TURUN YLIOPISTO
UNIVERSITY OF TURKU

LEARNING AND TEACHING SCIENTIFIC THINKING AT UNIVERSITIES

Heidi Salmento

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA – SER. B OSA – TOM. 650 | HUMANIORA | TURKU 2023

TURUN
YLIOPISTO
UNIVERSITY
OF TURKU

LEARNING AND TEACHING SCIENTIFIC THINKING AT UNIVERSITIES

Heidi Salmento

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA – SER. B OSA – TOM. 650 | HUMANIORA | TURKU 2023

University of Turku

Faculty of Education
Department of Teacher Education
Educational Sciences
& UTUPEDA – Centre for University Pedagogy and Research
Doctoral Programme on Learning, Teaching and Learning Environments Research

Supervised by

Professor Mari Murtonen
Department of Teacher Education
University of Turku, Finland

Doctor Tuike Iiskala
Department of Teacher Education
University of Turku, Finland

Professor Marjaana Veermans
Department of Teacher Education
University of Turku, Finland

Reviewed by

Doctor Kieran Balloo
University of Southern Queensland,
Australia

Docent Heidi Hyytinen
University of Helsinki, Finland

Opponent

Doctor Kieran Balloo
University of Southern Queensland,
Australia

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

Cover Image: Milla Stenman

ISBN 978-951-29-9533-2 (PRINT)
ISBN 978-951-29-9534-9 (PDF)
ISSN 0082-6987 (Print)
ISSN 2343-3191 (Online)
Painosalama, Turku, Finland 2023

UNIVERSITY OF TURKU
Faculty of Education
Department of Teacher Education
Educational Sciences
HEIDI SALMENTO: Learning and Teaching Scientific Thinking at Universities
Doctoral Dissertation, 139 pp.
Doctoral Programme on Learning, Teaching and Learning Environments Research
December 2023

ABSTRACT

The aim of this doctoral dissertation is to explore how learning and teaching scientific thinking skills can be promoted at universities. The dissertation consists of four studies that aimed to examine how university students (study I) and teachers (study II) representing different fields of science comprehend scientific thinking and how it develops. In addition, the dissertation explores how university students understand the concept of theory in its scientific meaning (study III) and what phases are related to learning a scientific way of thinking (study IV).

According to the findings, university students and teachers see the following elements as essential for scientific thinking: 1) critical thinking and the basics of science, 2) epistemic understanding, 3) research and methodology skills, 4) evidence-based reasoning, and 5) contextual understanding (studies I and II). However, learning these skills is not easy, and students face problems, for example, in understanding the concept of theory in its scientific meaning (study III). In this dissertation, four phases for learning to think scientifically were recognised: a) understanding the difference between scientific knowledge and knowledge in general, b) understanding the basics of the scientific research process and research methodology, c) figuring out the idea of a scientific way of thinking: receiving readiness to think scientifically, and d) learning to express scientific thinking and identifying oneself as a scientific thinker (study IV).

In conclusion, it is suggested that the significance of scientific thinking skills should be clarified in the university context. To proceed the development of students' scientific thinking skills, the development of scientific thinking should be more consciously paid attention to in curricular work. Instead of including scientific thinking skills in the curriculum as isolated components, scientific thinking could be integrated as a coherent main actor for the whole curriculum. The development of scientific thinking is a broad process in which the scientific community has a large role. The support of university teachers is irreplaceable, and more attention should be paid to explicitly supporting the development of students' scientific thinking.

KEYWORDS: scientific thinking; epistemic understanding, epistemic beliefs, research skills, research competence, scientific argumentation; university pedagogy

TURUN YLIOPISTO
Kasvatustieteiden tiedekunta
Opettajankoulutuslaitos
Kasvatustiede
HEIDI SALMENTO: Tieteellisen ajattelun oppiminen ja opettaminen yliopistoissa
Väitöskirja, 139 s.
Oppimisen, opetuksen ja oppimisympäristöjen tutkimuksen tohtoriohjelma
Joulukuu 2023

TIIVISTELMÄ

Tieteellisen ajattelutavan oppiminen on yksi yliopisto-opintojen keskeisimmistä tavoitteista. Tässä väitöskirjassa tutkitaan, miten tieteellisen ajattelun taitojen oppimista ja opettamista voitaisiin edistää yliopistoissa. Väitöskirja koostuu neljästä osatutkimuksesta, joissa selvitetään, mitä tieteellinen ajattelu on eri tieteenaloja edustavien yliopisto-opiskelijoiden (tutkimus I) ja yliopisto-opettajien näkökulmasta (tutkimus II). Lisäksi selvitetään, miten yliopisto-opiskelijat ymmärtävät käsitteen teoria sen tieteellisessä merkityksessä (tutkimus III) ja millaisia vaiheita tieteellisen ajattelun oppimisprosessiin liittyy (tutkimus IV).

