.

The learning outcomes related to the usage of the 3D technology in healthcare education

In sub study IV (Paper IV), the results present improved learning outcomes in a first aid course. First, the results of the study indicate that practical nursing students' knowledge of first aid was better when comparing those students who used 3D technology on a first aid course to those who did not. Although previously studies support the connection between 3D technology and enhanced first aid knowledge, they have included only 3D environments (Alcázar Artero et al., 2024; Chen & Liou, 2023). This study emphasizes, that 3D images and 3D printing may have positive effects on knowledge in first aid education, or at least, these may be worth future research. Additionally, Amin et al., (2021) writes about the benefits of 3D technology for long-term memory, and the results of this study indicate that the use of 3D technology may support the long-term memory of the practical nursing students, as the students who used 3D technology in their first aid course reported higher scores in a survey, than those students whose teaching was organized with traditional methods. This knowledge may be useful, as the cognitive load of nursing students must be optimized in the education to support better learning outcomes (Rogers & Franklin, 2021).

Second, sub study IV showed that using 3D technology may lead to improved CPR skills of practical nursing students. The results of this study are similar to the study by Chen and Liou (2023), who reported that the usage of 3D technology among healthcare students can result in better quality CRP than traditional methods. Additionally, for better general CRP-skills, this study underlines that 3D technology may support single performances in the CPR-protocol, as the students of this study performed statistically better when opening the airway after they had used 3D technology in first aid compared to students who had received traditional teaching. Moreover, it is worth noting that there were no performances where the control group would have had better scores.

Summary of the PHASE Ⅱ

The result of PHASE II (Papers III and IV) showed the possible usefulness of 3D technology among practical nursing students from two perspectives: technology acceptance (sub study III) and learning outcomes (sub study IV). More precisely, this study's results revealed that using 3D technology in a first aid course for practical nursing students may improve the technology acceptance of 3D technology and support the development of the students' knowledge and skills in first aid. In summary, the results of this phase show that by using 3D technology in VET, healthcare teachers can aim to improve technology acceptance or learning outcomes or both. This knowledge may also break the common understanding of univocal role concerning the usefulness of 3D environments in healthcare education. Finally, the results show that the usefulness can be targeted towards practical nursing education, while there is a lack of evidence-based knowledge in VET.

6.3 Summary of the discussion

The main purpose of this two-phased study was to analyse the pedagogical usage and outcomes of the 3D technology in healthcare education at the level of vocational education and training. As main results this study reveals the following: 1) 3D technology can include multiple 3D tools, which can be used in multiple pedagogical contexts and these tools are connected to promising outcomes in teaching and learning (Paper I), 2) healthcare teachers may need a structured framework to implement 3D technology, which they describe as a promising technological tool to use in vocational education (Paper II), 3) 3D technology may be useful to increase the technology acceptance of practical nursing students, who describe several benefits of the educational usage of 3D technology (Paper III), and 4) 3D technology may increase the learning outcomes concerning first aid knowledge and skills among practical nursing students (Paper IV). In summary, these main results show that 3D technology in general may be a pedagogically useful technological solution in vocational education for practical nursing students as long as healthcare teachers are prepared properly to utilize it. Implementing 3D technology also requires effort and resources from vocational institutes. However, when this effort is weighed against the promising results of the study, integrating 3D technology can be justified as a valuable component of the pedagogical framework in healthcare education.

6.4 Validity and reliability of the study

In this chapter, the validity, reliability and trustworthiness of this two-phased study are discussed. This includes the validity and reliability of the study design, theoretical framework, data collection, instruments, and the results.

6.4.1 Validity, reliability and trustworthiness of the study design, data collection and instruments used

PHASE I, *The development of the intervention*

In sub study I, the scoping review was conducted with a structured framework for scoping reviews without quality appraisal (Arksey & O'Malley, 2005). A scoping review can be seen as a justifiable design for this study because of the pre-known inconsistency in the concept of 3D technology (Kardong-Edgren et al., 2019), the general lack of research at the level of vocational education (Toepper et al., 2022b), and because of the assumed imbalance between medical education and nursing education in using some 3D technological tools, especially 3D images (Azer & Azer, 2016) and 3D printing (Garcia et al., 2018). For these reasons, with the scoping review, this study could include literature with a wider scope and describe case-report articles which may include valuable information about using certain no-researched 3D technological solutions (Arksey & O'Malley, 2005).

