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RADIOGRAPHY SCIENCE AS A DISCIPLINE

A framework towards a paradigm

Sanna Törnroos

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To my children, Saga and Leevi

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ABSTRACT

The beginning of radiography can be dated to the discovery of X-Rays in 1895. Radiography science as a discipline has more recent history, spanning approximately three decades. The starting point of this study is the fact that there does not seem to be a predominant international paradigm for this discipline.

The aim of this study was to explore radiography science as a discipline and to propose a framework for a paradigm. In Phase I, a scoping review was conducted to discover the phenomena radiography science investigates; this involved a Delphi study for the identification of research priorities within the discipline being performed. In Phase II, the core concepts and their interrelationships, and epistemic interests and nature of knowledge were explored with a document analysis. In Phase III, the data collected was synthesized using Kuhn's disciplinary matrix. The scoping review in the first stage discovered 14 relevant studies of the topic and in the two round Delphi study surveys were used to gather opinions from a panel of radiography experts (n=24, first round/n=20, second round). In Phase II the data consisted of 53 dissertations from the field of radiography science. In Phase III, no new data was collected.

The results of the study indicate that the phenomena radiography science investigates are the profession of radiographers, clinical practices, safe and high-quality use of radiation, technology, management and leadership as well as radiography as a discipline. Of these, the first four were identified as prioritized areas of research and core concepts of the discipline. (Phase I.) The statements indicating the interrelationships between core concepts demonstrated bilateral dependencies. Radiography science generates different types of knowledge for different epistemic interests with varying methodologies. (Phase II.) The framework for the paradigm was composed of shared values, symbolic generalizations, shared exemplars and metaphysical presumptions. Radiography science investigates humane, safe and high-quality radiography services mediated by technology in the health care environment for the well-being of individuals. (Phase III.)

In conclusion, radiography science is pluralistic in its ontological, epistemological and methodological choices and can be called a pragmatic discipline. Radiography science contributes to inquiries on health phenomena.

KEYWORDS: Radiography science, paradigm, discipline, disciplinary matrix

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TIIVISTELMÄ

Radiografian historia juontaa röntgensäteilyn keksimiseen vuonna 1895. Radiografiatieteen historia on tuoreempi ja ulottuu noin kolmen vuosikymmenen taakse. Tämän tutkimuksen lähtökohtana oli radiografiatieteen vallitsevan kansainvälisen paradigman puuttuminen.

Tutkimuksen tarkoituksena oli tarkastella radiografiatiedettä tieteenalana ja esittää viitekehys tieteenalan paradigmalle. Vaiheessa I toteutettiin scoping katsaus, radiografiatieteessä tutkittavien ilmiöiden tunnistamiseksi. Tätä seurasi tutkimuksen prioriteettien tunnistaminen Delphi tutkimuksen avulla. Vaiheessa II tieteenalan keskeisiä käsitteitä ja niiden välisiä suhteita, sekä episteemisiä intressejä ja tiedon luonnetta tarkasteltiin dokumenttianalyysillä. Vaiheessa III, aiemmin kerätystä aineistosta muodostettiin synteesi Kuhnin tieteenalamatriisin avulla. Aineisto koostui vaiheessa I scoping katsauksessa vertaisarvioiduista artikkeleista (n=14) ja kahden kierroksen Delphi tutkimuksessa aineisto koostui radiografian asiantuntijoista koostetun paneelin (n=24, 1. kierroksella/n=20, 2. kierroksella) kyselyllä kerätyistä mielipiteistä. Vaiheessa II aineisto koostui 53 radiografian alan väitöskirjasta. Vaiheessa III ei kerätty uutta aineistoa.

Tutkimuksen tulokset osoittavat, että radiografiatieteessä tutkitaan ilmiöitä, jotka liittyvät röntgenhoitajien professioon, kliiniseen käytäntöön, turvalliseen ja laadukkaaseen säteilyn käyttöön, teknologiaan, johtamiseen ja johtajuuteen sekä radiografiaan tieteenalana. Näistä neljä ensimmäistä tunnistettiin tieteenalan ensisijaiksi tutkimuskohteiksi ja keskeisiksi käsitteiksi. (Vaihe I.) Keskeisten käsitteiden väliset suhteet osoittivat kahdenvälisiä riippuvuuksia. Radiografiatiede tuottaa erilaista tietoa erilaisille episteemisille intresseille erilaisilla metodologioilla. (Vaihe II.) Tieteenalan viitekehys paradigmalle koostettiin jaetuista arvoista, symbolisista yleistyksistä, malliesimerkeistä ja metafyysisistä olettamuksista. Radiografiatiede tutkii inhimillisiä, turvallisia ja laadukkaita palveluja, joita tuotetaan teknologian välityksellä terveydenhuollon ympäristössä yksilöiden hyvinvoinnin edistämiseksi. (Vaihe III.)

Johtopäätöksenä todetaan, radiografiatieteen olevan monimuotoinen ontologisissa, epistemologisissa ja metodologisissa valinnoissa ja sitä voidaan kutsua pragmaattiseksi tieteenalaksi. Radiografiatiede edistää terveyteen liittyvien ilmiöiden tutkimusta.

AVAINSANAT: Radiografiatiede, paradigma, tieteenala, tieteenalamatriisi

Table of Contents

Abbreviations **8**

List of Original Publications **9**

1 Introduction **10**

2 Review of the Literature **13**
2.1 Definition of the main concepts of the study 13
2.1.1 Radiography 13
2.1.2 Science and disciplines 15
2.1.3 Paradigm 18
2.2 Development of science and disciplines 19
2.2.1 Falsification and verification 19
2.2.2 Paradigm shifts 20
2.2.3 Research programmes 21
2.2.4 Emergence of new disciplines 21
2.3 Organizing the paradigm through disciplinary matrix 22
2.3.1 Shared values: phenomena of interest and research priorities 23
2.3.2 Symbolic generalizations: the conceptual development of the discipline 24
2.3.3 Shared exemplars: accepted methodologies 24
2.3.4 Metaphysical presumptions: the nature of being and the nature of knowledge 24
2.4 Radiography science as one discipline of the health sciences 25
2.4.1 Health sciences 25
2.4.2 Nursing science and caring science (meta)paradigms 26
2.4.3 Development of the discipline of radiography science 29
2.5 Summary of the literature 33

3 Aim, objectives and research questions **35**

4 Materials and Methods **38**
4.1 Design, settings and sampling 38
4.2 Data collection 40
4.3 Data analysis 43
4.4 Ethical considerations 45

5 Results 47
5.1 Phenomena of interest and research priorities of the discipline of radiography science (Phase I) 47
5.2 The core concepts and their interrelationships (Phase II) 48
5.3 Epistemic interests and nature of knowledge (Phase II) 51
5.4 Organizing the paradigm of radiography science through disciplinary matrix (Phase III) 53
5.5 Summary of the results 56

6 Discussion 57
6.1 Discussion of the results 57
6.1.1 Radiography science as a discipline 58
6.1.2 The research focus of the discipline of radiography science 59
6.1.3 Identifying radiography science from close disciplines 61
6.1.4 Strengthening the knowledge base for radiography science 62
6.2 Validity and reliability and trustworthiness 63
6.3 Suggestions for future research 66
6.4 Practical implications 67

7 Conclusions 68

Acknowledgements 69

References 71

List of Figures and Tables 81

Original Publications 83

Abbreviations

ALARA	As Low As Reasonable Achievable
ASMIRT	Australian Society of Medical Imaging and Radiation Therapy
ASRT	American Society of Radiologic Technologists
CAMRT	Canadian Association of Medical Radiation Technologists
CoR	College of Radiographers
EANM	European Association of Nuclear Medicine
ECTS	European Credit Transfer and Accumulation System
EFRS	European Federation of Radiographer Societies
ESTRO	European Society for Radiotherapy and Oncology
ISRRT	International Society of Radiographers and Radiological Technologist
IQR	Interquartile range
NZIMRT	New Zealand Institute of Medical Radiation Technology
OATD	Open Access Thesis and Dissertations
OECD	Organisation for Economic Co-operation and Development
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
UNESCO	The United Nations Educational, Scientific and Cultural Organization

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 Törnroos S, Leino-Kilpi H, Metsälä E. Phenomena of radiography science - A scoping review. *Radiography,* 2021; 27 (4): 1231-1240.

II Törnroos S, Pasanen M, Leino-Kilpi H, Metsälä E. Identification of research priorities of radiography science – A modified Delphi study in Europe. *Nursing & Health Sciences*, 2022; 24(2):423-436.

III Törnroos S, Leino-Kilpi H, Siekkinen M, Metsälä E. Perspective of radiography science – A document analysis of dissertations. *Journal Of Medical Radiation Sciences*, 2024; 71(2): 222-232.

IV Törnroos S, Leino-Kilpi H, Siekkinen M, Metsälä E. The nature of knowledge and epistemic interests of radiography science - An analysis of doctoral dissertations using a critical normative epistemology framework. Unpublished manuscript.

1 Introduction

Radiography science is a discipline connected to diagnostic imaging and radiation therapy. Every year approximately 3,6 billion diagnostic imaging examinations are made globally and about 7,5 million radiation therapy treatments are given (World Health Organisation, n.d). Approximately half of all cancer patients undergo radiation therapy. Each year, an estimated 18 million new cancer cases are diagnosed, and this number continues to increase. (Cancer Research UK, n.d.) It is vital to conduct high-quality research to secure these services are evidence-based (European Commission, 2025).

This study examines the paradigm of the discipline of radiography science. Understanding the philosophical foundation of a discipline starts with understanding the paradigm. As with any philosophical question, the question of the paradigm is not a simple one and cannot be answered unequivocally. This study portrays radiography science as a discipline from the following perspectives: the phenomena it studies and research priorities (Phase I), its core concepts and the kind of knowledge it generates and why (Phase II). At the end of the study, a framework is proposed that can be used as starting point for building the paradigm of the discipline (Phase III).

With a paradigm, disciplines can reason their own unique perspective in the field of sciences, the way they view phenomena and what is the nature of their research and the limitations (Boon & Van Baalen, 2019; Donaldson & Crowley, 1978). Within the discipline, it provides the scholars with some consensus on how to approach the phenomena they are investigating, what theories, facts and methods are accepted, and validity and significance of any new research (Fanelli & Glänzel, 2013; Monti & Tingen, 1999).

Disciplines evolve over time, and what was once considered valid paradigm might no longer hold true under new evidence or perspectives (Hofstetter, 2012; Bridges, 2006). For example, paradigms might change with new evidence, new technologies or new methodologies (Glynn, 2022; Fishman et al., 2008). No paradigm is ever complete, even with established disciplines (Boon & Van Baalen, 2019). A discipline can also have multiple paradigms, but generally there is one predominant paradigm (Monti & Tingen, 1999). By investigating a paradigm, we can identify areas of research the discipline should focus on, and which areas need further development (Younas & Parsons, 2019). This can lead to the development of a discipline suited to addressing contemporary challenges. Investigation into the paradigm can encourage members of the discipline to think critically about accepted norms and practices, thus impelling the field forward (Younas & Parsons, 2019). Paradigms need to be investigated at regular intervals, as they can become outdated in response to changing societal, cultural, and technological contexts. By investigating the paradigm, the discipline can ensure it remains relevant and responsive to contemporary needs. (Pickler & Dorsey, 2022; Grace & Perry, 2013.)

Paradigms dictate how research is conducted and what is considered valid evidence (Kuhn, 1970b). Investigating the paradigm can uncover issues related to methodological bias or false assumptions, which may limit the scope of inquiry or distort findings. For example, a paradigm may focus too heavily on certain methods, disregarding other methodologies that may provide a deeper understanding of complex issues. Constantly reassessing the paradigm improves the credibility of the discipline by ensuring that it is progressing. (Pickler & Dorsey, 2022.)

The research focus and the core concepts of the discipline of radiography science have been previously investigated in a dissertation in Finland (Sorppanen, 2006). In that study, core concepts were determined using nursing science metaparadigm concepts as a starting point and data was collected in Finland. The study was important for the development of the discipline of radiography science in Finland but left open the question of international aspect of radiography science. Consequently, this study set out to seek the international viewpoint to radiography science. In the beginning of this study, there was no set predominant paradigm for the discipline of radiography science which is accepted internationally that could have been investigated and improved. Instead, it was necessary to start almost from the beginning. This meant starting to first investigate what are the phenomena and the priorities of research. Once these were discovered, the core concepts needed to be identified and investigated. To understand the metaphysical presumptions in the discipline, the nature of knowledge required examination. In order to be able to propose a framework and to understand the paradigm of the discipline as a whole, the knowledge gained in Phases I and II needed to be synthesized. This was done by examining the gained knowledge through the disciplinary matrix, a model presented by a philosopher of science Thomas Kuhn (1970b). The scope of this study is not to provide ultimate and final answers as to what is the paradigm, but rather to contribute to defining the paradigm of the discipline, so the following researcher do not need to start from the beginning again.

The structure of this dissertation is as follows. First the main concepts of the study are introduced, followed by a review of the relevant literature. After setting the aim and objectives for the study, a description of the methodologies used, and the ethical issues are presented. Then the results of the study are presented following the phases of the study. In the discussion chapter, the results of the study are discussed along with previous literature. In the discussion chapter, the validity and reliability of this study is also discussed, as well as suggestions for future research and the practical implications of the study. In the final chapter, the conclusions are presented.

2 Review of the Literature

In this chapter the study main concepts are defined, and the theoretical background of the study is presented. In the main concepts' definition (2.1), science is the broadest concept, covering both the methods used to gain knowledge and the knowledge itself. A discipline is a specific knowledge system within science, like for example, radiography science. A paradigm is a shared perspective or worldview within a discipline, which can be organized into a framework called a disciplinary matrix. The theoretical background reviews how science develops and how disciplines emerge (2.2), how paradigm can be organized into a disciplinary matrix (2.3) and in the last part of this chapter, the development of radiography science is viewed in conjunction with the development of nursing science (2.4).

2.1 Definition of the main concepts of the study

2.1.1 Radiography

Radiography as a concept has different meanings, depending on the context of the use (Ahonen, 2008; Lundgren et al., 2015; Lundgren & Lundén, 2023). For example, in physics, radiography refers to a technique for inspecting the composition and structure of objects or a general term for the field of using ionizing radiation. In health sciences it can mean the field of medical use of radiation, the education or practice of radiographers, or a discipline. (Ahonen, 2008.)

Radiography is used as an umbrella concept for a discipline, comprising of sub disciplines of radiotherapy, diagnostic imaging and nuclear medicine (EFRS, 2016) but there is variation globally as to what concept is used to denote the discipline and what sub disciplines are included (Table 1). Sometimes medical imaging (also known as diagnostic imaging) includes all the different imaging modalities (e.g. conventional X-rays, computed tomography, interventional radiology, fluoroscopy, ultrasound, magnetic resonance imaging), but sometimes magnetic resonance imaging and sonography (ultrasound imaging) are seen as separate. The position of nuclear medicine imaging is sometimes included in the medical imaging and sometimes as its own entity.

Table 1. The umbrella concepts defining the discipline of radiography science in different parts of the world.

SOCIETY (REGION) (REFERENCE)	UMBRELLA CONCEPT FOR THE DISCIPLINE	SUB DISCIPLINES INCLUDED
EFRS (EUROPE) (2016)*	Radiography/radiography science	Medical imaging, radiation therapy and nuclear medicine
ISRRT (GLOBAL) (2004)*	Radiography/radiologic technology/medical radiation technology/medical radiation sciences	Medical imaging, radiation therapy, nuclear medicine, sonography
ESTRO (EUROPE) (2019)**	Radiation oncology	Radiation therapy and oncology
EANM (EUROPE) (PIETRZAK ET AL., 2024)**	Nuclear medicine	Molecular imaging and radionuclide therapy
ASRT (UNITED STATES) (2015)*	Radiologic sciences	Medical imaging, radiation therapy, nuclear medicine, sonography, medical dosimetry
ASMIRT & NZIMRT (AUSTRALIA AND NEW ZEELAND) (N.D)*	Medical radiation sciences	Medical imaging, radiation therapy, nuclear medicine and sonography
CAMRT (CANADA) (N.D)*	Medical radiation sciences	Radiological technology, radiation therapy, nuclear medicine and magnetic resonance imaging

* professional society
**Scientific society

Radiography science does not have a globally unified name, and it is not mentioned in the OECD (Organisation for Economic Co-operation and Development) list of sciences and technology (OECD, 2006).