Tulosten perusteella sekä opiskelijoiden että opettajien näkemysten mukaan tieteellisen ajattelun keskeisimmät elementit ovat 1) kriittinen ajattelu ja tieteen perusteet, 2) episteeminen ymmärrys, 3) tutkimustaidot, 4) päättelytaidot ja 5) kontekstuaalinen ymmärrys (tutkimukset I ja II). Näiden taitojen oppiminen ei ole kuitenkaan helppoa ja opiskelijoilla on haasteita esimerkiksi käsitteen teoria ymmärtämisessä sen tieteellisessä merkityksessä (tutkimus III). Väitöskirjassa tunnistettiin neljä tieteellisen ajattelun oppimiseen liittyvää vaihetta: a) tieteellisen tiedon ja muun tiedon episteemisten erojen ymmärtäminen, b) tieteellisen tutkimusprosessin ja tutkimusmetodologian perusteiden ymmärtäminen, c) tieteellisen ajattelutavan idean hahmottaminen ja valmiuksien saavuttaminen tieteelliseen ajatteluun sekä d) tieteellisen ajattelun ilmaisun oppiminen ja itsensä tunnistaminen tieteellisenä ajattelijana (tutkimus IV).

Lopputuloksena esitetään, että tieteellisen ajattelun taitojen merkitystä pitäisi kirkastaa yliopistokontekstissa. Opiskelijoiden tieteellisen ajattelun taitojen oppimisen edistämiseksi tieteellinen ajattelu tulisi nostaa keskiöön erityisesti opetussuunnitelmatyössä. Oleellista olisi panostaa siihen, että tieteellisen ajattelun taidot eivät jäisi irrallisiksi palasiksi, vaan muodostaisivat punaisen langan opintoihin. Tieteellisen ajattelun kehittymisessä on kyse laajasta episteemisestä prosessista, jossa tiedeyhteisöllä on valtava merkitys. Yliopisto-opettajien tuella on merkittävä rooli tässä prosessissa ja opiskelijoiden tieteellisen ajattelun tukemiseen tulisi kiinnittää aiempaa eksplisiittisemmin huomiota.

AVAINSANAT: tieteellinen ajattelu, episteemiset uskomukset, episteeminen ajattelu, tutkimustaidot, tieteellinen argumentointi; yliopistopedagogiikka

Acknowledgements

This doctoral dissertation was made to increase understanding of learning and teaching scientific thinking at universities. This process has not always been easy and combining it with other aspects of life has sometimes been challenging. When writing these words, I feel great gratitude for all the people who have been making this process possible and supported me in different phases of the process.

First, I would want to thank both of the preliminary examiners for my dissertation: Doctor Kieran Balloo (University of Southern Queensland, Australia) and Docent Heidi Hyytinen (University of Helsinki, Finland). Thank you for your excellent and constructive feedback during the pre-examination stage. Your insights as highly esteemed researchers really helped me to finalise this work. It is a great honour to have Doctor Kieran Balloo act as opponent in the public defense of my doctoral dissertation.

I also want to express my greatest gratitude to my supervisors Professor Mari Murtonen, Doctor Tuike Iiskala and Professor Marjaana Veermans. I admire you all as researchers and I am grateful for all the support I have received from you during these years. Through this work, I have developed as a scientific thinker myself, and your role has been fundamental in promoting my learning process. You are first class researchers, teachers and supervisors and having you as supervisors of this dissertation has been an honour. Mari, thank you for seeing potential in me when I was writing my Master's thesis. You encouraged me to start this project and I have received support from you in every phase of it. We have had very abstract level discussions of the fundamental questions related to science, thinking and scientific thinking. These discussions have been crucial for the development of my scientific thinking and for the progress of this work. I truly appreciate your genuine willingness to help young researchers to develop. Tuike, I would like to thank you for all your support and your contribution especially for the fourth article. I am grateful of all the feedback and comments I have received from you during this process. Thank you also for participating in the above described abstract level discussions. Your expertise in the research field of metacognition deepened the discussions even further. Marjaana, I would want to thank you especially for inviting me to participate in your doctoral seminars. Thank you for your feedback and comments also on the summary of the dissertation.

I am also grateful for all the co-authors of the articles. In addition to above mentioned people, I would like to thank doctor Margaret Kiley (Australian National University, Canberra, Australia) for collaboration when writing the third article. Margaret, it was an honour to work with you and I learned a lot from you during the process.