The literature search was conducted in several databases with clear inclusion and exclusion criteria created using the PICO strategy (CDR, 2009). Search terms were discussed among the research group and a medical library (2019-2020) information expert before the actual search was conducted. However, there was a lack of systematic hand searching (for example of reference lists), which can be considered a limitation. Overall, the search was conducted in several databases, which widely cover both educational and nursing perspectives. Finally, to enhance the reliability of the review process, two independent researchers separately examined the literature following the protocol by Arksey and O'Malley (2005), reviewing the title, abstract, and full text. All possible conflicts were discussed before final decisions.

In sub-study II, the study design was a mixed methods approach and included a survey (TPACK-deep) and semi-structural interviews. The data was collected only by the researcher, which strengthens the reliability and trustworthiness of the data collection (Heale & Twycross, 2015;Graneheim & Lundman, 2004). Overall, this study was conducted with a predominantly qualitative approach. The theoretical frameworks of the TPACK method guided both the data collection and analysis. According to the validity, reliability and trustworthiness of this study, the utilization of the TPACK method has a corroborative effect as TPACK offered a structured and conceptual explanation for the phenomena (using 3D technology in VET), which has a lack of evidence-based knowledge (Luft et al., 2022). TPACK has also been utilized in vocational education previously for topics such as nutrition and economics, which encourages its utilization in healthcare as well (Torggler et al., 2023).

According to the validity and reliability of the survey, it is first notable that the survey was conducted with 15% of the teachers it was sent to, which can be considered a low response rate. However, it is important to note that the survey was conducted in the midst of the COVID-19 pandemic, which may have affected healthcare teachers' willingness to participate in this study. Additionally, the survey was conducted via the Internet, which may include further affect the response rate than a traditional approach (Jones et al., 2008). Moreover, the instrument (TPACK-deep) has been validated in education (Atar et al., 2019; Kabakci Yurdakul et al., 2012), but not among healthcare teachers in vocational education before. This may affect the validity of the usage, although in this study it was crucial to have an instrument which was in line with the theoretical framework (TPACK). Additionally, TPACK-deep was pre-tested with seven teachers to make the questions more understandable. The instrument was also subjected to statistical analysis, which yielded a Cronbach's alpha of 0.84 or higher for each item.

The interviews revealed that several factors related to trustworthiness must be taken into account. First, the question of credibility includes the question of the role of the interviewer and interviewees (Granheim & Lundman, 2004). In this kind of design, where the interviewer has a background of a healthcare teacher, there is a risk of severe bias (Noble & Smith, 2015). In this study, the interviewer reflected on his own role after each interview and focused on being objective and reminded himself of the research questions (Anderson, 2010). The interviewer used also the structured guidance of TPACK's categories, which helped the interviewer to self-disclose any misguiding assumptions (Creswell & Miller, 2000). The existence of TPACK also guided the content of the meaning units, which should increase the credibility of the study. Second, the question of dependability includes the aspect of the data collection period (Graneheim & Lundman, 2004). The data was collected during the COVID-19 pandemic, which may have positively or negatively affected the ideas of the healthcare teachers, although the data was collected over a few months. Finally, the consideration of transferability (Graneheim & Lundman, 2004) is reflected in the number of interviewed teachers (n = 17), which can be regarded as an appropriate sample size for qualitative research (Cobern & Adams, 2020).

In summary for sub study II, both methods (survey and interview) supported each other in the aim of deeply understanding the phenomena of healthcare teachers' perspectives on using 3D technology in vocational education (Anderson, 2010). TPACK itself was a good framework for this study and overall it presented a balanced structure for the survey and interviews. In this way, the results of this study can be more deeply understood, and certain aspects of content knowledge related to the ethical use of 3D technology can be more broadly explored through the TPACK-deep framework.