The European Federation of Radiographer Societies (EFRS) uses the term radiography to denote both the professional field and the discipline. Radiography encompasses in EFRS definition of medical imaging, radiotherapy and nuclear medicine sub disciplines (EFRS, 2016). However, this view is not unified even in Europe, as the European Society for radiotherapy and oncology (ESTRO) considers radiation therapy as its own discipline (ESTRO, 2019) and the European Association of Nuclear Medicine (EANM) deems nuclear medicine to be its own discipline (Pietrzak et al., 2024); this distinction can be explained with the differing focuses of these societies.

Medical radiation science is a concept used in some English-speaking countries, such as Australia, New Zeeland and Canada, to denote the connecting discipline for medical radiation technology professionals working in medical imaging, radiotherapy, nuclear medicine and sonography (ASMIRT, n.d; Lumsden & Schofield, 2011; NZIMRT, n.d). In the United States, the discipline connecting medical imaging, radiation therapy, nuclear medicine, sonography and medical dosimetry is called radiologic sciences (ASRT, 2015). In Finland, Sorppanen (2006) suggested the discipline could be called the clinical science of radiography and radiotherapy, which encompasses medical imaging, radiation therapy and nuclear medicine.

Education in radiography varies globally. The entry level education in the first cycle can be vocational training leading to an associated degree, or in higher education to a bachelor’s degree. Accordingly, the length varies from one and half to four years. (McNulty et al., 2021; Susiku et al., 2024.) In the second cycle, postgraduate education can lead to postgraduate certificates, diplomas or a master’s degree (McNulty et al., 2016) and in the third cycle, to a doctoral degree (Ekpo et al., 2017; Snaith et al., 2016). A doctoral degree is the highest level of education and a prerequisite for a career in research (Anderson & Okuda, 2021). In Europe, there is also variation in the education (Sá Dos Reis et al., 2018). The education is most often conducted through combined programmes including medical imaging, radiation therapy and nuclear medicine. The length of the education at the bachelor level varies from three to four years (180-240 ECTS). Master level education is provided in approximately 39 % of institutions having a radiography bachelor’s programme and doctoral programmes in 14 % of the institutions. (McNulty et al., 2016.)

Radiography is a widely used concept in Europe to describe the discipline (Malamateniou, 2009; Saukko et al., 2021; EFRS, 2016; Lundgren et al., 2019). However, due to the multiple uses for the concept radiography and the lack of a unified name for the discipline, in this study the term radiography science is used to denote the discipline of radiography from the practice or method of radiography. In this study, radiography encompasses medical imaging and radiation therapy. Medical imaging is understood broadly, and also includes nuclear medicine, magnetic resonance imaging and sonography.

2.1.2 Science and disciplines

Concept of science can be defined in multiple ways. One way to define it is to say that science is a knowledge derived from observations with a systematic method (Chalmers, 1999). Alternatively, we can define science as a belief system, one that is characterized with self-corrective method. Scientists solve cognitive problems by proposing hypotheses or theories which are tested through controlled methods. The reports of these studies are critically evaluated by other scientists. (Niiniluoto, 2002.)

UNESCO defines science as an individual or small group activity, where an organized attempt is made to discover causalities, relations or interactions. These activities are done by means of objective study and the validation of the results is done by a peer review process. The aim of science is to understand phenomena and processes in nature and society. (UNESCO, 2021.) Science is, in other words, at the same time a process (systematic method), a group activity and an outcome (knowledge).

Sciences can be divided into the natural sciences, engineering and technology, medical and health sciences, agricultural sciences, social sciences and humanities (OECD, 2006). A somewhat different categorization is done by Niiniluoto (2014; 2001), who divides sciences into being either descriptive or design sciences. Descriptive sciences are interested in how things are and design sciences in how things ought to be. Descriptive sciences, for example, the natural sciences, give explanations of reality as it is in the present condition. They also provide lawlike regularities and historical studies about the past, as well as predictive studies about the future. Design sciences, like medicine for example, do not typically express how things are but rather the means we should apply to achieve some end. (Niiniluoto, 2001.)

Discipline refers to a specific branch of science or knowledge system within academia (Coccia, 2020). A dictionary meaning of discipline is a practice of training people to obey or to become more able to control themselves, often in the form of rules, and punishments, or the behaviour produced by this training (Merriam-Webster dictionary, n.d.; Oxford Learner's Dictionary, n.d.). The dictionary meaning seems harsh but is not without connection to academic disciplines. Disciplines are said to control their disciples, namely the scholars within the discipline (Foucault, 1994).

A discipline shares the same knowledge base, goals and interests, even though individual researchers within a discipline might have conflicting interests (Meier, 2023). Each discipline has its own unique features as to how it can be recognized, and there are characteristics that separate it from other disciplines. However, these characteristics are not, according to Trowler (2014), always present. They are more like "family resemblances", meaning they are a cluster of characteristics that are significant to that discipline. They can be for example, a set of research concerns, or knowledge resources and dominant ontological and epistemological assumptions. (Trowler, 2014.) Generally, we can say that a discipline has scholars who practice in that discipline, share a history and traditions, have a specified research focus, a research methodology, and a conceptual structure unique to that discipline, as well as a specialized language and a curriculum (Serenko & Bontis, 2013). A discipline is distinct from a profession, even though these two are often confused. Discipline is concerned with generating knowledge in its domain, whereas a profession acts within that domain (Fordham, 2016; Niiniluoto, 2001). For example, nurses (profession) utilize knowledge from nursing science (science), which is generated by researchers in academia within the discipline of nursing science to improve nursing phenomena.

The relationship of science and a discipline is hierarchic (Figure 1). Science being the overarching belief system that guides how knowledge is generated and what is accepted as truth. A discipline is where science is practiced by members of a discipline and educated in that discipline that derives knowledge from science (Northrup et al., 2004).

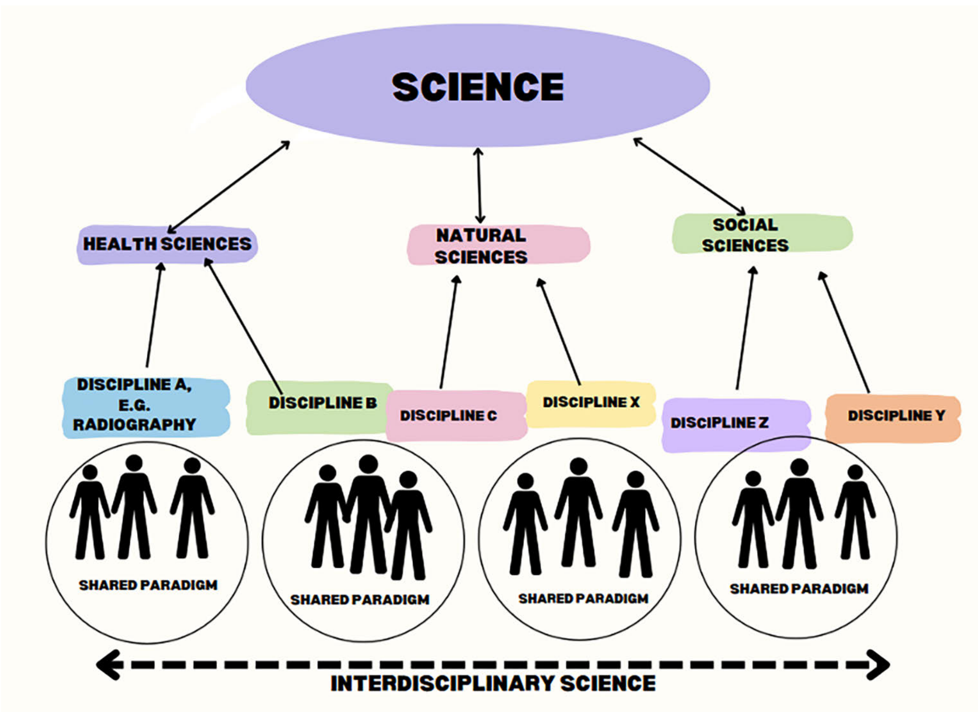

Figure 1. The relationship between science and disciplines.

With regard to science, there is a debate over what is considered as such and what is considered as other intellectual endeavours, such as arts, policy or ideology (Gieryn, 1983). This is called in the philosophy of science a demarcation problem. In a more narrowed sense, demarcation is done between different disciplines as to their goals, methods and substance and to distinguish one discipline from another. This is called boundary work. (Gieryn, 1983; McGreavy et al., 2013.) Every new discipline is under scrutiny and faces opposition from more established disciplines within academia (Fishman et al., 2008). A new discipline needs to justify its existence in relation to other disciplines as well as its need in society at large (Hofstetter, 2012).

Boundary work continues even if the new discipline succeeds in proving its existence (Hedgecoe, 2003), as disciplines are not fixed but they emerge, evolve, disband or disappear from the disciplinary field (Hofstetter, 2012; Nägel & Vera, 2020). For example, in the development of nursing science, the discipline has had to set boundaries to medicine and has had to defend its status as an independent discipline (Kalkas, 1986).

In this study, science is considered as a belief system, where knowledge related to phenomena within nature and society is gained by using a systematic method. A discipline is considered a specific branch of knowledge contributing to the progress of science and consisting of a community of scholars educated in the discipline and educating or doing research within that discipline and sharing a paradigm. Boundary work is done to differentiate disciplines from one another.

2.1.3 Paradigm

In general, a paradigm can be defined as a perspective or conceptual framework which guides the discipline (Boon, 2017). Paradigm is foremost a group commitment of a discipline (Kaehne, 2017; Kuhn, 1978). One aspect that a discipline gains through its paradigm is a criterion for selecting problems that are solvable. In fact, they can be considered the only problems the discipline admits as being scientifically valuable. When paradigms change, there usually is a shift to what problems and solutions are considered significant. (Kuhn, 1970b.)

The concept of paradigm is ambiguous and there are multiple different definitions (Masterman, 1970). In this study, Kuhn's (1970b) definition of a paradigm is used. Thomas Kuhn made the concept famous in his book "The structure of scientific revolutions" (Kuhn, 1962) He was not the first to use the concept paradigm, but he was the first person who made it known to a wider audience (Hacking, 2012). Kuhn (1970b) defines a paradigm as a worldview, an accepted theory or model of a scientific field, but also as a restriction to the same rules and standards of a particular discipline. In the postscript to the second edition of "The structure of scientific revolutions", Kuhn defined paradigm in the form of a disciplinary matrix. It can be viewed as a common perspective, a framework that offers field members guidelines on how to approach and resolve issues within the field. (Kuhn, 1970b.)

The concept of paradigm is problematic due to its circularity. It is supposed to exist before scientific action as a guide to the researchers thinking, but it cannot be defined before there is some scientific achievements to evaluate. This is especially problematic for new fields. (Kuhn, 1978; Masterman, 1970.) Paradigms cannot be proven or disproven unequivocally. However, they can be articulated, analysed, and disputed (Boon, 2017).

In this study, a paradigm is defined as a shared worldview of a discipline and the content of the paradigm can be organized in the form of a disciplinary matrix. Each discipline having their own specific paradigm with rules governing them and certain beliefs and assumptions shared with members of the discipline.

2.2 Development of science and disciplines

In the following, three models of scientific development are presented to provide an overview of how science and disciplines develop. These models represent scientific development through falsification and verification (Popper, 1959), through paradigm shifts (Kuhn, 1970b) and through research programmes (Lakatos, 1971). The three presented models are widely accepted in the philosophy of science, though they are not the only views of scientific development or progress. Emergence of new disciplines is also presented.

2.2.1 Falsification and verification

Development through falsification/verification briefly means, that science develops by trial and error or "true until proven otherwise" (Walker, 2010). Popper (1959) presented a model of scientific development through falsification and verification in his famous book "The logic of scientific discovery". Popper's model represents an idea of a science as an open society with unified scientific methods. In his writings he criticized the traditional model of development of science through accumulation of knowledge, where knowledge gradually grows based on facts gathered by scientists. He also criticized the inductive logic in scientific progress. Inductive logic, where inferences are made from the specific to the general, are according to Popper, not sustainable as we cannot know for sure if after 100 similar observations the 101st will be the same. Popper stated that science advances rather through deductive strategies, from the general to the specific. (Popper, 1959.)

Theories in science are constructed through deductive reasoning by constructing hypothesis from the previously known. When testing a new hypothesis, the result either refutes (falsification) or verifies (verification) the existing theory. A development in science occurs when a better corroborated theory supersedes the previous. Popper emphasized theoretical pluralism and the tentative nature of a knowledge base and emphasized that science is not a steadily advancing system where ultimate truth can be achieved. (Walker, 2010; Popper, 1959.)

According to Kuhn (Kuhn, 1970a), Popper's model describes the progress of an individual scientist very well but poorly describes the historical development of a discipline. This is because complete refutations of a theory are rare and do not occur in the context of normal science.

2.2.2 Paradigm shifts

According to Kuhn (1970b) science does not progress linearly but rather through scientific revolutions or paradigm shifts. Kuhn abandoned the accumulative model of scientific development, the same as Popper (Andersen, 1998; Lakatos, 1970). In pre-paradigmatic state of science, there are researchers who investigate groups of related phenomena but without generally accepted view of them. Without a common body of belief, they are always forced to start again from the foundations. Different researchers might confront the same phenomena but describe and interpret them divergently. There are multiple unsolved problems and a few or none accepted theories. In the absence of a paradigm, all problems seem equally relevant, and research might appear to be a random activity. (Kuhn, 1970b.)

In a paradigmatic state, sciences have established which phenomena they tend to investigate further, and those phenomena can then be studied in a more detailed and systematic way. A predominant paradigm is accepted because it has succeeded in solving important problems better than its rivals. The paradigm defines and explains the field of research in ways that most scientists can accept. When individual researchers can take a paradigm for granted, there is no need to always have to start from the basics and justify each concept used. Kuhn describes this phase as a state of normal science. (Kuhn, 1970b.)

Normal science values research directed to phenomena and theories supported by a paradigm. New phenomena, outside the box, are not often seen and researchers in the field might be intolerant toward ideas not fitting into the paradigm. However, if there are sufficient conflicting ideas with the paradigm, this leads to a state of crisis. The paradigm starts blurring and research starts to resemble a preparadigmatic state, where the rules of normal research are weakened. A crisis might end with the emergence of a new accepted paradigm, a so-called paradigm shift. Kuhn calls this transition period a “scientific revolution”. Science, according to Kuhn, progresses through revolutions rather than cumulatively. (Kuhn, 1970b.)

Kuhns model has been criticized and debated ever since it was published (Andersen, 1998). For example, Popper criticized Kuhn’s model and the idea of normal science and paradigms as limiting creativity in science (Popper, 1970; Walker, 2010) and a scientist adapting to a paradigm of normal science as being badly taught (Popper, 1970).

2.2.3 Research programmes

The scientific development through research programmes by Imre Lakatos, resembles Kuhns idea of paradigms (Walker, 2010). Lakatos, however, criticized Kuhn for irrationality and mystification of emergent paradigm shifts (Walker, 2010; Lakatos, 1970). Research programmes were Lakatos' attempt to combine the ideas of Popper and Kuhn and improve it (Lakatos, 1970).

According to Lakatos (Lakatos, 1971, 1970), all scientific research programmes can be described through their hard core. Research programmes are sequences of theories of a discipline (Musgrave & Pigden, 2023). Hard core could be described as the main theoretical assumptions of that research programme that cannot be completely abandoned without changing the entire programme. Researchers within the programme create auxiliary hypotheses supporting the hard core and these hypothesises are tested, adjusted or replaced to defend the hard core. (Lakatos, 1971.)