I am very grateful to the University of Turku and the Doctoral Programme on Learning, Teaching and Learning Environments Research (OPPI) for enabling this process. Also, I would like to thank all the teachers and students who participated in the studies. Without you this work would not have been born. I also want to express my gratitude for all my colleagues in UTUPEDA (Centre for University Pedagogy and Research at the University of Turku). I have enjoyed working with you and many of you have been in some way part of this dissertation process. Thank you especially Mari Murtonen, Henna Vilppu, Kalypso Filippou, Hanna Nori and Jere Riekkinen. I would also want to thank all the the students in the doctoral seminars of Mari Murtonen. I have learned a lot from your presentations and also received valuable feedback concerning my research. In addition, I want to express my gratitude for all my colleagues in Opetuki (Educational Support Services at the University of Turku). You have supported me when finalising this dissertation alongside work. I would want to thank especially Minna Vuorio-Lehti for all the support and your encouraging words during the process. Also, I want to express my gratitude to Suvi Ylioja for proofreading parts of the dissertation.

Finally, I would want to thank my family. Petteri, thank you for everything. This process has not always been easy for you either. Thank you Oskari and Emilia, you are the diamonds of our lives and there are no words to describe how much I love you. I would want to thank also all the friends and loved ones around us. Thank you especially äiti, Jari, Marika, Milla, Ella, Eveliina, Lydia, Heikki, Teemu, Irmeli-mumma, Heikki-paappa, Satu, Jappe, Marika, Eetu and Erin.

Sincerely,
Heidi Salmento
November 2023

Table of Contents

Tables

Figures

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 Salmento, H., & Murtonen, M. (2019). The roles of epistemic understanding and research skills in students' views of scientific thinking. In M. Murtonen & K. Balloo (Eds.), *Redefining scientific thinking for higher education: Higher-order thinking, evidence-based reasoning and research skills* (pp. 31–57). Palgrave Macmillan.

Salmento was responsible for the study design, data collection, data analysis, interpretation, and writing of the manuscript. Murtonen contributed to the study design and analysis as the second coder of the data. Both authors critically revised the manuscript and approved the final version for publication, but Salmento was the main author responsible for accepting the final version.

II Murtonen, M., & Salmento, H. (2019). Broadening the theory of scientific thinking for higher education. In M. Murtonen & K. Balloo (Eds.), *Redefining scientific thinking for higher education: Higher-order thinking, evidence-based reasoning and research skills* (pp. 3–29). Palgrave Macmillan.

Salmento contributed to the study conception and design, data collection, data analysis and interpretation, and writing of the manuscript. She was responsible for data transcription and analysis as the second coder of the data. Murtonen was responsible for writing the manuscript. Both authors critically revised the manuscript and approved the final version for publication.

III Salmento, H., Murtonen, M., & Kiley, M. (2021). Understanding teacher education students' research competence through their conceptions of theory. *Frontiers in Education*, 6, 461–470.

Salmento was responsible for the study conception and design, data collection, data analysis and interpretation, and writing of the manuscript. Murtonen contributed to the analysis as the second coder of the data. All authors critically revised the manuscript and approved the final version for publication, but Salmento was the main author responsible for accepting the final version.

IV Salmento, H., Murtonen, M., & Iiskala, T. (Under review). Teaching university students to think scientifically: Focus on epistemic understanding and research skills.

Salmento was the main author responsible for the study conception and design, data collection, data analysis and interpretation, and writing of the manuscript. All authors critically revised the final manuscript and approved the final version for publication, but Salmento was the main author responsible for accepting the final version.

1 Introduction

This doctoral dissertation aims to deepen our understanding of learning and teaching scientific thinking at universities. The aim is to explore the fundamental elements of scientific thinking in the university context and how the development of students' scientific thinking can be promoted effectively. In this work, scientific thinking is understood in a broad way, and the phenomenon is approached from a multidisciplinary point of view. A broad picture of scientific thinking is drawn by exploring how university students and teachers representing different fields of science understand the phenomenon of scientific thinking. In addition, attention is paid to the development of students' epistemic understanding and research skills, as well as teachers' perceptions of the critical phases in the process of learning to think scientifically. Summarising the results of the four studies, this doctoral dissertation aims to provide tools for university teachers to help their students proceed in the process of learning to think scientifically.

Learning a scientific way of thinking has long been a central goal of university education. Scientific thinking is understood differently in different contexts, and there is variation in how scientific thinking has been defined in the field of research. In this work, scientific thinking is approached as a tool for understanding the complex world (see, e.g., Donovan & Hoover, 2013; Kuhn, 1989), and providing such tools for students is seen as the responsibility of university education. Because scientific and non-scientific knowledge is increasingly available via media (Abd-El-Khalick & Lederman, 2023; Höttecke & Allchin, 2020), everyone needs skills to critically evaluate the reliability and origins of the knowledge. However, public understanding of science is not as sophisticated (see, e.g., Rutjens et al., 2021; Sinatra et al., 2014; Sinatra & Hofer, 2016), and people often believe the knowledge that is simply suitable for their own worldview (Kuhn & Modrek, 2022; Sharon & Baram-Tsabari, 2020). Because societal issues are unlikely to become less complex in the future, the world needs scientific thinkers to participate in solving problems and promoting public understanding of science. By combining the findings of the studies included in this dissertation, pedagogical and practical implications will be suggested to promote learning and teaching scientific thinking in universities.