PHASE Ⅱ, T*he analysis of the outcomes of the intervention*

In the mixed methods design (sub study III) there was a survey (TAM2) and focus group interviews. The TAM and TAM2 theoretical frameworks guided both methods. TAM itself was a justified framework for this study because of its multidimensional usage in different educational settings (Lee et al., 2003). Additionally, with a mixed methods design it was possible to describe the practical nursing students' technology acceptance in a multisided way. Besides, TAM as a theoretical framework has also been utilized in healthcare education (Fontenot et al., 2024), although not with practical nursing students. Additionally, TAM can be seen as a student-oriented theory and it does not highlight any pre-knowledge (Mohammadi, 2015), which was a meaningful element in this study because 3D technology may be a new experience for some students. However, the profession-related content of the TAM model (such as job relevance) may lead students to form unfamiliar or unrealistic perceptions.

As an instrument TAM2 has been validated in educational settings (Lin & Yu, 2023), which supports the choice of the instrument in this study. Additionally, TAM2 was in line with the theoretical frameworks of the focus group interviews, which can be considered to enhance the validity, reliability and trustworthiness of this mixed methods study. The instrument was completed by 30 students in the pre-test and 28 in the post-test, out of a total of 32 practical nursing students. This can be considered a good result, as the study was conducted during the COVID-19 restrictions. The participants all used 3D technology in their first aid course and surveys were conducted in a classroom environment with pen and paper. Although, the researcher underlined the voluntariness of participation in the study, there may have been some amount of social pressure to participate, when everyone in the group can use new technology. The instrument was pre-tested among 15 practical nursing students to ensure that the content was understandable. When analysing the validity of instrument (TAM2) for this study, one statement in the category "result demonstrability" was deleted, because of its negative correlation with other statements in all categories. After this item was removed, the instrument's internal consistency reached a level, with a Cronbach's alpha of 0.79, and the instrument was deemed suitable for use in this study.

The trustworthiness of the focus group interviews included the same kind of risk of biases as the individual interviews (Graneheim & Lundman, 2004), although the role of the guiding moderator (interviewer) is more crucial (Lauri, 2019). Nevertheless, through this method, the students built upon each other's thoughts and statements, enriching and broadening the content of the interviews, which may enhance their credibility (Graneheim & Lundman, 2004). It is also important to highlight that the researcher did not have teacher-student relationships with the participants, even though the researcher had experience of teaching practical nursing students in another vocational institute. It is important to understand, that even though the researcher reflected his own thoughts and perspectives aiming to achieve objectivity, the background of the teacher may have affected the interviews. Moreover, the interviewer had a clear and structured framework in every interview as a reminder of the aims of the interview. In line with the concept of dependability (Graneheim & Lundman, 2004), all the interviews were made in the same period one month after the first aid course had ended. This underlines the systematic data collection. Finally, the participation of 30 practical students in focus groups was a further element that also increases the transferability of this sub study (Cobern & Adams, 2020; Graneheim & Lundman, 2004).

In summary, both methods complemented each other, enabling a comprehensive description of the practical nursing students' technology acceptance regarding the use of 3D technology in education (Anderson, 2010). The theoretical framework was flexible enough to utilize among practical nursing students and was also suitable for semi-structured interviewing guidance. This study encourages future researchers to utilize TAM in vocational education and with practical nursing students, when 3D technology is adapted.

In sub study IV, the quasi-experimental design was implemented with two different data collection methods: a knowledge test and observation tool. The design was considered valid, because of the aim to study actual learning outcomes (Lavis et al., 2017). The lack of randomization is a notable limitation in the validity of this research (Patil, 2023); however, this study prioritized the vocational institute's needs to minimize the impact on the students' curricula. Additionally, the availability of the 3D technology limited the possibilities in this study. On the other hand, this study aimed to be as objective as possible with minimizing random variables. The same teacher (intervention and control group) ran each first aid course and all the students were guided in the same way, which can be considered to improve the validity of this study (Lavis et al., 2017). Both the knowledge test and the observation tool were developed specifically for this study, which should be acknowledged as a limitation in terms of validity and reliability (Kimberlin & Winterstein, 2008). Furthermore, this research employed internationally recognized frameworks for the knowledge test and observation tool, and the content followed a protocol-like structure (Olasveengen et al., 2021; International First Aid, Resuscitation, and Education Guidelines, 2020), these measures can help reduce the risks of bias or misleading results (Leon et al., 2022). The statistical analysis for the instruments was also carried out carefully. In the knowledge test there appeared to be six outliers, which overly affected the model (repeated mixed model). To enhance the validity of the study, the same outliers were excluded from the observations.