What makes a research programme successful, is the progressive nature of the hypotheses, the framing of problems and the explanatory power of theories. Researchers in research programmes generally select problems which they can satisfactorily solve, rather than anomaly problems. A mature discipline can be recognized through research programmes, where new theories with explanatory power are created, not only new facts. Immature disciplines can produce valid research as well but with disconnected theories. Lakatos advocated theoretical pluralism, rather than one predominant paradigm as Kuhn did. (Lakatos, 1970.)

2.2.4 Emergence of new disciplines

New fields of research arise with new discoveries of new phenomena, new technology or new methodologies (Fishman et al., 2008; Glynn, 2022). These new fields of research may or may not evolve to new disciplines due to various reasons, such as educational politics, lack of acceptance in the larger scientific community or society (Clark, 2006; Fishman et al., 2008).

According to Niiniluoto (1995), there are six different models for how new disciplines emerge. The first one, separation from philosophy can be traced back to the development of the natural sciences. At first everything was studied under philosophy but then separated to scientific specialities, such as physics and mathematics. The second model is created by branching or migration from other sciences. (Niiniluoto, 1995.) This branching can be also called internal emergence of disciplines. Internally disciplines emerge through internal intellectual processes and internal social processes (Hofstetter, 2012; Lemaine et al., 2012). Internal differentiation is a process of division inside the discipline where new research fields evolve into new discipline of scientific specialization (Coccia, 2020).

In the third model, a completely new subject matter for investigation emerges (Niiniluoto, 1995). If a completely new subject matter emerges, this can be also called external emergence of disciplines. New problems arise that do not seem to fit into any existing discipline and there is a need to form a completely new discipline to investigate these phenomena. (Hofstetter, 2012; Lemaine et al., 2012).

The fourth model is the collecting of related disciplines. The fifth model, is the inclusion by theoretical integration of separate disciplines and finally, the sixth model is the scientification of human arts and technologies. (Niiniluoto, 1995.) The last model means for example, the scientification of old and new academic professional disciplines, such as nursing science. This is where knowledge has been accumulated and its own scientific discipline provides a source for knowledge development. (Gieryn, 1983; Hofstetter, 2012.)

2.3 Organizing the paradigm through disciplinary matrix

Next, the disciplinary matrix and its different elements are presented. Disciplinary matrix can be viewed as a common perspective, a framework that offers members of a discipline guidelines on how to approach and resolve issues (Kuhn, 1970b). The disciplinary matrix can be used to organize the content of a paradigm, as a paradigm is an abstract concept that can be difficult to illustrate (Jaksland, 2021). A disciplinary matrix has been utilized in recent years to organize the content for example in design science (Roy & McLain, 2024), palaeontology (Estrup & Achiam, 2019) and in the paradigm of interdisciplinary research (Boon & Van Baalen, 2019). Organizing the paradigm through a disciplinary matrix can be useful to unify the diverse educational traditions inside the discipline, and for critical reflexion in the academic development of the discipline (Roy & McLain, 2024). It is useful as a framework enabling the researchers to communicate their disciplinary perspective (Boon & Van Baalen, 2019).

A disciplinary matrix aids in visualizing the abstract concept of a paradigm. A disciplinary matrix contains the shared values, metaphysical presumptions, symbolic generalizations and shared exemplars of the scientific community (Figure 2). (Kuhn, 1970b). These elements of the disciplinary matrix support and reinforce each other (Boon, 2017).

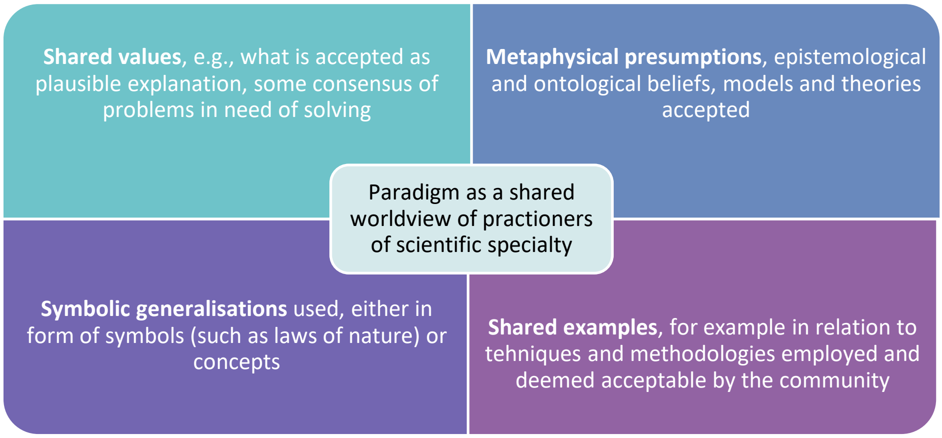

Figure 2. Elements of the disciplinary matrix according to Kuhn (1970b)

In this study a disciplinary matrix is used to organize the elements of the paradigm of the discipline of radiography science. The following chapters present in more detail how the elements of the disciplinary matrix are understood in this study.

2.3.1 Shared values: phenomena of interest and research priorities

Value is a concept with many meanings. It can have moral a dimension: what is considered as right conduct. It can also mean that something is worthy economically, socially or aesthetically. (Biedenbach & Jacobsson, 2016.) In Kuhn's thinking, shared values refer to shared scientific values, such as what is accepted as a plausible explanation within discipline. For example, causal explanation where it is assumed that a certain cause leads to a certain effect, might be in some disciplines the only valued way to reach the right conclusion. Values also define how such things as accuracy or consistency are seen within the discipline. Additionally, values guide the choices made, which problems are deemed more important than others to be solved or which theories are more plausible. (Kuhn, 1970b.) If for example, environmental sustainability is valued, then more effort and resources are directed towards that research (Biedenbach & Jacobsson, 2016). Similarly, the availability of funding can impact what type of research is conducted. (Resnik & Elliott, 2023). In this study, the assumption is made that the phenomena of interest in a discipline and the research priorities of a discipline are guided by what is valued. Thus, even though the phenomena of interest are not values per se, they and the priorities of research indicate what is valued.

2.3.2 Symbolic generalizations: the conceptual development of the discipline

Symbolic generalizations are the theoretical content of the discipline, such as laws in a symbolic form, for example, the law of mechanics in physics (Boon, 2017; Kuhn, 1978) or concepts expressed in words (Kuhn, 1978). They are expressions that can be accepted by the scientific community without too much questioning (Kuhn, 1978). In health sciences there are very few (if any) symbolic generalizations that can be expressed in laws. The laws used are generally borrowed from other sciences. Concepts thus can be understood as the symbolic generalizations used. In general, it can be said that conceptual clarification is needed for the knowledge base to develop (Hellman, 2024; Tofthagen & Fagerstrøm, 2010). Concepts convey the ideas of the phenomena under investigation and determination of the essential or core concepts of the discipline is important for both the understanding and the development of a discipline (Eriksson, 2010). In this study, the core concepts and the interrelation statements are understood as the symbolic generalizations of the discipline of radiography science.

2.3.3 Shared exemplars: accepted methodologies

Shared exemplars are accepted ways to solve problems, for example in relation to techniques and methodologies employed. When encountering a problem, members of the discipline seek exemplars as to how the problem in question has been solved previously. This is a socialization process in that particular scientific community. (Kuhn, 1978.) In natural sciences, the longstanding ethos has been reliance on experimental research designs, quantitative methodologies and correspondingly on methods with objective measurements (Boyd & Matthiessen, 2024). Whereas for example, in human sciences more emphasis has been placed on interpretation of human experience with various qualitative methodologies (Brown, 2019; Dua, 2021). In health sciences, it is understood that the phenomena are complex and require inquiry with different types of methodologies (Hamilton & Finley, 2019). However, it has been argued that within health sciences randomized controlled trials and other intervention studies are preferred over studies using qualitative methodologies (Greenhalgh et al., 2016). In this study, the methodological choices are understood as shared exemplars of the discipline.

2.3.4 Metaphysical presumptions: the nature of being and the nature of knowledge

Metaphysical presumptions within the discipline include, e.g., the ontological and epistemological presumptions of how the nature of being and the nature of knowledge are understood (Kuhn, 1970b). Ontology refers to the nature of being and a way reality is understood. In ontological realism, reality is seen as being objective and independent from the mind. The perceptions may be subjective but real-life phenomena exist even if there is no one to observe them. With scientific methods, it is possible to pursue universal truths about phenomena. (Garrett & Cutting, 2015.) Relativistic ontology argues that there are no universal truths and phenomena are just what we have labelled them in our minds. If there is no one to observe, the phenomena do not exist. (Weaver & Olson, 2006.)

The metaphysical presumptions are often presented in the form of models (Kuhn, 1970b). These models give the members of the discipline a way to understand the phenomena they are investigating (Roy & McLain, 2024). In this study, metaphysical presumptions are understood as the epistemological and ontological choices the researchers in the discipline make.

2.4 Radiography science as one discipline of the health sciences

In this chapter, radiography science has been described as one discipline of the health sciences. Subsequently, nursing science development is used as an example of how a paradigm has developed and how it has been investigated. Finally, a reviewed is presented concerning how radiography science as a discipline has developed and what is currently know about the paradigm of the discipline.

Radiography science is claimed to be a health science discipline investigating phenomena related to medical imaging and radiation therapy and the patients undergoing these procedures and treatments, as well as the interaction between the radiographer and the patient (Metsälä & Fridell, 2018; Cox et al., 2009; Pakarinen & Jussila, 2007). Radiography science shares a corresponding history with nursing science and they both can be considered as an art and a science (Marchuk, 2014; Metsälä & Fridell, 2018). They both have emanated from a professional history of the health care professions (Ferris & Winslow, 2009; Tobbell, 2018). They share similar interests to promote health and well-being (Kalkas, 1986). Therefore, it seems reasonable to review them together because nursing science has a longer history of defining its paradigm (Weaver & Olson, 2006) and radiography science can take advantage of this.

2.4.1 Health sciences

Health sciences is a broad field, connecting various disciplines with a common interest in health and wellbeing, and the improvement of these through research with varying methodological approaches (Ratti & Russo, 2024). The OECD divides health sciences into health care sciences and services (including administration and financing), nursing, nutrition, dietetics, public and environmental health, occupational health, sport and fitness sciences, social biomedical sciences and medical ethics (OECD, 2006). Radiography science has not been mentioned in the OECD listing, however, radiography science has been classified in other sources as a health science discipline (Pakarinen & Jussila, 2007).

The common features in different health sciences paradigms are human orientated and patient centred approaches, with a shared value of health (Turcotte et al., 2023). Health sciences can be seen as both value laden and value promoting, as the interest is not often how things are but rather how they ought to be and what health choices to make. In the sphere of sciences, health sciences are not merely located in the biophysical natural sciences but also the sociological-humanistic sciences, because the concepts of health and wellbeing are complex. (Ratti & Russo, 2024; Acolin & Fishman, 2023.) To understand what effects health or wellbeing, there is a need to understand the bio-chemical factors, socioeconomical factors, ethical factors as well as the behaviour of human beings. (Ratti & Russo, 2024; Acolin & Fishman, 2023).

2.4.2 Nursing science and caring science (meta)paradigms

Nursing science, like any new discipline, has had to prove its own knowledge base and unique perspective (Newman, 1994). At the end of the 1950s, a growing number of nurse educators began to emphasize the need to establish a separate academic discipline (Tobbell, 2018). In the 1950s and 60s, most nursing scholars were educated in other disciplines and influenced by the medical model and positivist epistemology (Chen, 2022; Tobbell, 2018), even though the first doctoral nursing programme had already been established in the United States in the 1930s (Tobbell, 2018). However, the nursing scholars came to question the methods employed as positivistic approaches are not always the best way to approach many nursing phenomena. At the same time, many nursing scientists were educated in anthropology or sociology and they realized there are multiple ways to view the world. The nursing science started to formulate their separation from medicine by claiming more humanistic and holistic perspective to health and well-being. (Monti & Tingen, 1999; Tobbell, 2018.)

The nursing science paradigm has been discussed since the 1970s, when the concept was first introduced by Margaret Hardy (Bender, 2018). Kuhn’s ideas of paradigms were influential in this discussion and there is ongoing discussion whether nursing science is in state of preparadigmatic, normal or mature science and whether nursing science has one or multiple paradigms (Younas & Parsons, 2019). Nowadays, there are mainly two different traditions within nursing academics regarding the paradigm, those who see health as the main focus of nursing and those who see caring as the main focus (Kalkas, 1986; Newman, 1994).

Health as a focus for discipline

The focus of a discipline distinguishes its essence from that of other disciplines (Willis et al., 2008). There are several nursing science theorists who have presented their views on the focus of the discipline, starting from Nightingale. A comprehensive review is not provided here; instead, a few influential and widely spread theories are presented. Peplau's (1952) theory of interpersonal relations in nursing had impact in making the patient and the nurse-patient relationship in the focus. Rogers theory of unitary human-beings facilitated the nursing science holistic view of health (Newman et al., 2008). Rogers argues that nursing science focuses on the exploration of humans and environments as a unified, indivisible, and irreducible whole. The view of unitary human beings, is a holistic view where individuals cannot be separated from the energy fields, and according to Rogers, is distinct to nursing science and thus makes the discipline unique. (Rogers, 1992.) Following the idea of unitary human beings, it has also been suggested that the unifying focus for nursing science is the nurse-patient relationship and the core concepts are health, caring, consciousness, mutual process, patterning, presence and meaning (Newman et al., 2008).

The nursing science metaparadigm was introduced by Fawcett in 1984, focusing on health dimensions. According to Fawcett (Fawcett, 1996), the nursing metaparadigm identifies an area of research for the discipline. It is distinctive from any other research areas and involves all phenomena of interest, does not mirror any specific paradigm or conceptual model and is recognized globally. A metaparadigm is a unifying higher-level paradigm that consists of several paradigms and can be explained through four core concepts identifying the phenomena of interest in a discipline and in the relational statements of those concepts. These core concepts in nursing science are person, health, environment and nursing actions. (Fawcett, 1984, 1996.) Person is all the different patients or customers who benefit from nursing actions, health is the persons state of well-being, environment is the context and the setting where nursing occurs and nursing is the actions taken by nurses and the outcomes of the nursing activities (Fawcett, 1996). Nursing science focuses on various processes within its scope, including human welfare, behaviour in interaction with the environment during both normal and critical situations, nursing interventions, and the health of individuals in relation to their surroundings (Fawcett, 1996). In a recent article, Fawcett developed the metaparadigm concepts to human beings, global environment, planetary health and nursologists' activities (Fawcett, 2023).

Kim (Kim, 1987) organized the nursing knowledge system into four domains: client domain, the domain of environment, the client-nurse domain, and the practice domain. The domains represent a larger group of phenomena that are of interest to nursing science. Kim criticized the metaparadigm concepts, claiming they are not satisfactory enough to describe nursing science. The domains she proposed give structure to the nursing paradigm and according to her, are useful when analyzing and identifying the boundaries of nursing science interests, guiding the conceptualization of phenomena of interest and assessing the knowledge development in nursing science. (Kim, 1998.)

Another view is that nursing science is concerned with the process and experience of humans undergoing transitions. Facilitating transitions is the focus of the discipline. These transitions are for example, individual developmental transitions (e.g., adolescence), situational transitions (e.g., changing professional roles) or health/illness transitions (e.g., recovery process). (Meleis & Trangenstein, 1994.) It has also been suggested that the nursing science metaparadigm concept should include human living (Kim, 2000).