1.1 Scientific Thinking in the University Context

To frame the theoretical background of this doctoral dissertation, the most important concepts are discussed in this chapter. First, the concept of *scientific thinking* is defined and situated in the context of this work. Then, the concepts of epistemic understanding and research skills are defined, and their roles in scientific thinking are discussed. In addition, their relation to other concepts used for similar purposes in the field of research is reflected. Finally, findings from previous research concerning issues in learning and teaching scientific thinking are discussed to demonstrate the need to explore the topic further.

Defining the concept of *scientific thinking* is not unambiguous. The concept and parallel concepts (as scientific literacy, see, e.g., Aristeidou et al., 2020; Laugksch, 2000; Sharon & Baram-Tsabari, 2020) are used differently in different situations. In the English language, the word *science* is often related to the natural sciences, and scientific thinking is sometimes understood as a way of understanding the natural sciences. In these cases, scientific thinking is typically measured by inference tasks that originate in the natural sciences (see, e.g., Piaget, 1971). However, this approach is too narrow to understand scientific thinking in the multidisciplinary university context. Moreover, some of the research and theories in the field are focused on the development of children's scientific thinking (see, e.g., Koerber & Osterhaus, 2019; O'Connor et al., 2021; van der Graaf et al., 2019). Because university students are most often adults, understanding the development of children's scientific thinking is not sufficient. Furthermore, research-based university education (see, e.g., Böttcher & Thiel, 2018; Thiem et al., 2023) as a target of this work makes it necessary to pay attention to scientific research as a conscious knowledge construction process.

The definition of scientific thinking in this work is based on Kuhn's view of the coordination of theories and evidence as the heart of scientific thinking (see, e.g., Kuhn, 1989; Kuhn et al., 1988; Kuhn et al., 2008). Kuhn's theory is based on the idea that small children, lay adults, and scientists coordinate theory and evidence in their thinking, but scientists do so in a conscious and controlled way (see, e.g., Kuhn et al., 2008). Scientists consciously reconcile their thinking with evidence (Kuhn, 1989), but in everyday life, people rarely seek evidence for the claims they face in different situations (Kuhn & Modrek, 2022). Thus, when aiming to proceed the development of university students' scientific thinking, it is important to explicitly support the development of their skills to consciously coordinate theory and evidence in their thinking. That makes the difference between children as intuitive scientists and university graduates as academic scientific thinkers. As Kuhn and co-authors have recognised, skills for coordinating theory and evidence are also crucial for scientific argumentation skills (Kuhn, 2010; Kuhn & Lerman, 2021; Kuhn & Modrek, 2022).

Consciously coordinating theory and evidence is also important for critical thinking (Kuhn, 1999), which is understood as the ability to identify, reason, judge, analyse, evaluate, and make decisions about assumptions (Halpern, 2013; Hyytinen et al., 2014; Hyytinen et al., 2019). In addition to cognitive aspects, critical thinking is about knowledge, skills, willingness to use critical thinking skills (see e.g. Hyytinen et al., 2019; 2023; Halpern, 2014). As Hyytinen et al. (2019, 65) stated, the terms scientific thinking and critical thinking can be interpreted differently in different contexts but the concepts are sometimes used interchangeably. For example, critical thinking can be understood as a sub-component of scientific thinking, or on the other hand, as a foundation for it (Hyytinen et al., 2019). Because critical thinking does not fully describe the thinking that university education aims for (including handling, for example, basic scientific research methods), in this dissertation critical thinking is seen as one of the crucial components of scientific thinking. Critical thinking is a broad concept and people use it in different contexts and situations in their everyday lives. However, in this dissertation the focus is on understanding critical thinking and other scientific thinking skills in scientific contexts.

The ability to coordinate theory and evidence is important for the development of scientific inference skills (see, e.g., Lehman & Nisbett, 1990), which are part of scientific thinking (Kuhn & Pearsall, 2000). Inference skills together with scientific research have a fundamental role at universities as academic institutions. Since the aim of this dissertation was to understand scientific thinking in a university context, attention was paid especially to research skills as part of scientific thinking. Building on an assumption that understanding scientific research (as the origin of scientific knowledge) is challenging without understanding the nature of scientific knowledge (epistemic understanding of science), epistemic understanding was selected to be another main perspective. Thus, the main focus of this dissertation is in the learning of the methods with which scientific knowledge is produced (scientific research) and understanding the nature of scientific knowledge (the epistemology of science). The development of epistemic understanding and research skills and their role in scientific thinking are discussed in more detail in the following section.