The participation in this quasi-experimental study can be considered moderate, as 59 (n=59) students were invited to study and nearly all enrolled for the knowledge test and CPR-test. Of course, it is understandable that some students did not want to participate in the CPR-test, because it was not a mandatory part of the course. There are issues with CPR testing that should be considered, as they may reduce the validity of this study. Although the observation tool was same for each student, the use of the manikin's data may include misleading information, even though the manikin was calibrated before each group.

In summary, the quasi-experimental design was a valid approach to study the learning outcomes of 3D technology in first aid course among practical nurse students. The instruments were structural and clear (yes or no- answers). With this design this study produced new knowledge, which may be useful to future research in randomized control trials.

6.4.2 Validity, reliability and trustworthiness of the result

PHASE Ⅰ, *The development of the intervention*

According to the validity, reliability and trustworthiness of the results of PHASE I, there are some issues to present. First in sub study I, the protocol followed (Arksey & O'Malley, 2005) increases the validity and reliability of the results. However, the lack of a systematic quality appraisal of the selected articles may have weakened the quality of the results. Secondly, the results include a thematic and narrative approach, which, especially in the categories of 3D image, 3D environment, 3D hologram, and 3D printing, must be critically reviewed. Moreover, the result clarifies the concept of 3D technology more precisely, which has formerly been identified as being too versatile (Kardong-Edgren et al., 2019). Thirdly, the exclusion of Second Life® should be acknowledged when presenting the results. Although including Second Life® would have emphasized the one-sidedness of the influence of 3D environments and highlighted the confusing definitions of 3D technology, some studies may have taken the definition of 3D technology for granted (Paper I).

According to the validity, reliability and trustworthiness of the mixed methods (sub study II) results, both methods should be considered separately. The quantitative results cover a small response rate (15%), which reduces the validity and reliability of the results. There was also a lack of power analysis before the survey, because of the qualitative dominance of the study. The survey was conducted only once and lacked any comparisons. However, the instrument used (TPACK-deep) has been validated in several contexts, and the survey's purpose was to support the qualitative part of the study. The interview results must be viewed from the perspective of TPACK, acknowledging that some perspectives may naturally be missing. The researcher enhanced the trustworthiness of the qualitative results by analyzing the data in a way that preserved the original meaning (Castleberry & Nolen, 2018). For this reason, the researcher also used direct quotes from the narratives to increase the credibility of this study (Elo & Kyngäs, 2008). One researcher conducted the analysis and discussed the findings with the research group to ensure the transparency of the results (Castleberry & Nolen, 2018). Moreover, all the participants were professionals in healthcare education and the level of vocational education, which may increase the transferability of this study (Graneheim & Lundman, 2004), although the researcher did not reflect on the results with the participants (Paper II).

PHASE Ⅱ, *The analysis of the outcomes of the intervention*

It is important to note at the outset that the intervention used in this study—3D technology—did not follow the formal protocol for intervention development as outlined by O'Cathain et al. (2019). This also highlights the absence of a feasibility study (Bowen et al., 2009), which should be taken into account when assessing the validity and reliability of the findings. Despite this, the structure of the intervention was guided by Phase I principles, and the intervention's content has been thoroughly described using the TIDieR checklist (Hoffmann et al., 2014).