Caring as a focus for discipline

In caring science, caring is the focus of the discipline (Watson, 2007; Eriksson, 2002). This view of the discipline for nursing was endorsed by Watson (2007) and in Finland by Eriksson (2002). According to Eriksson (2002), the name caring science refers to the focus being on caring, not the profession of nursing. Caring science is humanistic discipline, investigating living phenomena of human experiences in caring, health and healing, including spiritual and philosophical-ethical-moral dimensions. Caring is alleviating human suffering and preserving health and life. The living phenomena are manifested in caritas processes, caritas being the connection between caring, loving and human living processes. (Eriksson, 2002; Watson, 2007.) The metaparadigm concepts in caring science are caring, human being, health, suffering and environment (Näsman, 2020). The relationship between the carer and the one being holistically cared is in the centre (Bergbom et al., 2022).

Evolving paradigms

The multiple paradigms in nursing science are an indication of a healthy and creative science and they enable the discipline to investigate human behaviour from different viewpoints (Monti & Tingen, 1999). It is also noteworthy that paradigms evolve over time (Fawcett, 1996). The ever growing role of technology, as well as biotechnology and informatics within nursing has inspired the addition of technology as one core concepts in the nursing metaparadigm (Bayuo et al., 2023; Johnson & Carrington, 2023; Monteiro, 2016).

2.4.3 Development of the discipline of radiography science

Development of the discipline and education

The development of the discipline of radiography has emerged from the scientifical discovery of X-rays, which led to the development of technology to image and treat people with radiation (Decker & Iphofen, 2005; Larkin, 1978). The first society of radiographers was established in United Kingdom in 1921 and radiography has evolved from vocation to profession as the radiography services have increased in complexity (Larkin, 1978). Research in its own field has been recognised as a key element to develop the profession, discipline and knowledge base in radiography (Nixon, 2001; Saukko et al., 2021) and not least because whoever controls the new knowledge and techniques, has a dominance over the field (Larkin, 1978).

Radiography education has significant differences globally (McNulty et al., 2021). In some countries there are separate radiation therapy programs and diagnostic imaging programs but nowadays in Europe the orientation is towards combined programs (EFRS, 2019). However, generally it can be said that in countries where the radiography education has been moved to higher education, the research activity has increased as well (Decker & Iphofen, 2005). In the United Kingdom and Finland, this education was moved to higher education in the 1990s (Challen et al., 1996; Pakarinen & Jussila, 2007), in Sweden in the early 2000s (Andersson et al., 2020). In the United States, the education in radiologic sciences still varies from state to state, and can be anything from a hospital based certification to higher education (Cox & Killion, 2010).

The academic workforce, with varying teaching and research responsibilities, in radiography encompasses approximately 1.67 % of radiographers, according to a study made in the United Kingdom (Knapp et al., 2017). In radiography academics, the highest education level is typically a master's degree, followed by a doctoral degree. A small percentage of individuals hold a bachelor's degree. (Zanardo et al., 2023.)

Radiographers as researchers

Clinical radiographers are health care professionals working within medical imaging, radiation therapy and nuclear medicine. They operate at the intersection of patient care and technology, emphasizing patient safety, particularly in terms of radiation safety and protection. (Reeves & Decker, 2012.) Academic radiographers are both educators and researchers or just one or the other (EFRS, 2022; Zanardo et al., 2023). According to EFRS, research should be a part of both clinical and academic radiographers' work (EFRS, 2022) and there has been several publications promoting the need for radiographers to do research (Iweka & Hyde, 2023; Paulo, 2020; Hogg et al., 2020; Vikestad et al., 2017). Radiographers generally have a positive attitude towards evidence-based practice and an interest towards research but many barriers to conducting research have been reported globally. These include challenges with research infrastructure, funding, research skills and the overall research culture (Al Balushi et al., 2024; Oliveira et al., 2024; Vils Pedersen, 2023; Saukko et al., 2021; Vikestad et al., 2017; Probst et al., 2015; Abuzaid et al., 2023). The motivators to pursuing a research career have been reported to be the importance of radiographic research, contribution to patient care, importance of radiographer participation to research, self-motivation and professional development (Abuzaid et al., 2023; Diaby et al., 2024; Vils Pedersen, 2023).

Radiographers are more likely to be assistants or collectors of research data than lead researchers (Dennett et al., 2021; Saukko et al., 2021) and research activity is lower than in other allied health professions (Probst et al., 2015). Being a lead researcher requires skills often gained with a doctoral degree. It is estimated that around 0.1-0.3 % of the workforce of radiographers have a doctoral degree (Andersson et al., 2020; Ekpo et al., 2017; Metcalf et al., 2010; Snaith et al., 2016). In comparison, the number of nurses with a doctoral degree has been estimated to be around 1.0- 1.9 % of the workforce (Orton et al., 2022; Rosenfeld et al., 2022). It has also been reported that radiographers often gain their doctoral degree closer to the end of their active working years, leading to short research careers (Andersson et al., 2020; Ekpo et al., 2017; Metcalf et al., 2010; Snaith et al., 2016). The lack of dedicated academic radiography paths in many countries, such as a lack of doctoral programmes, is also a challenge, leading many radiographers interested in research to pursue a career in other fields (Diaby et al., 2024; Zanardo et al., 2023).

Research domain of the discipline of radiography science

Research is essential to support high-quality, safe and efficient services within radiography (Neep, 2021; Strudwick et al., 2021). Research is important for the clinical practice, patients and professionals alike (Diaby et al., 2024). Without research the services provided in radiography would deteriorate, as well as the progress in diagnosis, treatment and care (Hogg et al., 2020). Research has also significant impacts on the education of radiography, the management of radiography services, and the professionalism of radiographers (Malamateniou, 2009).

Radiography science is dualistic by nature, containing humanistic and technical elements. The nature of radiography science knowledge can be located somewhere between natural sciences, technology and humanities (Ahonen, 2008; Castle, 2000; Hammick, 1995). This is supported by the study of epistemology of radiography science research, claiming that the knowledge interests of radiography science are almost equally aimed at developing, assessing or explaining technical solutions as well as understanding phenomena related to human perceptions within radiography (Metsälä & Fridell, 2018).

The paradigm of the discipline has been scantly investigated and there has been very little discussion in the radiographic community about the philosophical foundation of the discipline. The research focus of radiography science was investigated in Finland by Sorppanen in her doctoral dissertation (Sorppanen, 2006). In Finland, radiography science has developed by branching from nursing science and the starting point for the study was a nursing science metaparadigm and the four core concepts of nursing science: person, health, environment and nursing. Sorppanen investigated the core concepts from radiography point of view and concluded that in radiography science, the core concepts differ from nursing science and are the radiographers work within healthcare, health and illness, the environment and the individual. The research focus comes from the dynamic connections of these core concepts. (Sorppanen, 2006.) In the United Kingdom, where radiography research has been perhaps most active in recent decades, the discipline has developed through the scientification of a professional discipline and the need to develop evidence-based practices (Malamateniou, 2009). However, radiography science has not developed similarly in all parts of the world and therefore these findings cannot be generalized to radiography science globally.

A study conducted in Sweden identified the main research areas in radiography science as structural factors, clinical radiography, advancements in radiographic technology, and educational methods (Lundgren et al., 2019). The ontological substance of radiography science has been investigated to consist of X-ray and radiation, human beings and opaque objects, as well as processes and images. Common characteristics with other health sciences is the interest to human, health and health promotion but radiography differs from other disciplines as humans are often seen as objects in need of an examination or treatment. (Lundgren & Lundén, 2023.) It should be noted that in Sweden radiography science contains only diagnostic radiography, radiation therapy is a terrain of nursing.

Quantitative methodologies have been said to be more predominant in radiography science (Murphy & Yielder, 2010; Ng & White, 2005), however, qualitative methodologies have been advocated to create a deeper understanding of the phenomena related to experiences, perceptions (Adams & Smith, 2003; Hammick, 1995) and behaviours (Cuthbertson et al., 2020). Research published within radiography specific peer reviewed journals is often conducted with quantitative methods, descriptive or non-randomized single centre experimental designs being the most common. Qualitative and mixed-methods studies have been published less frequently (Iweka et al., 2024). Another study indicated, that the methods used in Radiography journal are most often surveys, qualitative approaches, clinical studies and experimental designs (Nightingale, 2017). Review of Swedish doctoral theses in radiography science indicated there is variety in methods used. The most frequent data collection methods were interviews, questionnaires and documents. Qualitative content analysis was the most common analysis method, followed by statistical analysis methods. (Lundgren et al., 2019.) The somewhat conflicting findings support the knowledge that radiography science does not have any unified methodology.

The aims of radiography science research

The aims of research represent a strategic goal that guides the development within the discipline. There are different statements made regarding the aims of radiography science research. The College of Radiographers (CoR) in the United Kingdom has outlined three primary research aims: facilitating research across all levels of radiography practice and education, enhancing the impact of radiography through high-quality research aimed at improving patient care and radiographic services, and increasing research capacity (Strudwick et al., 2021). The EFRS (EFRS, 2016) has six aims for research: promoting the development of radiography science and validated methodologies, supporting development of research groups, developing radiography specific concepts, promoting the dissemination of research outcomes and investigating opportunities for research funding. The radiography science research focus, according to EFRS, is on medical imaging, radiotherapy and nuclear medicine clinical practice, technology development, patient care, education, leadership and management. (EFRS, 2016.) The EFRS statements for research emphasize the significance of research to radiography practice, patient involvement in all stages of research process and radiographers taking responsibility for research. The priority in research should be placed on projects aiming to improve quality of care, improve diagnosis and treatment, safety of new technologies or techniques, and minimize radiation dose. Research is also needed to develop radiography science. (EFRS, 2022.) In Finland, specific statements regarding radiography science research aims have not been made, but the statements from the EFRS are used.

Radiography science's boundaries to related disciplines

Radiography science is said to be aligned to radiology, nursing and medical physics but having a unique perspective (Lundgren & Lundén, 2023). Boundary work requires determining how a discipline draws from other discipline's theories and research methods, as well as identifying what are the differing features of the discipline compared to its aligned disciplines (Tobbell, 2018). In relation to this, it is known that radiography science has much imported knowledge from other fields, namely from medicine and physics (Nixon, 2001) and other health sciences, such as nursing science (Lundén et al., 2016; Lundgren et al., 2019) and radiography science is pluralistic in its methodologies (Metsälä & Fridell, 2018; Lundén et al., 2016).

Radiography science is a discipline focused on medical imaging and radiation therapy. These are environments where radiographers usually control the technical performance of imaging or treatment and are responsible for the care of clients or patients (EFRS, 2022). Through these areas of dominance, it is possible to identify the differing features to related disciplines. Medical physics in this environment is focused on evaluating and analysing medical technology and measuring quality and radiation (Samei & Grist, 2019). Radiography science on the other hand is more interested in the functionality of the processes and services and the actual technical performance (Ahonen, 2008; Reeves & Decker, 2012). Nursing and radiography science have similar interests to patient care, but their view is different. Nursing has a more holistic view of health and care (Willis et al., 2008) whereas in radiography, care is often more short term and task focused (Strudwick, 2016). Radiology is a medical discipline producing diagnosis through interpretation of medical images (Petrou et al. 2009). In diagnostic radiography the process before the diagnosis is essential (Reeves & Decker, 2012).

These distinctions however are not always clear. Measuring quality and radiation protection are also important in radiography science as in physics (Mekis et al., 2024). Moreover, sometimes nurses are responsible for patient care in medical imaging and radiation therapy environments and there are studies conducted in nursing science within these environments (Leclerc et al., 2024). An increasing number of radiography science studies are also focused on image interpretation and other phenomena previously belonging to the realm of radiology (Clerkin et al., 2024; Squibb et al., 2015). The boundaries are transient.

2.5 Summary of the literature

This study examines radiography science as a discipline. In the theoretical background, three models of scientific development were presented. They are in some ways incommensurable. Poppers (1959) model represents an idea of a science as an open society, and he emphasized the unity of science. Kuhn (1970b) however, thought that science is not unified but divided into closed communities, governed by a paradigm. Lakatos (1970; 1971) wanted to examine science through the hard core of research programmes. When examining a specific discipline, such as radiography science, it seems more fitting to treat the discipline as a closed community governed by a paradigm, as in Kuhns model, rather than examining the unity of science. Lakatos' hard core could be examined, if radiography science had more established theories, as the development of science according to Lakatos can be seen though the hard core, meaning the theories that are widely accepted within the discipline.

Even though Kuhns model has been criticized, in this study it will be used because it is functional for new fields as it describes the early stages of a scientific development more properly than its competitors. It also organizes the paradigm through a disciplinary matrix which brings structure to an abstract conception. Kuhn model has been used widely in many different fields, though he originally referred only to natural sciences. For example, in nursing science, Kuhns idea of paradigms was a guiding philosophical view in the early development of the discipline.

There are six models by which new disciplines can emerge (Niiniluoto, 1995). Radiography science has been claimed to have emerged through internal differentiation, branching from nursing science (Sorppanen, 2006). However, it can also be said to have emerged through the scientification of the professional discipline (Malamateniou, 2009). This is not contradictory due to the fact that radiography science has developed differently in different parts of the world.

There is a societal need for radiography science as research is essential to support high-quality, safe and efficient services (Diaby et al., 2024; Hogg et al., 2020; Neep, 2021; Strudwick et al., 2021). The radiography science research community has stated aims for the research (EFRS, 2016, 2022; Strudwick et al., 2021) and radiographers are motivated to develop radiographic services but lack time, funding and proper education (Al Balushi et al., 2024; Oliveira et al., 2024; Vils Pedersen, 2023; Saukko et al., 2021; Vikestad et al., 2017; Probst et al., 2015; Abuzaid et al., 2023). One challenge identified is the lack of educational paths for doctoral degrees in this field (Diaby et al., 2024; Zanardo et al., 2023). To develop this, the philosophical foundation needs to be strengthened. Some studies have been conducted on the research focus (Lundgren et al., 2019; Sorppanen, 2006), epistemology and ontology (Lundén et al., 2016; Lundgren & Lundén, 2023; Metsälä & Fridell, 2018) and methodologies (Iweka et al., 2024; Lundgren et al., 2019; Nightingale, 2017) of the discipline but the paradigm of the discipline as a whole has not been investigated previously.

3 Aim, objectives and research questions

The aim of this study was to explore radiography science as a discipline and to propose a framework for the paradigm of the discipline.

To reach this aim, a set of objectives was set for the three phases of the study (Table 2). In Phase I, the objective was to identify the phenomena radiography science investigates and to determine the research priorities and core concepts. In Phase II, based on the findings of Phase I, the objective was to clarify the identified priority areas of radiography science by defining the core concepts and their interrelationships, as well as describing the epistemic interests and nature of knowledge within the discipline. In Phase III, the objective was to synthesize the knowledge gained from Phases I and II, using Kuhn's idea of a disciplinary matrix to gain an understanding of the paradigm of the discipline of radiography science. The specific research questions this thesis seeks to answer are:

Phase I:

1) What phenomena does radiography science as a discipline investigate? (Paper I)
2) What are the research priorities in radiography science? (Paper II)

Phase II:

1) How have the core concepts of radiography science been defined? (Paper III)
2) What are the interrelationships of the core concepts? (Paper III)
3) What are the epistemic interests of radiography science? (Paper IV)
4) What is the nature of knowledge in radiography science? (Paper IV)

Phase III:

1) What is the paradigm of radiography science?

Table 2. Phases of research and research questions (2020-2025).