1.2 The Roles of Epistemic Understanding and Research Skills in Scientific Thinking

To understand scientific knowledge, it is important to understand its nature and origins (Kuhn et al., 2008), especially in higher education context. The advanced type of scientific thinking, that for example university students are expected to learn, includes understanding that scientific knowledge is constructed by humans (see e.g. Kuhn et al., 2008) and that it is not just discovered in the world (Sandoval, 2005). In addition, scientific thinking in university context includes understanding scientific research as an active process in which people construct scientific knowledge. Since Perry's (1968, 1970) pioneering work on beliefs of knowledge and knowing, substantial research has explored people's understanding of and beliefs about the nature and origins of knowledge (see reviews by Hofer & Pintrich, 1997; Sandoval et al., 2016), called epistemic understanding in this dissertation. In addition, considerable research has explored students' research skills (see, e.g., Balloo, 2019; Murtonen, 2015), also referred to as research competence (see, e.g., Böttcher & Thiel, 2018) or inquiry skills (see, e.g., Lederman, 2019). Helping students understand the nature of science, often shortened as NOS (see, e.g., Abd-El-Khalick & Lederman, 2023; Lederman, 2019; Lederman & Lederman, 2019), is also seen as central in the research field of scientific literacy (see, e.g., Khishfe, 2022). However, there is variation in the emphasis of research skills between theories and research contexts (see, e.g., Abd-El-Khalick & Lederman, 2023; Lederman, 2019; Lederman & Lederman, 2019). Next, the concepts of epistemic understanding and research skills are discussed in more detail, and their relationship is reflected in the context of this dissertation.

Perry's (1968, 1970) original theory of *epistemic understanding* is based on nine developmental stages describing the development of thinking from absolutist right-wrong thinking and dualistic assumptions toward relativism. If one reaches the last stages, there comes a need for personal commitment to form one's identity and orientation in a relativistic world. According to Perry (1970), people face challenges at each stage, but two of the stages are more critical than the others. The first critical challenge is faced at stages 4 and 5 when moving from dualistic to relativistic assumptions. In practice, this means that students need to change their beliefs about truth and the certainty of knowledge and understand that scientific knowledge is also tentative and constructed by people. The second critical challenge is faced in the undertaking of a personal commitment in a relativistic world at stages 5, 6, and 7. The criticality of this is about identifying one's identity and understanding personal responsibilities and risks in a relativistic world. This means constructing a personal worldview that is based on conscious 'acts of choice and orientation in a relative world' (Perry, 1968, p. 36). What is important in the critical stages is the growth toward belonging to an expert community that enables the process (Perry, 1968).

From the perspective of this dissertation, it is not relevant to pay attention to all the nine steps of Perry's original model in more detail. Instead, his idea about certain challenges in epistemic growth that can be overcome with the support of the expert community is relevant in the context of this work. Despite the theory being over 50 years old and the criticism towards it (similarly to other well-known theories in the research field of epistemic understanding, see Hyytinen et al., 2020 to read more), it is applied here to describe the role of epistemic understanding in scientific thinking.

To clarify, adapting Perry's original idea, students probably need help from the scientific community especially when a) they advance from dualistic conceptions of knowledge towards more relativistic conceptions and b) they begin to construct their own identity as scientific thinkers by building commitment to knowledge.

Since Perry's work, multiple developmental models and theories of epistemic understanding have been developed. Usually, the models describe epistemic development through stages that follow each other, such as absolutist, multiplist, and evaluativist (see, e.g., Kuhn et al., 2000; Kuhn & Weinstock, 2002). Another way to understand people's epistemic understanding concentrates on seeking dimensions of personal epistemology that are more or less dependent on each other. For example, Schommer's (1990) model consisting of five elements related to the development of epistemic understanding (certain knowledge, simple knowledge, omniscient authority, quick learning, and innate ability) has been widely used. The research field of epistemic cognition has approached epistemic understanding by seeking answers to questions such as how people think about what they know, how they know, and what knowledge is (see the review by Sandoval et al., 2016).

Some of the studies in the field of epistemic understanding have focused on exploring whether epistemic understanding is domain-generic or domain-specific. Moreover, there has been discussion about whether epistemic understanding of science differs from epistemic understanding in general (see, e.g., Leung, 2020). In addition to the domain-specific level, some researchers have suggested that there is a topic-specific level (Merk et al., 2018; Bråten et al., 2008). However, many studies have suggested that epistemic beliefs could be both domain-generic and -specific (Hofer, 2006, Sinatra et al., 2016; Muis et al., 2006). In addition to exploring how to promote students' epistemic understanding, attention has been paid to how to promote public understanding of the nature and origins of scientific knowledge (see, e.g., Leung, 2020).

Because scientific knowledge originates in scientific research, epistemic understanding (defined as the nature and *origins* of knowledge) is closely related to understanding scientific research. In this doctoral dissertation, the relationship between epistemic understanding and research skills is assumed to be intertwined, and their roles in scientific thinking (in university context) are seen as mutually supportive. Epistemological questions and research have also been combined in previous studies and theories. However, there is variation in the emphasis on the nature of science and research skills in the studies (see, e.g., Abd-El-Khalick & Lederman, 2023; Lederman, 2019; Lederman & Lederman, 2019).