According to the validity, reliability and trustworthiness of the results of the PHASE II, sub study III and the sub study IV have to be evaluated separately. Sub study III included a survey (TAM2) and focus group interviews. The result of the survey covered nearly all possible students at that time, which increases the validity of the result, although the actual number of participants was relatively low. In this case, as in PHASE I, the survey's role was supportive of the qualitative results, which were dominant. Nevertheless, TAM2 is a validated instrument in the educational field, which for its own part strengthens the validity of the results. The trustworthiness of the results from the focus group interviews must be evaluated from the perspective of theoretical framework of TAM, which at the same time enhances the credibility of the results but also may narrow the result to focus on certain perspectives, which must be considered when study's transferability is evaluated (Graneheim & Lundman, 2004). The transparency of the results has been verified by following the Consolidated Criteria for Reporting Qualitative Research (COREQ)—framework (Tong et al., 2007) and by ensuring, e.g. using direct quotes, so that the analysis did not alter the original narrative (Elo & Kyngäs, 2008). The strength of the focus group lies also in that certain sayings can cumulate more easily, which may confirm the narrative behind the result (Lauri, 2019).

Sub study IV included the result from a quasi-experimental study. There was also a lack of power analysis, which need to be highlighted considering the validity of this quasi-experimental design. There were only certain groups, that suited inclusion criteria and the aim was to engage them all, if possible. The result has been reported according to the "Transparent Reporting of Evaluation with Non-Randomized Desing (TREND)"–framework (Des Jarlais et al., 2004) and the process of the analysis has been implemented logical and accurately. The result may have been affected by several random variables, for example discussions with students, which may reduce the generalisability (external validity) of the result. This study employed several different 3D technologies, making it difficult to determine which specific technology may have influenced the results. On the other hand, the usefulness of the result can be seen through its' versatility, which may present more possibilities to consider. The context of first aid is also narrow and raises the question of implementing 3D technology in some other area. Beside the topical area, the educational level of this study was vocational education, which needs to be considered when generalizing the results in nursing education.

6.5 Implications for healthcare and practical nursing education and also future research suggestions

The overall goal of this study was to generate new insights into the use of 3D technology in healthcare education, helping educators assess its pedagogical potential for teaching and learning with evidence-based knowledge. While the focus is on practical nursing education, the findings may also have broader implications for healthcare education in general (e.g., nursing education). According to this overall goal the following suggestions are presented:

Implications for the healthcare and practical nursing education:

- 3D technology should be considered as a technological option in teaching and learning. The vocational institutions' pedagogical frameworks should guide teachers to consider using 3D technologies in their teaching and learning.
- The vocational institutes need to target resources to valid, creative, future-oriented and multisided technological solutions in healthcare education and

3D technology may be seen as one option. This should be the basis for every technological purchase.

- 3D technology should be understood as a broad concept encompassing various technological solutions, including 3D images, 3D environments, 3D holograms, and 3D printing. In this way the understanding will not be too one-sided.

Suggestions for future research:

- This study implemented a scoping review as a descriptive method for the concept of 3D technology. It may be useful in the future to study the concept of 3D technology with a more systematic approach for a more specific description of the different outcomes of different 3D technological tools.
- This study was conducted within the fields of nursing science and health pedagogy, both of which also emphasize the connection to vocational education and training (VET). In future nursing science and health pedagogy should have a more transparent role in practical nursing education.
- This study found that the healthcare teachers saw 3D technology as a promising tool, but it would be meaningful to study healthcare teachers using 3D technology with observation methods. In this way more concrete examples about the usage of 3D technology could be explored.
- This study described the technology acceptance and learning outcomes of 3D technology with practical nursing students. It would be beneficial to gain a deeper and more precise understanding of these through randomized controlled trials.
- This study utilized two different theoretical frameworks (TPACK and TAM2) to study the 3D technology. These theoretical frameworks should be used repeatedly to validate their use.

Suggestions for the intervention:

- This study defined the concept of 3D technology to include 3D images, 3D environments, 3D holograms, and 3D printing. Although it is justified to study the concept with this way, it also opens the possibility to study 3D technology as an intervention involving two or three different kinds of solutions together for example mixing 3D images and 3D printing.
- 3D technology may serve as an effective tool to create synergy between practical nursing education and other professional fields.

- This study focused on first aid education. It would be beneficial, if the intervention could be studied in some other context as well, for example in teaching home care.
- This study suggests that the intervention should be examined with follow-up studies.