Phase and research question	Design and method	Setting	Sampling	Data collection	Analysis	Outcome
Phase I identification (2020-2022)						
What phenomena does radiography science as a discipline investigate? (Paper I)	Descriptive design - Scoping review	Existing literature on what is known about the phenomena radiography science investigates	Systemized search of peer reviewed articles of any design pertaining to the research of the discipline of radiography science or research interests	n=14 articles fulfilling the inclusion criteria	Inductive content analysis	Six main phenomena radiography science investigates were identified
What are the research priorities in radiography science? (Paper II)	Exploratory design - Delphi technique	Consensus sought from panel of experts on radiography research, recruited around Europe	Purposive sampling. Participants n=24 in first round and n=20, second round.	Survey, two rounds	Descriptive statistical analysis, stability of responses between rounds, interquartile range	Four priority areas of research and core concepts of radiography science identified
Phase II Clarification (2022-2024)						
How have the core concepts of radiography science been defined? What are the interrelationships of the core concepts? (Paper III)	Exploratory design - Document analysis	Core concepts and bilateral statements indicating relationship examined	Purposive sampling. Dissertations from the field of radiography science, investigating the core concepts	n= 53, all sections of the dissertations, apart from the methodology section	Semantic analysis statement synthesis	The attributes and properties of the four core concepts defined and statements expressing their interrelations presented
What are the epistemic interests of radiography science? What is the nature of knowledge?	Exploratory design - Document analysis	Existing studies in radiography science and the descriptions of the aims, purpose and methodologies of those studies	Purposive sampling. Dissertations from the field of radiography science, investigating the core concepts	n=53, aims and purpose of the dissertations and methodology section	Abductive analysis	Different types of epistemic interests and knowledge types identified.

Phase III synthesis (2024-2025)						
What is the paradigm of the discipline of radiography science?	Interpretative synthesis using Kuhn's disciplinary matrix	Evaluating the data of phases I and II	Not applicable	Not applicable	Interpretive synthesis	Framework for the paradigm of the discipline of radiography science

4 Materials and Methods

This chapter presents the overall study design, data collection and analysis methods (Table 2) and ethical considerations. Different approaches were used in different phases of the study.

4.1 Design, settings and sampling

Phase I

In the first phase of the study the objective was to identify the phenomena radiography science investigates, the research priorities and the core concepts. The design was two-staged: descriptive when the existing literature was mapped, and exploratory when based on existing literature; for which a consensus was sought. The sampling for existing literature was done by systematically seeking peer-reviewed articles of any design pertaining to the research on the discipline of radiography science or research interests. Sampling for the consensus was done with a purposive sampling of radiography experts.

The existing literature was mapped with a scoping review. The scoping review was conducted using the PRISMA framework for scoping reviews (Tricco et al., 2018). A scoping review was used to map the existing knowledge of the phenomena radiography science investigates. Scoping reviews have been used for example, in synthesizing existing evidence, identifying concepts and knowledge gaps (Tricco et al., 2018). In this study, a scoping review was found suitable as there was scant previous knowledge on the topic and the main aim of Phase I was to identify the phenomena radiography science investigates and ultimately to identify the core concepts of the discipline. A scoping review alone was not sufficient for this task but after identifying the main phenomena, there was a need to study further. Further study identified which of the phenomena in the scoping review were considered by the radiography researchers' community as the priorities for research and thus the core concepts.

The Delphi technique was used to identify the priorities of the research. The Delphi technique is a methodology where expert opinions are gathered to form a consensus on the matter at hand (Keeney et al., 2011). Experts in this study, were defined as people who have formal education in radiography and have participated in radiography research. The expert panel was recruited through an advertisement in the European Federation of Radiographers Societies (EFRS). The traditional Delphi technique generally uses three iterative rounds but, in this study, only two rounds were conducted. The decision to use two rounds was made because there was no need for an open first round, as the research areas of radiography science, the phenomena it investigates, were already identified in the scoping review. The Delphi survey questionnaire was formed based on the scoping review results. In this phase, priorities were established, and it concluded that the four main research areas identified as priorities also represent the core concepts of the discipline.

Phase II

In Phase II, the objective was to clarify the identified priority areas of radiography science by defining the core concepts and their interrelationships; as well as describing the epistemic interests and nature of knowledge within the discipline. Sampling was done by systematized method.

A document analysis (Bowen, 2009) was used as a method to define the core concepts and to examine the interrelationships of the concepts. Document analysis is a methodology were existing documents, e.g., case reports, policy documents or any other documents in textual form are analysed to gain an understanding through interpretation of the documents. (Bowen, 2009). Document analysis was chosen because it was thought that the conceptual definitions are in the purest form as a textual representation of the documents of the discipline. There are several documents that can be associated with disciplines. These could be e.g., curriculums, educational materials, publications (books, reviews etc.) and published original research. In this study, dissertations were chosen as the documents. In dissertations, doctoral candidates generate new knowledge for the discipline but they also generally build upon existing knowledge of the discipline (Zeng & Pang, 2012). Dissertations are also generally openly available, even though sometimes difficult to locate. Therefore, dissertations seemed suitable for finding descriptions of the core concepts and assumably the interrelationships were possible to define from these documents. It was decided to use entire dissertations, apart from the methodology section. Phase II also involved the exploration of the epistemic interests and nature of radiographic knowledge. This involved using the same documents to investigate the core concepts but this time, the aims, purposes, and methodology sections were scrutinized.

Phase III

The objective for Phase III was to examine the knowledge gained from Phases I and II to gain an understanding of the paradigm of the discipline of radiography science and to develop the framework for the paradigm. A paradigm is an abstract and complicated concept; therefore Kuhn's (1970b) disciplinary matrix was used to organize the data, and it gave the theoretical structure for the framework. There are several ways to synthesize knowledge. A method chosen in this study was creating a taxonomy. Taxonomies are a way of classifying knowledge into hierarchical structures and they can show the conceptual range of findings (Sandelowski & Barroso, 2007; Syyrilä et al., 2024). Taxonomies can be made by organizing data into hierarchical thematic themes, or domains, inductively from the data. Another way to organize the data into a taxonomy is by pre-existing theoretical categories. (Spradley, 1979.) The latter was chosen, and the knowledge gained was organized through the disciplinary matrix and its existing categories of shared values, symbolic generalizations, shared exemplars and metaphysical presumptions.

4.2 Data collection

Phase I

In the scoping review (Paper I), a data search was conducted in four different databases to identify the literature extensively. The selected databases were Science Direct, PubMed, CINAHL and Scopus. Search terms were purposively left broad, to be able to identify as many relevant studies as possible. The search terms used with different combinations were radiography, research focus, research paradigm, research interest, radiography science and medical radiation science. Altogether 14 peer-reviewed articles were selected for the review (Figure 3). There was variety within the selected articles. Three articles were reviews and the rest original research studies, using different methodologies. The studies these articles reported were conducted in Australia, United Kingdom, and the Nordic countries (Finland, Sweden and Norway). The quality of the selected articles was evaluated using the Joanna Briggs Institute quality assessment criteria for analytical cross sectional studies (Moola et al., 2020), case series (Munn et al., 2020), qualitative research (Lockwood et al., 2015), systematic reviews (Aromataris et al., 2015) and texts and opinions (McArthur et al., 2015). Two researchers selected the articles and evaluated the quality independently.

In Paper II, the Delphi panel recruitment resulted in a panel of 28 experts from which 24 responded to the first round and 20 to the second round. Four experts who indicated they wished to be part of the panel never contributed to the study. The participant experts were from ten different European countries (United Kingdom, Norway, Denmark, Switzerland, Sweden, Hungary, Italy, Malta, Portugal and Spain). The most common academic qualification was a doctoral degree (54.2/55 %), followed by a master's degree (37.5/35 %). The majority of the experts indicated their entry education to a profession had been diagnostic radiography (58.3/65%). Other entry education subjects were a dedicated radiotherapy programme (12.5/10%) and a combined programme of diagnostic radiography, radiotherapy and nuclear medicine (29.2/25%) respectively. Seventy percent of the experts (n=17) in the first round (75 % second round, n=15) were working as academics and only two experts as clinical radiographers (one in the second round).

Data was collected with a survey designed from scoping review results. The experts rated different research topics according to their importance to radiography science research (seven-point Likert scale). Research topics were grouped into six main categories which presented the main phenomena identified in the scoping review. Altogether 84 topics were rated in the first round. The experts were given a chance to suggest new important research topics and 25 new topics were introduced in the second round for rating. In the second round, experts received their own answers as a reminder and median and range of other experts' answers. The research topics were rated again, and experts were advised that they were allowed to revise their opinion (Figure 3).

Phase II

Dissertations for the document analysis were sought through two databases: OATD (open access thesis and dissertations) and ProQuest thesis and dissertations. It was not possible to identify all radiography science dissertations globally, nor was it practical either as the number of dissertations to analyse might have been too exhaustive. As the core concepts were under scrutiny, it was decided to use the core concepts as search terms and involve only those dissertations studying topics related to one or more core concepts. Search terms used with different combinations included radiographer, radiotherapist, radiological technologist, nuclear medicine technologist, clinical, radiography, quality, radiation, safety, and technology. Inclusion criteria for the selected dissertations were: they needed to be in English, involve original research related somehow to the core concepts, published electronically and open access, and to be from the field of radiography science. The last criterion was most difficult to define. It is not straightforward what dissertations are from radiography science as it is not always mentioned in the publishing information of the dissertations. In cases where it was not mentioned, the decision to include the dissertation was made from the content of the dissertation and the authors information. Authors information was checked by searching for other publications related to radiography. Altogether 53 dissertations were selected (Figure 3). The selected dissertations were from United Kingdom (n= 31), the United States of America (n=17), Australia (n=2), Canada (n=1), Hong Kong (n=1) and South Africa (n=1). The dissertations were published between 1998 and 2020. The author of this thesis did the searches and selection, but the selection was discussed and checked by the research team and involved the supervisors of thesis together with the author. (Papers III and IV).

Phase III did not involve a new data collection, instead the data collected in Phases I and II were re-examined.

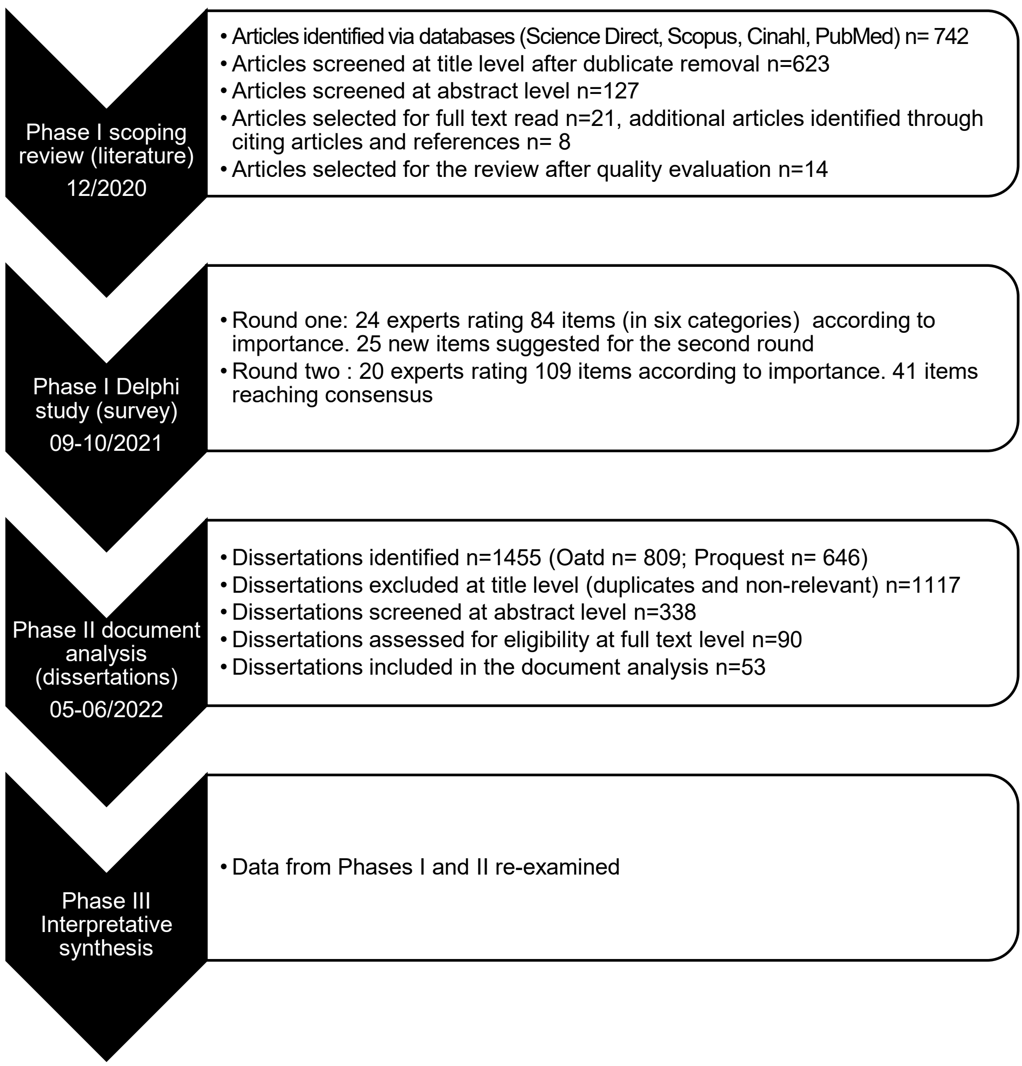

Figure 3. Data collection in Phases I-III.

4.3 Data analysis

Phase I

In the scoping review (Paper I), the data was analyzed with inductive content analysis (Elo & Kyngäs, 2008). Inductive content analysis was found suitable as there were no previous theories to draw upon. Data was first grouped into excel, where basic information was collected (the name of study, authors, year of publication, aim, participants, data collection, analysis methods) as well as the key findings. The key findings were organised around the research question, the meaning unit were the potential areas for research in radiography science. The meaning units were simplified and categorized into subcategories, categories, and main categories.

The Delphi study survey results were analysed with IBM SPSS Statistics version 27. Descriptive statistical analysis was performed to obtain an overview of the data. The data did not follow normal distribution as most variables (research topics) were rated of high importance, therefore median values and quartiles were more reliable indicators of the level of agreement. The level of consensus was measured from an interquartile range (IQR). IQR of one or less was set as the level of consensus, meaning that more than half of the opinions are within one point on the scale (Von Der Gracht, 2012). Bootstrapped paired t-test was used to measure the stability of the responses between the rounds and p-value of < 0.05 was an indication of significant changes in the responses. (Paper II.)

Phase II

The core concepts from the dissertations were first extracted to an extraction matrix (an Excel document). The extraction matrix was pilot tested with a small number of the dissertations. A validity cross-check was done by one of the supervisors of the thesis. She randomly selected 10 dissertations and made the analysis using the extraction matrix. The extraction matrix was found suitable and there were only a few differences of opinion in the analysis. These were discussed and the analysis proceeded. Nvivo 20 software was used to assist in the analysis process. There were 8 777 pages of text to analyse, so to be able to identify all the ways the concepts were used in the dissertations, the Nvivo text query function was used. The information gathered into the extraction matrix included identifying information of the document, columns for each four core concepts and situation where that concept was used, as well as columns for statements indicating bilateral relationships of each of the concepts. An analysis unit was a passage of text with the same meaning. Sentences were simplified and all sentences containing information on one or more concepts were subjected to statement analysis. Statements of interrelationship between the concepts were categorized using the classification presented by Walker and Avant (Walker & Avant, 2014) (Table 3) and significance of the statements' interrelationships was further analyzed semantically (Spradley, 1979). (Paper III.)

Table 3. Types of relationships in statements according to Walker and Avant (2014).

TYPE OF RELATIONSHIP	MEANING
Causal	Cause of the other
Concurrent	Existing together
Conditional	Occurs only in the presence of a third concept
Necessary	One and only one concept/event can lead to the second concept or event
Sufficient	The presence of the first concept guarantees the presence of the second concept
Time-ordered	Some period intervenes between first concept and the second

The epistemic interests and nature of knowledge was analysed from the dissertations aims, purpose and methodology sections using an abductive analysis approach where data and theory are analysed iteratively (Timmermans & Tavory, 2012). The starting point for the analysis was a framework of critical normative epistemology (Kim, 2010). Classifications (Table 4) made by Kim (2010) were reflected on as regard the findings of the study and classified similarly. There were some findings that did not fit into the Kim's classification and were analysed alongside theoretical epistemology literature. (Paper IV.)

Table 4. Framework for nursing science epistemology according to Kim (2010).