In addition, there is variation in how research skills, or research competence and inquiry skills as corresponding concepts, are understood in studies. Although most university students will likely not work as researchers in their future careers, they need skills to evaluate, compare, and apply scientific knowledge when making decisions when in expert positions (Lehtinen et al., 2019). In this doctoral dissertation, research skills are seen as tools for students in their future work in expert positions. Thus, research is comprehended as a set of skills that are needed to understand scientific research and conduct it, at least at a very basic level. This means skills for understanding the central scientific concepts, for example, the concept of theory in its scientific meaning. Research skills also includes understanding basic research methods, such as tools for conducting scientific research. Although one would not conduct scientific research by oneself, a basic methodological understanding is needed to utilize the scientific research conducted by others.

1.3 Challenges in Learning and Teaching Scientific Thinking

Although scientific thinking skills are understood as a significant learning goal for university education, learning and teaching them are not unproblematic. Understanding the epistemic nature of scientific knowledge is challenging for students and they face problems in learning research skills (see, e.g., Balloo et al., 2018; Murtonen, 2005, 2015). Research-based university education (see, e.g., Böttcher & Thiel, 2018; Thiem et al., 2023) may differ by the nature from students' previous learning experiences and, for example, the quantity of different scientific theories can cause confusion. Without understanding the nature of scientific knowledge and the scientific research process behind it, it can be difficult to comprehend why there are various theories around one topic and how to deal with them. To overcome this confusion, students need to move from dualistic to relativistic assumptions (the first critical phase in Perry's theory). As Perry (1970) stated, the support of the academic community is crucial in helping students proceed in the process.

University students also face challenges in understanding central scientific concepts; for example, the concepts of qualitative and quantitative research are difficult for students to understand (Murtonen, 2015). Assuming that understanding basic scientific concepts is important for the development of research skills, it is important to ensure that all students achieve at least a basic understanding of the most central concepts. In addition, learning research methods is challenging for students, and as Balloo (2019) stated, the difficulties during research methods training can act as potential barriers to the development of students' scientific thinking. Furthermore, integrating the theoretical parts of their education with practice is confusing for many students (see, e.g., Murtonen et al., 2008), and they are not always able to apply the learned scientific content in practice.

In addition to challenges in learning scientific thinking skills, there are challenges in teaching scientific thinking. Student groups are often large, and it is not always easy for teachers to be aware of individual students' beliefs and conceptions. However, some kind of understanding is needed, and it is important to consciously pay attention to students' conceptions (see, e.g., Barzilai & Zohar, 2016; Strømsø & Bråten, 2011). To help the development of students' scientific thinking, it is important to encourage them to consciously reflect not only on their own but also on other people's beliefs and conceptions (see, e.g., Barzilai & Zohar, 2016; Brownlee et al., 2011). Additionally, it is important for teachers to reflect on their own conceptions and beliefs (see, e.g., Barzilai & Zohar, 2016; Brownlee et al., 2011; Brownlee et al., 2017). This is beneficial for the development of not only teachers' thinking but also for their students, as teachers' epistemic understanding is related to how they teach their students (see, e.g., Strømsø & Bråten, 2011).

In addition to promoting students' epistemic understanding, university teachers play an important role in helping students learn research skills. However, there is variation in teachers' conceptions of undergraduate research, and they use different methods to promote their students' research skills (see, e.g., Brew & Mantai, 2017; Brew & Saunders, 2020; Lorencová et al., 2019). Because students' conceptions of research methodology courses are not always positive (see, e.g., Murtonen, 2005; Murtonen et al., 2008), and they might have conceptions of research methods as difficult (see, e.g., Balloo et al., 2018), there might be challenges in motivating students to learn. Thus, it is important to explore what kinds of conceptions students have to help them overcome possible barriers (Balloo, 2019). By presenting the results of four studies, this doctoral dissertation aims to increase our understanding of students' and teachers' learning and teaching of scientific thinking at universities.

1.4 Research Questions

The aim of this dissertation is to deepen the understanding of learning and teaching scientific thinking at universities. By exploring students' and teachers' conceptions of scientific thinking in the university context, this work aims to increase the understanding of the key aspects to when aiming to promote learning and teaching scientific thinking in this context.