7 Conclusion

Health pedagogy and healthcare education continually need valid new pedagogical knowledge about the technological possibilities to utilize in teaching and learning. 3D technology includes the clear potential to enhance learning outcomes, motivate students and teachers, increase the positivity in teaching and provide future healthcare professionals with greater preparedness for the changing technological world around them and increase the technology acceptance of the users. This study highlights that 3D technology encompasses more than just virtual reality; for instance, the potential value of 3D printing in healthcare education may be underestimated. With this study, 3D technology can also be seen as a technological solution that makes teaching and learning richer for both teachers and students. However, the usage of 3D technology needs to be easy and simple for every user.

Moreover, this study underlines the importance of research in vocational education and training. The study focused on practical nursing students and their teachers, but at the same time PHASE I illustrated that most research concerning 3D technology and healthcare education has been targeted at higher education. This needs to be more balanced in the future. In that way we can make sure to have high-quality education for extensive professionals. The usage and study of 3D technology can be one small part of that balancing process.

Acknowledgements

Years of work and now I am here. Standing proudly and filled with gratitude. However, this situation would not be possible without important persons, who have travelled this journey beside me. Thank you all for the support and effort you have given to me!

Professor Leena Salminen and Professor Marjaana Veermans, you have been my supervisors, and your support has been irreplaceable. Your advice, comments, questions and "you name it" have made this journey as a learning process, that I won't never forget. There are no single issues to thank you for, because I will thank you for everything. And those thanks and gratitude come from the bottom of my heart. You are really the best and I was really the lucky one.

Thank you, University of Turku and Department of Nursing Science. You have made it possible to pursue doctoral studies in a deeply scientific environment, which has supported my learning and knowledge. Thank you, professors Anna Axelin, and Riitta Suhonen, who guided me in critical times. Thank you Anni Pakarinen, whose effort was truly important at the beginning of my journey. Last, but not least, thank you Camilla Strandell-Laine, whose effort was meaningful during my thesis.

I am deeply grateful for Professor Kaija Saranto and Professor Thomas Martens, who served as the official pre-examiners of my work, giving constructive feedback. Thank you, Professor Marco Tomietto, for agreeing to serve the official opponent for my defense.

I would like to express my sincere gratitude to Salpaus Further Education and special to Hanna Nurmi and Sari Kotonen, who were perfect colleagues during the phase of intervention implementation. Without your effort, help and encouragement, the implementation of 3D technology would not have been so smooth.

I extend my gratitude to Turku Vocational Institute, which was my professional home as a teacher during this PhD path. Special thanks to my manager Kalle Ojanen, whose innovative touch often unlocked challenging situations as well as my friend Marja-Liisa Gustafsson's peer support. I am also grateful to Petteri Johansson, whose general support and professional solutions were irreplaceable during this journey. Great thanks belong absolutely to my friend Jenni Rinne, whose guidance, support and perspectives were in the front line, when I struggled to my way to this point.

I have received funding from the OKKA foundations and from the University of Turku. I want to acknowledge these parties for making it possible to finish my thesis without external pressures.

The most important elements during this journey were friends and family. First, I want to thank all my friends, but especially Kalle, who have also been my statistician and always listened to my worries as a friend. Thank you Ossi and Juha, who always asked me, how are you, and truly helped me my way to finish this. Also, my two sons, Leevi and Kaapo, deserve my acknowledgement. They always remembered me, what is the most important thing in life and without their comments like "hide-and-seek is now more important than your work" made me realize, where I got my energy from. Thank you Eija Heikkilä for often taking care of issues like babysitting, when there was a critical time for me to focus my PhD. Finally, the biggest acknowledgements belong to my wife Susanna. You truly are the love one. I have no words about this, but you were there for me when I needed you. These were the points where I needed to sit down and think about what I will do in the future. And because of these points, I am here now.

Lieto, August 20th, 2025
Mika Alhonkoski

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TURUN
YLIOPISTO
UNIVERSITY
OF TURKU

Painosalama, Turku, Finland 2025

ISBN 978-952-02-0330-6 (PRINT)
ISBN 978-952-02-0331-3 (PDF)
ISSN 0355-9483 (Print)
ISSN 2343-3213 (Online)