CRITICAL NORMATIVE EPISTEMOLOGY		
Ontology	**Cognitive need**	**Type of knowledge**
Ontology of human nature	Inferential cognitive need	Generalized knowledge
Ontology of human living	Referential cognitive need	Situated hermeneutic knowledge
Ontology of human agency	Transformative cognitive need	Critical hermeneutic knowledge
Ontology of human practice	Normative cognitive need	Ethical knowledge
	Desiderative cognitive need	Aesthetic knowledge

Phase III

The data analysis in Phase III involved organising the knowledge gained in previous phases into a disciplinary matrix, idea presented by Kuhn (1970b). This Phase did not involve new analysis of the data, but rather synthesizing the existing data and interpreting of how the data fit the categories of the disciplinary matrix and the hierarchy of the taxonomy. Spradley's (1979) idea of creating a taxonomy was utilized. The taxonomy was created by selecting first the domain for taxonomy, in this case it was the paradigm of the discipline of radiography science and then the theoretical frame to be utilized was chosen as Kuhn's disciplinary matrix. The third step, searching for possible subsets, involved determining how the gained knowledge from previous phases fit the existing categories of the disciplinary matrix. Then a tentative taxonomy was created, and this was tested by formulating structural questions, such as "what are the different kinds of metaphysical presumptions?", "is an epistemological presumption a kind of metaphysical presumption? and "are there any other kinds of metaphysical presumptions?". The complete taxonomy can be found in the results, Chapter 5.5.

4.4 Ethical considerations

All through the study, the guidelines of the Finnish national board on research integrity (TENK) was followed to ensure responsible conduct for the research (TENK, 2023) as well as the ethical principles of the Declaration of Helsinki (World Medical Association, 2001), including respecting human integrity. Specific ethical considerations in each phase are addressed next.

Phase I

There were two different data in Phase I, data collected for the scoping review and data for the Delphi study. In the scoping review all stages of the review were conducted and reported transparently. The citations of the selected articles were presented truthfully to give the proper credit to the authors of the original studies.

An ethical approval was applied and received from the University of Turku human sciences ethical board prior to starting the Delphi study (dated 7.6 2021/ref 21/2021). The data in the Delphi study contained direct identifying information from the participants. To be able to conduct two rounds with same participants, e-mail addresses from the recruits was requested. Survey background questions (age, education, country) together with the e-mail had a potential risk of identifying the participants. All the data was stored in secure place with only the author of this thesis having access to this data. The list of e-mail addresses of the participants was destroyed immediately after the two Delphi rounds were conducted as this information was no longer needed. The results of the study were reported as being anonymised. At all times the data was handled in accordance with the European General Data Protection Regulations (European Union, 2016). Participants of the study were given participant information sheets and data privacy notices. The participation was voluntary, and all participants gave their informed consent to participate in the study. A research permit was granted for the pilot survey in Finland from the Finnish Society of Radiography Research that distributed the questionnaire to its members. Another research permit was granted for the actual study participant recruitment from the European Federation of Radiographer Societies, which distributed the advertisement.

Phase II

All stages of the document analysis were conducted and reported transparently. The documents selected were openly available and no ethical approval was needed.

Phase III

All stages of the interpretative synthesis were conducted and reported transparently. This phase did not involve new data collection and therefore no ethical approval was needed.

5 Results

The results are organized according to the phases of the study and answering the research questions set. More detailed results can be found in the original publications (Papers I-IV).

5.1 Phenomena of interest and research priorities of the discipline of radiography science (Phase I)

In Paper I, a scoping review was made to discover the phenomena that radiography science investigates. Initially, a total of 117 research topics of interest were identified, and these were then grouped into six themes, representing a broader set of phenomena, i.e. observable facts or events of scientific interest.

The study revealed that radiography science investigates the profession of radiographers, the clinical practices in radiography, the safe and high-quality use of radiation, technology used in radiography, the discipline of radiography and radiography management and leadership. These six phenomena were not however placed in any order either by how much each phenomenon was investigated or how important they were thought to be. In addition, which problems inside the phenomena were prioritized was also not investigated. (Paper I.)

Paper II set out to solve this problem. All the research topics which were identified and grouped into six broader phenomena in Paper I, were evaluated by their importance to radiography science on a seven-point scale by a panel of radiography experts. In the first round, the experts were able to suggest new research topics for each phenomena category. Twenty-five new research topics were suggested. A second round of evaluations was made with the new topics suggested together with all the same ones from first round. Experts were allowed to change their opinion when given the chance to review other expert's opinions. Finally, at the end of two rounds, there were altogether 35 research topics that were rated important or very important (median 6-7, IQR 1). The highest rated problems to be solved were 1) the benefits of using Artificial intelligence in radiography, 2) safe integration of artificial intelligence into practice, 3) impact of new technology, 4) evidence-based clinical practices, 5) radiation safety issues, 6) radiation optimization issues, 7) patient outcomes in medical imaging, and 8) radiographers' role in image interpretation. All the research topics rated as important were from the four phenomena categories: radiographers' profession, clinical practices, safe- and high-quality use of radiation and technology in radiography. Thus, it was concluded that these four broad phenomena represent the research priorities within the discipline of radiography science. As concepts are determined by categorizing or grouping similar items or ideas and forming concepts out of them (Andersen, 1998; Eriksson, 2010), it was clear that core concepts were in fact those priority phenomena determined.

5.2 The core concepts and their interrelationships (Phase II)

The core concepts of the discipline of radiography science are radiographers' profession, clinical practices, safe- and high-quality use of radiation and technology in radiography.

The profession of radiographers was seen as consisting of both radiography professionals and radiography work. The profession of a radiographer entails professions such as radiographers, radiation therapists, nuclear medicine technologist and radiologic technologists. It had attributes such as the formal education and qualifications required, legal and ethical responsibilities and accepted standards of practice. Some of the properties linked to radiographers' profession were the necessity for continuous professional development to maintain skills and competences throughout the career, as well as the professional values such as respectful behaviour, maintaining trust, dignity, privacy and confidentiality. (Paper III.)

Clinical practice in radiography was seen as the service in a healthcare context and in everyday actions, procedures and care within radiography environments. It had attributes such as service in various healthcare environments (e.g., medical imaging departments, radiation therapy wards and mobile services) and diagnostic and therapeutic procedures. A property linked to clinical practice was that the service can be given at different phases of patient pathways (e.g., early diagnosis, control, treatment, rehabilitation). It was defined by short encounters with patients/clients and a technical environment. (Paper III.)

Safe and high-quality use of radiation was seen as conforming to safety culture and quality requirements while operating with radiation. In radiography the use of radiation occurs within the context of diagnostic imaging, radiation therapy or nuclear medicine. This concept had attributes such as beneficial when used correctly and harmful if safety and quality requirements are not met. The ALARA principle (keeping the doses as low as reasonably achievable) was one defining property. (Paper III.)

Technology in radiography was seen as consisting of both the physical equipment (hard technology) and the impact the technology has on values, care and interaction between humans and technology (soft technology). Attributes included rapid advancement and efficiency. (Paper III.)

Interrelationships of the core concepts were defined bilaterally between each concept (Figure 4). Radiography science research occurs in the intersections of the core concepts and the statements of interrelationships indicate the focus of research.

When examining the relationship between the radiographers' profession and clinical practice, it was noticed that the clinical practice is the environment in which radiographers work is mostly associated. The profession has a monopoly over that practice within certain limits. Radiographers are mediators between patients and the practice within an environment that is technical and cold in some ways. Radiographers adapt to individual needs of patients and make sure the quality and safety standards apply in clinical practice. The clinical practice is in constant change and is complex. The profession of radiographers' needs to adapt to the change and complexity by redefining roles and responsibilities. It was concluded that the relationship between radiographers' profession (RP) and clinical practice (CP) is concurrent. Meaning they exist together and are dependent on each other. Radiographers provide their knowledge and skills for the service of clinical practice and on the other hand, the mandate for the profession is dependent on the clinical practice. The interrelationship can be formulated: if CP, then also RP / if RP, then also CP. (Paper III.)

The profession of radiographers' relationship to safe and high-quality use of radiation (SHQR) is that of necessity and it goes both ways. This means that knowledgeable professionals are needed to ensure quality and safety in radiation use and they need to use the radiation safely to be able to produce good quality diagnostic images or treat patients with radiation. The interrelationship can be formulated: if and only if RP, then SHQR/ if and only if SHQR, then RP. (Paper III.)

The radiographers' profession depends on technology to operate. The relationship between technology (T) and the profession is causal. Meaning the advancement of the technology forces the profession to change. It can be said the identity of the profession is closely linked to technology used in radiography. The interrelationship can be formulated: if T, then RP. (Paper III.)

Examining the interrelationship of the concepts of clinical practice and safe and high-quality radiation use, it was concluded that the concepts have a necessary relationship. This means that radiation has a functional use in clinical practice and clinical practice is dependent on safe and high-quality use of radiation to provide services where safety and quality are incremental. The interrelationship can be formulated: if and only if SHQR, then CP. (Paper III.)

Clinical practice and technology have a sufficient relationship. In other words, if changes occur in either one, then these changes reflect to the other one as well. If technology changes then practices should reflect these changes and vice versa. There is interdependency between the concepts. Clinical practice in radiography does not exist without the imaging or radiation therapy technology, and on the other hand there is no need for this technology if there is not an environment where it can be used. The interrelationship can be formulated: if CP, then T, regardless of anything else/ if T, then CP, regardless of anything else. (Paper III.)

The relationship between safe and high-quality radiation use and technology was found to be conditional and also conflicting. A conditional relationship means in this case, that there is a need to a have some third concept to be able to define the relationship. For example, if there are no qualified professionals to use the technology, we cannot say if radiation is used safely and in high-quality manner. A conflicting relationship comes from the notion that with advancing technology both increase and decrease of safe and high-quality radiation use has been reported. Here again a third concept comes in place, for example the impact of quality assurance measures or radiographers' competence to use the technology. The interrelationship can be formulated: if T, then SHQR, but only in presence of RP. (Paper III.)

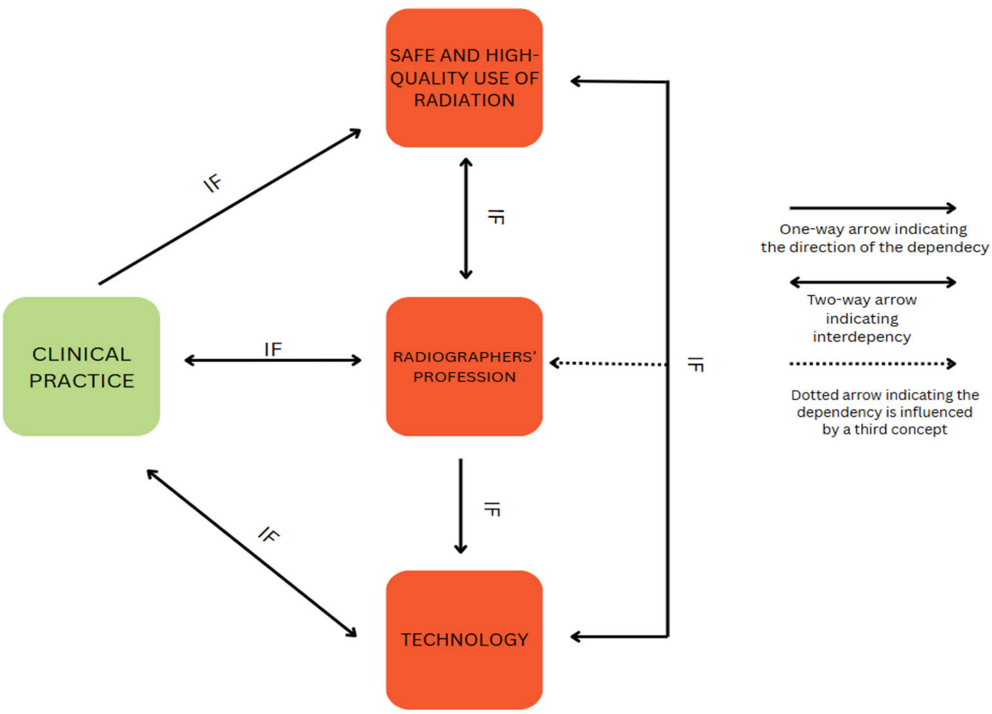

Figure 4. The interrelationships of the core concepts.

5.3 Epistemic interests and nature of knowledge (Phase II)

The epistemological assumption in radiography science were studied through epistemic interests and the nature of knowledge. The epistemic interests refer to what kind of goal as regards knowledge the discipline seeks to find in the studies. For example, if the knowledge is gained to understand, explain, explore, predict, develop or emancipate some phenomenon. The nature of knowledge refers to what type of knowledge is produced within the discipline. In Paper IV, the epistemic interests and nature of knowledge were examined through Kim's critical normative epistemology framework (Kim, 2010).

The division of the epistemic interests in the fifty-three examined dissertations are presented in Figure 5. The interests were mostly inferential (n=16) and referential (n=16). The studies with inferential epistemic interests sought to explain or explore some phenomena in a patterned way. There were also interest in predicting how or why something happens. For example, explaining differences between radiographer and radiologist reporting, explaining the relationship between education and quality of care or predicting the use or acceptance of technology. The studies with referential interests for example, wished to understand feelings or perceptions of patients undergoing radiography procedures, explore contemporary radiography practices, identify or describe scantly investigated phenomena or conceptualize something. (Paper IV.)

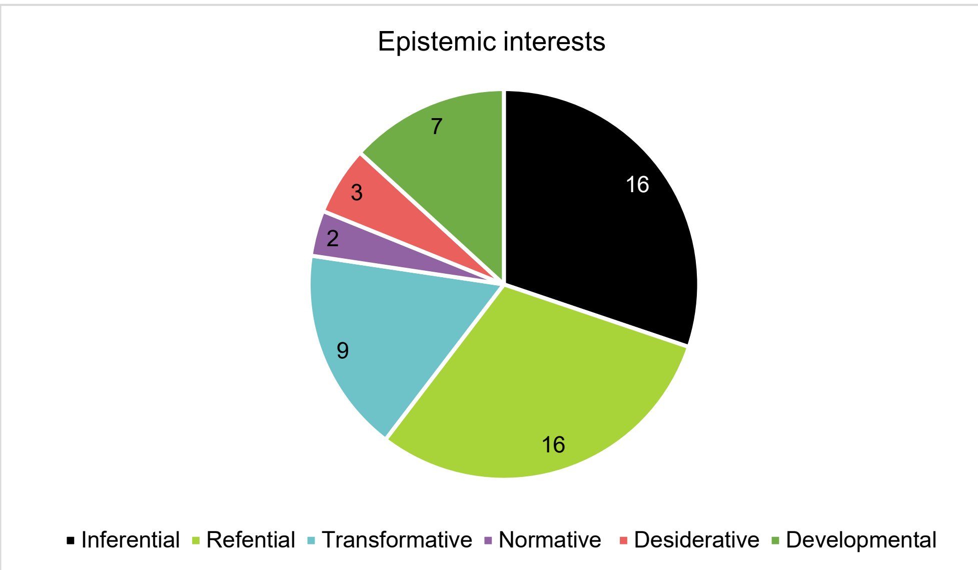

Figure 5. The division of epistemic interests in radiography science dissertations (n=53).

Dissertations with transformative interests (n=9) aimed to understand humans in a social or cultural context. The assumption was that issues of power, gender or structures somehow affect people in these contexts. The goal of these studies was to empower or emancipate the studied population, whether it be the professionals and their development or patients participating in their own care. Normative epistemic interests were found only in two dissertations. The goal in these dissertations was to explore ethical behaviour or professional values concerning the radiography community. Desiderative interests were found in three dissertations. The goal was to understand practices, processes or the culture of radiography to present an ideal, desiderative way of doing something. (Paper IV.)