Given this background, the research questions are as follows:

1) What are the central elements of scientific thinking in the university context conceptualised by university students and teachers?
    a. What are the central elements of scientific thinking conceptualised by university students? (study I)

   b. What are the central elements of scientific thinking conceptualised by university teachers? (study II)

2) What kind of connections between epistemic understanding and research skills can be identified in students' and teachers' conceptions of scientific thinking in the university context?

   a. What kind of connections between epistemic understanding and research skills can be identified in university students' conceptions of scientific thinking? (study II & study III)

   b. What kind of connections between epistemic understanding and research skills can be identified in university teachers' conceptions of scientific thinking? (study IV)

   c. What kind of connections between epistemic understanding and research skills can be identified in university students' conceptions of theory? (study III)

3) What kind of conceptions university teachers have of promoting university students' scientific thinking in the university context?

   a. What kind of phases of promoting university students' learning to think scientifically can be identified? (study IV)

2 Methods

2.1 Research Design and Instrument Selection

The aim of this doctoral dissertation is to deepen the understanding of learning and teaching scientific thinking in the university context. The phenomenon was approached from students' (studies I and III) and teachers' (studies II and IV) pointsof view. The methods used in the studies to deepen understanding of scientific thinking were mainly qualitative. In addition, some quantitative methods were utilised to compare participants' responses (studies I, II, and III).

Studies I, II, and III were conducted by analysing teachers' and students' written open-ended answers to questions regarding what they think scientific thinking is, how it develops (studies I and II), and what they think the concept of theory means (study III). Despite studies I and II were conducted as separated studies, the same method was deliberately selected to allow comparing the results later. Qualitative surveys were selected as the method because they allow respondents to describe their experiences and views in their own words, bringing out depth that quantitative methods may not reveal. Thus, the written responses were expected to provide a deeper understanding of participants' thinking than for example quantitative questionnaires. In studies I and II, the aim was to start constructing an understanding of the phenomena and questionnaires were developed to fit for that purpose. Despite the limitations of the qualitative questionnaires, the data the data provided answers to the research questions concerning students' and teachers' conceptions of scientific thinking and also the concept of theory.

The theoretical understanding of the topic had increased during studies I, II and III and thus, it provided a basis to begin to deepen understanding with more complex methods. Study IV was conducted by analysing focus group interviews with university teachers. This method was selected because focus group interviews were expected to deepen understanding of university teachers' conceptions of the development of students' scientific thinking. In focus group interviews, participants can build on other participants' thoughts and thus they can provide a deeper understanding of the topic than individual interviews (see, e.g., Wilkinson, 2004).

To increase the understanding of scientific thinking on the multidisciplinary level, studies that directly aimed to explore students' and teachers' conceptions of scientific thinking in the university context (studies I, II and IV) were conducted as cross-disciplinary. This cross-disciplinary setting was not applied in study III to minimise the possible impact of differences in degree structures between disciplines, since the aim was to explore students' conceptions of theory and compare if there are differences between students in different phases of their studies at a university.

2.2 Participants

The participants of the studies in this dissertation (N = 426) were Finnish university students (n = 324) and teachers (n = 102), representing various disciplines. Studies I and III concentrated on students' conceptions of scientific thinking, and studies II and IV looked at the phenomenon from university teachers' point of view (see table 1).

Table 1. Study participants.

STUDY	**PARTICIPANTS**	**N**
I	University students representing different disciplines	145
II	University teachers representing different disciplines	87
III	Teacher education students	179
IV	University teachers representing different disciplines	15
TOTAL		426

The participants in studies I, II, and IV represented different disciplines, and the participants in study III were teacher education students in the faculty of education. The number of participants by faculty is presented in table 2.

Table 2. Study participants by discipline.

FACULTY	STUDENTS	TEACHERS
FACULTY OF HUMANITIES	18	20
FACULTY OF ECONOMICS	16	10
FACULTY OF EDUCATION	183	2
FACULTY OF LAW	0	3
FACULTY OF MEDICINE	20	23
FACULTY OF SCIENCE	42	23
FACULTY OF SOCIAL SCIENCES	45	6
FACULTY OF TECHNOLOGY	0	3
UNKNOWN	0	12
TOTAL	324	102
TOTAL NUMBER OF PARTICIPANTS	**426**	

The participants in studies I, II, and III were selected by asking students (in studies I and III) or teachers (in study II) who were participating in certain lectures or seminars to respond to a questionnaire. Participation was voluntary, and all students who responded were selected as participants. The participants in study IV were selected by asking teachers who were participating in the university pedagogical course if they wanted to participate. All teachers who were interested were selected as participants. Participation in all studies was voluntary, and before data collection, the participants were briefly informed about the purposes of the research and that their data would be handled anonymously. There is a minor possibility that some participants took part in more than one study and are therefore counted twice.

2.3 Data Collection

Data Collection in Study I

The data for study I were collected anonymously from Finnish university students (N = 145) with a paper-and-pencil questionnaire during lectures or seminars. The students were instructed to describe what they think scientific thinking is and how it develops during their university education. Participation was voluntary. The average word count of the students’ responses was 57, and the length of the responses varied between 11 and 107 words.