There were nine dissertations that did not fit into Kim's framework of epistemology (Kim, 2010). These were classified as having a practical developmental interest. The goal in these studies was to explore radiography practices and processes in order to develop them. For example, to establish new protocol or to design new methods to measure or evaluate safety or quality in radiography. (Paper IV.)

Regarding the types of knowledge, radiography science produces generalized knowledge, situated hermeneutic knowledge, critical hermeneutic knowledge, ethical and aesthetical knowledge and applied knowledge. Generalized knowledge is produced with quantitative methodologies from positivist epistemological standpoint. It provides generalizations, explanations of differences between groups and predictions to something. (Paper IV.)

Situated hermeneutic knowledge contributes to radiography science by bringing perceptions from patients, radiographers and other actors in radiographic context. Knowledge is produced with different qualitative methodologies and the epistemological standpoint is interpretivism. Critical hermeneutic knowledge is produced with critical qualitative methodologies, such as critical ethnography. There are no specified methodologies to gain ethical and aesthetical knowledge, nor specific epistemological standpoint. They can vary. However, ethical knowledge is produced with normative interests and aesthetical knowledge with desiderative interests. (Paper IV.)

Applied knowledge is produced when something is developed within radiography science that has direct implications on practice. Knowledge can be presented in a form of a model or a framework guiding practice or concrete designed products. (Paper IV.)

There is no single methodology that is used over any other in research in radiography science. Quantitative methods are used as much as qualitative methods. In Paper IV, fifty-three dissertations from the field of radiography science were examined and it was discovered that little a less than half (n=22) used some quantitative method, and a qualitative method was used in over half of the dissertations (n=34). Some mixed-method approaches were used in nine dissertations. It is noteworthy that some dissertations used more than one methodology. It seems that the aim of the research, whether it be to understand, explain or predict a phenomenon directs the choice of methodology more than an established disciplinary example. (Paper IV.) Causal-mechanistic explanations are as equally accepted as phenomenological-existentialist explanations. Radiography science studies with a critically orientated goal seem to be adapting to a dialogical explanation. (Paper IV.)

The ontological assumptions are not always explicitly communicated in radiography science, but they can be investigated through choice of methodologies and examining how the researcher has positioned herself/himself in relation to the study subject or object. For example, if a researcher has chosen some qualitative methodology and the knowledge is gained from informants' subjective perceptions, we can assume the ontological standpoint is relativist. There are multiple truths, not a single truth that can be observed objectively as in a realist ontological view. (Paper IV.) When analysing the dissertations, it was discovered that the ontological assumption was relativist in 24 dissertations (45%), realist in 18 (34%). In 11 dissertations (21%) it was not possible to define any particular ontological assumption due to variation or conflict between the research methodologies and the researchers' position. (Paper IV.)

5.4 Organizing the paradigm of radiography science through disciplinary matrix (Phase III)

In Phase III, Kuhn's disciplinary matrix (1970b) was utilized to synthesize the knowledge gained in previous phases. A disciplinary matrix consists of shared values, symbolic generalizations, shared exemplars and metaphysical presumptions.

Shared values in a discipline help to define which problems are deemed more important than others and what choices need to be to be made, for example, what is deemed as a plausible explanation (Kuhn, 1970b). The phenomena that a discipline investigates are those that are seemingly deemed worthy of research. The phenomena that are seen as research priorities of a discipline are the problems deemed more important than others. Therefore, shared values in radiography science disciplinary matrix are problems related to radiographers' profession, problems related to clinical practice in radiography, problems related to safe and high-quality use of radiation and problems related to technology used in radiography. (Paper II.) Plausible explanations were investigated to be causal (logical empiricist) in quantitative studies, phenomenologist-existentialist in qualitative studies and dialogical in critically orientated studies (Paper IV).

Symbolic generalizations are according to Kuhn (1970b) laws in symbolic form or concepts expressed in words. The core concepts of radiography science and their interrelationships can be seen as the symbolic generalizations within the discipline. Therefore, the symbolic generalizations of radiography science are the four core concepts (the radiographers' profession, clinical practice in radiography, safe and high-quality use of radiation and technology in radiography) and bilateral statements indicating their interrelationships. (Paper III.)

Kuhn presented shared examples as tools for researchers to solve new problems (Kuhn, 1970b). These can be for example, established models or laws. Radiography does not have own laws and few models; therefore, these were not specifically investigated in this study. Instead, the methodologies used give an insight as to how researchers approach the research problem that needs solving and are considered as shared examples of the discipline. Radiography science seems to be pragmatic in the choice of methodologies and qualitative, quantitative and mixed methodologies are accepted equally, depending on the aims and purpose of the study. (Paper IV.)

The metaphysical presumptions of a discipline are the ontological and epistemological assumptions that a discipline has (Kuhn, 1970b). In radiography science, the ontological assumptions can be realist or relativist. Epistemological assumptions in radiography science are presented in the epistemic interests and the types of knowledge discipline generates. Epistemic interests in radiography science are inferential, referential, transformative, normative, desiderative and developmental interests. Knowledge types associated to these interests are generalized, situated hermeneutic, critical hermeneutic, ethical, aesthetical and applied knowledge. (Paper IV.)

The proposed framework for the paradigm of the discipline of radiography science is presented as a taxonomy and containing the elements of a disciplinary matrix: shared values, symbolic generalizations, shared examples and metaphysical presumptions (Table 5). Taxonomies are a way of classifying knowledge into hierarchical structures and they can show the conceptual range of findings (Sandelowski & Barroso, 2007). Therefore, it was found to be suitable way to present the framework.

Table 5. The framework for the paradigm of the discipline of radiography science.

DISCIPLINARY MATRIX OF RADIOGRAPHY SCIENCE

A. **Shared values**	1. Prioritized problems to solve	a. Problems related to radiographers' profession
		b. Problems related to clinical practice in radiography
		c. Problems related to safe and high-quality use of radiation
		d. Problems related to technology used in radiography
	2. Plausible explanations	a. Causal (logical empiricist) in quantitative studies
		b. Phenomenologist-existentialist in qualitative studies
		c. Dialogical in critically orientated studies
B. Symbolic generalizations	1. The core concepts of the discipline	a. Radiographers' profession
		b. Clinical practice in radiography
		c. Safe and high-quality use of radiation
		d. Technology in radiography
	2. Statements of interrelationships of the core concepts	a. Radiographers' profession - Clinical practice: *the monopoly of profession over practice, professions responsibility to secure the well-being of patients in practice, the professions role as a mediator in practice, complexity of the practice and constant change forcing the profession to redefine itself.*
		b. Radiographers' profession - Safe and high-quality use of radiation: *profession protecting the public from medical radiation*.
		c. Radiographers' profession - Technology: *dependency from the technology, advancement of technology changing the profession, identity of the profession linked to technology*
		d. Clinical practice - Safe and high-quality use of radiation: *the critical role of safety in clinical practice*.
		e. Clinical practice - Technology: a*dvancement of technology changing the practice and vice versa*
		f. Safe and high-quality use of radiation - Technology: *advancement of technology may increase or decrease safe use of radiation*.
C. Shared examples	1. Methodological choices	a. Quantitative methodologies
		b. Qualitative methodologies
		c. Mixed methodologies
D. Metaphysical presumptions	1. Ontological assumptions	a. Realist ontology
		b. Relativist ontology
	2. Epistemological assumptions	a. Epistemic interests: *inferential, referential, transformative, normative, desiderative, developmental*
		b. Knowledge types: *generalized, situated hermeneutic, critical hermeneutic, ethical, aesthetical, applied*

5.5 Summary of the results

The aim of this study was to explore radiography science as a discipline and to propose a framework for the paradigm of the discipline. To reach this aim, the objectives of this study were first to identify the phenomena radiography science investigates and to determine the research priorities and core concepts. This was followed by clarifying the identified priority areas of radiography science by defining the core concepts and their interrelationships and describing the epistemic interests and nature of knowledge within the discipline. And finally, to synthesize the knowledge gained using Kuhn's idea of a disciplinary matrix to gain an understanding of the paradigm of the discipline of radiography science.

The phenomena radiography science investigates were identified to be the radiographers' profession, the clinical practice of radiography, safe and high-quality use of radiation, technology in radiography, leadership and management and the discipline of radiography science. The research priorities, and at the same time, the core concepts are the radiographers' profession, clinical practice, safe and high-quality use of radiation and technology in radiography. The interrelationship statements of the core concepts indicate the focus of radiography science research, which forms a unique domain for radiography research. Radiography science research occurs in the intersections of the core concepts. The focus can be summarized as follows: radiography science is a discipline in which the central focus is investigating and by means of research, improving humane, safe and high-quality radiography services mediated by technology in the health care environment for the well-being of individuals.

The discipline of radiography science is pluralistic in methodologies and there are no radiography science specific research methods, rather this choice is pragmatic, depending on the study aims and objectives. The epistemic interests of radiography science and the types of knowledge associated with the interests are versatile. They reflect the need to understand the phenomena from different perspectives and to have knowledge that is objective and can be generalized, as well as subjective hermeneutic knowledge that is either situated or critical. Radiography science builds evidence for the radiography practice and therefore, ethical, aesthetic and applied knowledge is needed to support that.

The framework of the paradigm of the discipline of radiography science is organized through the disciplinary matrix (Table 5). The disciplinary matrix is presented in the form of taxonomy, showing the structure of the paradigm. It consists of shared values, symbolic generalizations, shared exemplars and metaphysical presumptions.

6 Discussion

Within this discussion chapter the main findings of this study are discussed together with the existing literature. The trustworthiness and validity of the research is addressed, as well as suggestions for future research and the practical implications of the study.

6.1 Discussion of the results

The aim of this study was to explore radiography science as a discipline. The study set out to address the research gap identified in the literature that research into the paradigm internationally is scant. Some studies have been conducted, for example, into different research focuses for the discipline (Lundgren et al., 2019; Sorppanen, 2006), ontological concepts (Lundgren & Lundén, 2023; Sorppanen, 2006) and epistemological interests (Lundén et al., 2016; Metsälä & Fridell, 2018). However, the previous studies have not attempted to view the paradigm as a whole. This study provided new knowledge of the phenomena radiography science investigates and the research priorities of the discipline. It clarified the identified core concepts and their interrelationships, as well as described the epistemic interests and nature of knowledge within the discipline. This study proposed a framework for the paradigm of the discipline of radiography science. The paradigm was synthesized using Kuhns disciplinary matrix.

The disciplinary matrix was found to be useful in this study for organizing the paradigm. However, it does require some interpretation. Kuhn was somewhat obscure when describing the paradigm and the disciplinary matrix, a point for which he was criticized by his contemporary philosophers of science (Masterman, 1970; Popper, 1970). Examples from other disciplines (Roy & McLain, 2024; Estrup & Achiam, 2019; Boon & Van Baalen, 2019) aided in this interpretation and the use of taxonomy.

The strength of this study lies in its investigation of the abstract concept of paradigm using a systematic methodology. The findings are reported transparently, allowing the radiography science community to evaluate them. The data is international, encompassing several countries, thus providing a broader perspective rather than a single-country view. However, the study has some weaknesses. There was scant previous research to build upon, leaving gaps in the proposed paradigm. Additionally, the study relied heavily on textual evidence from documents, which limited the inclusion of radiography researchers' perceptions.

In the next sections, the implications of the findings of this study are discussed. The implications of this study include understanding what we know about radiography science as a discipline based on this study and previous evidence, identifying the research focus of the discipline, distinguishing radiography science from related disciplines, and strengthening the knowledge base of radiography science

6.1.1 Radiography science as a discipline

In the review of literature chapter, science was defined as a group activity of scientist solving cognitive problems, using controlled methods, in attempt to discover causalities, relations and interactions. It was defined as both a process and an outcome (knowledge). (Chalmers, 1999; Niiniluoto, 2002; UNESCO, 2021). Similarly, based on the results of this study, we can define that radiography science has a group of scientists solving cognitive problems (Papers I-IV). Radiography science uses controlled methods to discover causalities, relationships and interactions. It has a systematic process, and its outcome is radiography specific knowledge (Paper IV).

A discipline was defined to share the same knowledge base, goals and interests (Meier, 2023), as well as having unique characteristics (Serenko & Bontis, 2013; Trowler, 2014). Radiography science has unique characteristics such as the specific phenomena it investigates (Paper I), prioritized research interests (Paper II), core concepts (Paper III) and ontological and epistemological assumptions (Paper IV). Radiographers have scholars who practice in the discipline, which can be demonstrated through radiography science research; in this study it is namely through the dissertations investigated (Papers III and IV). A discipline has a paradigm, demonstrated in this study.

Discipline was said to be concerned with generating knowledge in its domain, whereas a profession acts within that domain (Fordham, 2016; Niiniluoto, 2001). In regard to radiography science, radiographers are the professional’s drawing knowledge from radiography science. This knowledge is generated in academia by researchers within the discipline of radiography science. The knowledge is used to improve phenomena related to radiographers’ profession, clinical practice in radiography, safe and high-quality use of radiation and radiography related technology (Papers I-IV).

This study confirms that radiography science is dualistic in nature, containing characteristics from natural and human sciences as was stated previously by

Hammick (1995), Castle (2000) and Ahonen (2008). This is demonstrated in the phenomena of interest which can be anything from human experience to technology within radiography (Paper I).

Kuhn (1970b) claimed that science develops through scientific revolutions and disciplines can be either in a pre-paradigmatic, paradigmatic or transition state. This study has suggested a framework for the paradigm of radiography science. However, it does not necessarily mean that the discipline is in paradigmatic state. Even disciplines that have a longer history of defining their paradigm, there are disputes about their state, as was shown in the example of nursing science. In radiography science, where there has not been rigorous discussion about its paradigm, this is even more challenging. There is evidence to suggest that radiography science is in pre-paradigmatic state. There are still multiple unsolved problems and few accepted theories. The frequent use of descriptive and non-randomized designs in studies, as indicated in study related to research published within radiography peer-reviewed journals (Iweka et al., 2024) gives a hint that there is still rather scanty theoretical knowledge within radiography science and multiple unanswered problems. Similarly, in this study, the methods most used were cross-sectional surveys and case studies (Paper IV).

On the other hand, there is also evidence to suggest radiography science being in a paradigmatic state. All problems are not equally relevant (Paper II), and radiography science research is not a random activity, as was demonstrated in this study as well. In a paradigmatic state, sciences have established which phenomena they investigate (Kuhn, 1970b) and these, if not fixed, at least have been identified in radiography science (Paper I). However, more research needs to be done into the paradigm. Hence, radiography science can be said to be somewhere in the transition phase between pre-paradigmatic and paradigmatic discipline.

6.1.2 The research focus of the discipline of radiography science

Research focus in radiography science has been said to be in the dynamic connections between the work of radiographers within healthcare, and health and illness, the environment and individual (Sorppanen, 2006). In the EFRS definition, the focus is on medical imaging, radiotherapy and nuclear medicine clinical practice, technology development, patient care, education, leadership and management (EFRS, 2016). However, it has also been suggested that the foci are in structural factors, clinical radiography, radiographic technological development and pedagogical factors (Lundgren et al., 2019). These differ because they are at different levels of abstraction. Where Sorppanen attempted to define an overarching focus for the discipline, the EFRS and Lundgren et al. are in fact discussing the research areas of the discipline.

This study has taken broad definition of radiography science, consisting of medical imaging, including modalities using non-ionizing radiation and nuclear medicine, and radiation therapy. Even though differing definitions have been made (Pietrzak et al., 2024; ESTRO, 2019). With the broad definition in mind, this study set out explore the paradigm and discovered connecting features applicable to all fields of radiography science research and these served as the basis for the research focus on radiography science. This study suggests the research focus of the discipline could be investigating and by means of research, improving humane, safe and high-quality radiography services mediated by technology in the health care environment for the well-being of individuals. There are similarities between this definition and Sorppanen's definition. However, the distinction between these two definitions is that Sorppanen did not take into account the central role of technology within radiography science, as well as safety and quality. The reason might be that her starting point was the core concepts of nursing science, which do not include technology, even though it has been recently suggested to be a new core concept in nursing science too (Bayuo et al., 2023; Johnson & Carrington, 2023; Monteiro, 2016).

Another main difference between this study and the study by Sorppanen (2006) was that Sorppanen approached radiography science from the viewpoint of another discipline, nursing science, and from the viewpoint of a one country; whereas in this study, radiography science was viewed internationally and there was no predominant paradigm to explore and develop. As previously known, there are global differences as to how radiography science is seen due variations in tradition and education (Cowling & Lawson, 2020; Couto et al., 2018). For example, in the Nordic countries, the viewpoint has been more humanistic and focused equally on patient care and technology (Lundvall et al., 2021; Andersson et al., 2008), rather than, for example, in more technologically orientated Southern European countries (Sá Dos Reis et al., 2018). The data in this study was mainly from western countries, Europe, United States, Canada and Australia. Outside these countries, radiography science might be seen differently and together its research focus and paradigm. Therefore, a comprehensive global view of the paradigm of the discipline is still lacking, despite the steps this study has taken towards achieving it. The research focus might also differ if radiography science were viewed more narrowly, focusing solely on either medical imaging or radiation therapy.

6.1.3 Identifying radiography science from close disciplines

The boundary work, identifying the disciplines unique features from close disciplines is an important step when reasoning the disciplines necessity to exist (Gieryn, 1983). It was stated that with a paradigm, disciplines can reason their own perspective, the way they view phenomena the nature of their research and its limits (Boon & Van Baalen, 2019; Donaldson & Crowley, 1978). Comparing the nursing science paradigms and the paradigm of the discipline of radiography science, differences can be seen. The core concepts differ (Paper III; Fawcett, 1996). As a discipline, nursing science is interested in life-processes, human actions, nursing actions and health of human beings in interaction with their environments (Fawcett, 1996) or facilitating transitions (Meleis & Trangenstein, 1994). Radiography science on the other hand is interested in investigating and improving humane, safe and high-quality radiography services. The similarities exist because of the same interest in the health of humans.

Comparing radiography science to caring science; caring science is humanistic discipline, investigating living phenomena of human experiences in caring, health and healing, including spiritual and philosophical-ethical-moral dimensions (Bergbom et al., 2022; Watson, 2007; Eriksson, 2002). The metaparadigm concepts in caring science are caring, human being, health, suffering and environment (Näsman, 2020). The paradigm concepts differ between caring science and radiography science, even though some similarities can be seen in same interest to human experiences in caring and health. However, radiography science is not similarly interested in spiritual dimensions and is more technically orientated. Therefore, it is possible to say that the paradigm of radiography science differs from nursing science and caring science paradigm.

Radiography, radiology, and medical physics have been intertwined throughout their existence. The medical paradigm has been dominant in medical imaging and radiation therapy, whereas radiography has been seen as subordinate to medicine (Lewis et al., 2008; Larkin, 1978). These three disciplines are interested in the same phenomena, but their perspectives, and therefore paradigms, differ. Medical physics is interested in assessing, optimizing, and analyzing medical technology and follows the natural sciences paradigm (Samei & Grist, 2019). Radiology, as a discipline, is interested in more accurate and efficient diagnosis or treatment and follows the medical paradigm (Najjar, 2023). Compared to the medical physics and radiology paradigms, the paradigm of the discipline of radiography science allows for approaching the same phenomena with more flexible methodologies, including qualitative methods to examine human experiences in medical imaging and radiation therapy environments (Paper IV).

According to the findings of this study, radiography science research occurs in the intersections of the core concepts (Paper III). This means that we can recognize the boundaries to related disciplines through these intersections. For example, if medical imaging technology is investigated, the research generally is situated in the domain of medical engineering or medical physics. However, if the medical imaging technology is investigated in relation to clinical practice (its applications, processes, optimization) it becomes radiography science research. Or if a phenomenon within clinical practice, for example the health of the patient is studied, the research typically (not always) is situated within medicine or nursing, but when the health of the patient is studied within the context of radiography clinical practice in interaction with the radiographers' profession, or safe and high-quality use of radiations, it becomes radiography science research. This study provides researchers with knowledge to structure and direct radiography science research.

6.1.4 Strengthening the knowledge base for radiography science

The solution for strengthening the knowledge base in radiography science has been suggested to be increasing the amount of radiographer led research (Iweka & Hyde, 2023; Hogg et al., 2020; Paulo, 2020; Vikestad et al., 2017). It is important; however, it is not sufficient. Simply having a radiographer doing research does not contribute to the knowledge base of the discipline if the radiographers doing the research are borrowing concepts and methods from other disciplines (Newman, 1994; Saukko et al., 2021). We need to consider which phenomena, concepts, theories and methods are most suitable for building specific knowledge on radiography science, and on what epistemological and ontological foundations radiography science research is built. Philosophical studies are underrepresented in radiography specific publications, even though they are important in developing the knowledge base and the education (Grace & Perry, 2013).

Several barriers have been identified for radiographer conducted research (Al Balushi et al., 2024; Oliveira et al., 2024; Vils Pedersen, 2023; Saukko et al., 2021; Vikestad et al., 2017; Probst et al., 2015; Abuzaid et al., 2023), including research funding and the research culture. Funding problems are not easily solved but the overall research culture in radiography science could be strengthened with a clearer focus for the research and some consensus as regards to the paradigm of the discipline. One suggestion for the paradigm of discipline has been presented in this study.

It is noteworthy that radiographers are motivated to do research and they see it as an important way to improve services and patient care (Abuzaid et al., 2023; Diaby et al., 2024; Vils Pedersen, 2023), but the lack of dedicated academic radiography science paths in many countries, such as lack of doctoral programmes, leads many radiographers interested in research to pursue careers in other fields (Diaby et al., 2024; Zanardo et al., 2023). This is partly a problem of not having a recognised paradigm for the discipline, as it hinders the development of the discipline. The EFRS (2016) has also identified that radiography science needs to be developed as a discipline, as well as its methodologies and radiography science specific concepts. Education in radiography science should be centred around its own paradigm, with dedicated doctoral programs available at universities for those interested in pursuing a career in research.

A distinct benefit from some common understanding of the paradigm globally would be, that it might further international research among radiography scientists. The lack of collaboration globally has been recognised also by radiography researchers (Hogg, 2016). Nevertheless, the complex problems in need of solving would require the collaboration of international research teams. A predominant paradigm provides researchers with some consensus as to how to approach the phenomena they are investigating, what theories, facts and methods are accepted, and the validity and significance of any new research (Fanelli & Glänzel, 2013; Monti & Tingen, 1999). The problem of different paradigms has been identified as a hindrance in research collaboration (Boon & Van Baalen, 2019).

The paradigm needs to be examined critically from time to time, as science and disciplines evolve over time (Hofstetter, 2012; Bridges, 2006). Radiography science as a fast-paced evolving discipline is not an exception to this. The paradigm needs to be examined at regular intervals to strengthen the knowledge base and to be better responsive to contemporary needs in research.

6.2 Validity and reliability and trustworthiness

Validity refers to how accurately the results of the study reflect the data. Reliability is the consistency of the research process, including biases that might affect the results. Generalisability refers to the degree of transferability of the results to other settings and applicability in other contexts.

Validity and reliability are most often connected to quantitative research, whereas in discussing the rigour of qualitative research, trustworthiness has been suggested to place the concepts of validity and reliability. Trustworthiness consists of credibility, transferability, dependability and confirmability. This study used different methodologies in different phases of the study and next the validity and reliability are assessed critically in each phase.

Phase I

In the scoping review (Paper I), the validity was ensured by following the Prisma scoping review guidelines (Tricco et al., 2018). Aims, objectives and research questions were defined and based on those, a search strategy was established with predetermined search terms and inclusion and exclusion criteria. Four different databases were selected to ensure comprehensive search. Additionally, references and citing articles of those selected were also screened. Quality appraisal was done for the selected articles. There was variability in the methodologies and designs of the selected articles. This makes synthesizing the results more difficult and might add limitations to the validity of the results. All fourteen selected articles were peer-reviewed but three were non-systematic reviews. The rest were original research studies. Data analysis was reported explicitly. Transparent reporting of all the phases of the study was made for others to reproduce the study.

Reliability was ensured by trying to eliminate biases in different stages. A blind review process was used when searching and selecting the data. Two researchers independently searched and selected the data with pre-established inclusion and exclusion criteria. There were some differences of opinion in the selection phase, but these were discussed, and consensus was achieved. The scoping review data search did not include unpublished studies, which is a possible publication bias. The search terms were only in English which is a language bias, eliminating other than English language articles from the findings. The consistency of the search process might have been influenced due to the search terms not including all possible related concepts to the search terms. The critical appraisal tools used were not all meant for the types of studies we used them. We decided to use Joanna Briggs Institute (JBI) appraisal tools, but JBI does not have a tool for Delphi studies, instead we used a tool for case series.

In the Delphi study (Paper II) content validity was ensured by creating the Delphi survey based on the results of the scoping review and testing the clarity of the items and readability of the instructions. Four people with experience in radiography research tested the questionnaire. Content validity was further ensured in the Delphi study, as experts in the panel were able to add new items in each category. The composition of the expert panel in Delphi studies is a validity issue, as the results of the study are group opinion about some topic. The panel experts in Paper II were recruited via the EFRS, the invitation to participate was sent to 40 national societies and 60 academic institutions of education in Europe. The experts to be recruited had to meet certain criteria. They needed to have at least a bachelor's degree in radiography, a minimum of two published research articles in the past five years, clinical experience in radiography, able to answer questions in English and willing to participate voluntarily. The experts recruited met these criteria. They had a long professional history in radiography (mean 25 years) and they had experience in research (mean 13 publications in past five years). Over half of the experts had a doctoral degree, and only one had only a bachelor's degree. The stability of the answers between the rounds was measured with a bootstrapped paired t-test, suitable for samples with not normal distribution. Significance was set to $p < 0.05$, indicating that items having a smaller p-value than 0.05 have had changes in responses between rounds. There were five items with a p-value lower than 0.05. Answers were allowed to change between Delphi rounds, so it did not measure reliability very well.

There were some limitations in the Delphi study. There was only representation from ten different countries and the total number of experts was 24 in first round and 20 in second. With a larger number of experts representing radiography experts globally, the results might have been different.

Phase II

In Phase II, the two studies (Papers III and IV) were both a qualitative document analysis. Therefore, the trustworthiness is evaluated instead of validity and reliability. They are discussed here together as both studies consisted of the same documents, even though different parts of the documents were used as data. The credibility of the studies was strengthened with references to original data and transparent reporting of all stages of the research. The extraction matrices in both studies were pilot tested independently by two researchers. In the pilot, ten documents were randomly selected and analysed using the matrices.

Dependability refers to how well the whole process has been documented, and how other researcher can reproduce the study. In both studies, descriptions of the research process were reported transparently, including the data selection and data analysis. Examples of data analysis was given and extraction matrices with findings attached to appendixes of the published studies. This allows other researchers to make their own interpretations of the data. Confirmability refers to possible biases. Researcher bias is a possibility identified in qualitative research. In the research team (author of the thesis and supervisors) three had a background in radiography. The understanding of the field is a benefit in the analysis process, but it is possible that personal opinions might affect the interpretations. This was recognized and it was tackled by being conscious about results stemming from data and separating them from the researcher's own opinion. In research team one person did not have a background in radiography, which brought valuable outsider perspective. There is also a publication bias as only English language dissertations were accepted to the document analysis, possibly leaving many dissertations outside of the analysis. Transferability of the findings to other contexts has not been tested.

Phase III

Phase III did not involve any new data collection, but the data from the earlier phases was interpreted and synthesized in new way by the author of this dissertation. A limitation in this procedure is the interpretation of a single author. However, the process of synthesis and the findings have been reported accurately in this dissertation for readers to judge.

6.3 Suggestions for future research

There are multiple things that are still unknown about the paradigm of radiography science. Paradigm of a discipline consists of shared values, symbolic generalizations, shared exemplars and metaphysical presumptions. More research is needed in:

Shared values of radiography science:

- Investigation is needed on the values of radiography science and the values of the researchers
- Investigation is needed on plausible explanations, accuracy and consistency of radiography science research
- Investigation is needed on how radiography researchers choose the problems they intend to study and what guides their choices.

Symbolic generalizations of radiography science:

- Investigation is needed on the theoretical content of the discipline. What theories and models there are, how they are tested and utilized in further inquiries, education and in clinical practice.
- The conceptual structure needs to be further explored, and the core concepts presented in this study further tested and developed.

Shared exemplars of radiography science:

- Investigation is needed on shared exemplars of radiography science, including the textbooks used in the education.
- Investigation is needed on methodologies used in radiography science and to develop radiography science specific methodologies

Metaphysical presumptions of radiography science:

- Investigation is needed on metaphysical presumptions of radiography science, including ontological and epistemological structure of the discipline.

Paradigm of radiography science:

- The framework of the paradigm of the discipline needs to be developed further into a theory on the paradigm of radiography science.

6.4 Practical implications

The concrete implications of this study are:

- In radiography science: the framework developed in this study can serve as a starting point for discussions about the paradigm of the discipline. It can help identify the boundaries and possibilities of radiography research. Additionally, the framework can be utilized in international radiography science collaborations to establish common ground for research.
- In research: researchers in the field of radiography can utilize the results of this study to argument their own basis for their research. In interdisciplinary research especially it is important to be able to state the radiography contribution to the common area of research.
- In education: acknowledging the framework of radiography science in all levels of radiography education. The results of this study can be utilized to strengthen the understanding of the knowledge base of the discipline. The framework for the paradigm of radiography science can be utilized when developing university education for radiography science.
- In the clinical practice of radiography: recognizing the paradigm of radiography science empowers the profession of radiographers and supports their autonomy. Ultimately, the development of research within radiography will develop the evidence base in clinical practice. This in turn improves the services provided within radiography.

7 Conclusions

This study has shown that even though radiography science has developed differently in different parts of the world and is defined differently by the relevant stakeholders as to what belongs to radiography science and although it there is no unified name for the discipline, it is still possible to find common elements that can constitute the paradigm of the discipline of radiography science. Kuhns disciplinary matrix is useful in organizing the content of a discipline's paradigm. The elements of the disciplinary matrix are manifested in 1) shared values as to what is considered priority problems to solve and plausible explanations 2) symbolic generalizations of core concepts and their interrelations 3) shared examples of choice of methodologies and 4) metaphysical presumptions of the nature of being and knowing.

Radiography science as a discipline is pluralistic in its ontological, epistemological and methodological choices. It can be called a pragmatic discipline, and the choice of methodologies depends on what is studied, e.g., whether it is human experience or technological advances within radiography that are studied. Radiography science is a health science discipline, as it contributes to the inquiry about health phenomena by investigating and improving humane, safe and high-quality radiography services mediated by technology in the health care environment for the well-being of individuals. The core concepts of radiography science are radiographers' profession, clinical practice, safe and high-quality use of radiation and technology. The core concepts have dependency relationships and radiography science research occurs in the intersections of these core concepts.

The findings of this study can be beneficial to developing the discipline of radiography science, research within the discipline and education, as well as the profession of radiographers. The potential impact of future research within the paradigm of the discipline might lead to more detailed understanding of its norms, practices and its contribution to the progress of science.

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List of Figures and Tables

Figures

Figure 1. The relationship between science and disciplines. 17
Figure 2. Elements of the disciplinary matrix according to Kuhn (1970b) 23
Figure 3. Data collection in Phases I-III.. 42
Figure 4. The interrelationships of the core concepts........................ 50
Figure 5. The division of epistemic interests in radiography science dissertations 51

Tables

Table 1. The umbrella concepts defining the discipline of radiography science in different parts of the world. 14
Table 2. Phases of research and research questions (2020-2025). 36
Table 3. Types of relationships in statements according to Walker and Avant (2014). 44
Table 4. Framework for nursing science epistemology according to Kim (2010). 44
Table 5. The framework for the paradigm of the discipline of radiography science.. 55

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