Data Collection in Study II

The data for study II were collected from Finnish university teachers (N = 87) with a paper-and-pencil questionnaire in pedagogical training seminars. Teachers were asked to describe the aspects of scientific thinking they felt that students should develop during their university education, and what this scientific thinking consists of. The questionnaire was one A4 page, with the instructions at the top of the page. The rest of the single-sided page was for the responses. The average word count of the teachers' answers was 92 and varied between 24 and 141 words.

Data Collection in Study III

The data for study III were collected from Finnish teacher education students (N = 179) with a questionnaire. Students answered an open-ended question: "What do you think the concept of theory means?" Approximately two-thirds of the participants (n = 126) answered by completing a paper-and-pencil hard-copy questionnaire, and about one-third of the students (n = 53) completed the questionnaire online.

Data Collection in Study IV

The data for study IV were collected by conducting focus group interviews (see, e.g., Wilkinson, 2004) in groups of three to four university teachers. All the teachers (N = 15) attended university pedagogical courses at the University of Turku. They voluntarily expressed their interest in participating in an interview. The interviews were organized through the Zoom video conferencing platform, and the duration of the interviews varied between 38 and 75 minutes. The average length was 59 minutes.

2.4 Analysis Methods

Data Analysis in Studies I and II

In studies I and II, the data collected with the paper-and-pencil questionnaire were transcribed and pseudonymised. Then, in both studies, the data were analysed using theory and data-driven content analysis (see, e.g., Green, 2004). The preliminary categories for the analysis were defined based on theories of higher-order thinking in higher education, and new categories were added based on the data. The data for study II were analysed first. The following theory-driven classification categories were assumed based on previous theories: (1) the basics of science and critical thinking, (2) epistemic understanding, (3) research and methodology skills, and (4) evidence-based reasoning. In addition to the theory-driven categories, the researchers added data-driven categories if the responses could not be classified into the theory-driven categories. The suggested new data-driven categories were discussed among the researchers, and one new category was selected and named contextual understanding. Pearson's correlation test was used to explore possible connections between the categories, and a Mann–Whitney U-test was conducted to explore the relationship between epistemic understanding and the other categories. Descriptive statistics were utilized to report the results.

In study II, both researchers classified the data according to the five agreed-upon categories. Both authors read all the answers and coded 1 for each category if a notion of the classification categories was found and 0 if there was no mention of the categories. A teacher's answers could be categorized into more than one category if the notions met the criteria in more than one category. An inter-rater reliability check of the codes for the entire five-category model was calculated, resulting in 86% agreement between the coders. Disagreements were discussed until consensus was obtained for each classification. The same method and coding system were used analys the data for study I. The same five categories were identified, and a need for new categories was not found. For the final analysis in study I, the first author analysed all data, and the second author analysed about half (56.6%) of the responses. Inter-rater reliability was calculated for the data, resulting in 83% agreement. Descriptive statistics were utilized to report the results.

Data Analysis in Study III

In study III, the students' open-ended answers were transcribed, and the data were anonymized by assigning an ID number to each student. Part of the data was collected with an online questionnaire, and transcription was not needed. Online data were also anonymized by assigning ID numbers and then combined with paper-and-pencil data. The data-driven analysis revealed that there were two kinds of answers: 1) answers that did not include any scientific concepts and were related to everyday conceptions of theory and 2) answers that showed some kind of understanding of the concept of theory in a scientific context. Thus, the analysis was performed first by separating the answers into two main categories: 1) non-scientific conceptions and 2) scientific conceptions of the concept of theory. Then, the answers grouped into the scientific conceptions category were analysed in more detail. Three sub-categories for scientific conceptions of theory were created based on previous research (Salmento & Murtonen, 2019) and were named declarative level, procedural level, and epistemic level. Although the original categorization in previous research was based on students' conceptions of research, the idea of the categorization also proved to be applicable to conceptions of the theory.

The categorization was conducted with a top-down method, meaning that when reading each answer, the researcher checked first to see if the answer reached the highest epistemic level. If it did, the answer was categorized into this category. If not, but when checked, it reached the next procedural level, it was then categorized in the procedural category. If not, but when checked, it reached the lowest level (i.e., the declarative level), it was grouped into this category. However, if the answer could not be sorted into one of these three categories, then in conjunction with a co-researcher, it was considered whether the answer should have been categorised as a non-scientific conception at the beginning of the analysis. The first and second authors of the study analysed 30% of the data by coding the answers based on the categorisation. The inter-rater reliability was 86%. The first author analysed the rest of the data. Descriptive statistics were utilized to report the results.

Data Analysis in Study IV

In study IV, the interviews were transcribed and pseudonymised. Then, a data-driven content analysis was conducted to find out how teachers perceive the developmental process of their students scientific thinking. The discussions were explored to find out how the teachers believe that scientific thinking develops and whether there are some phases that they agreed are important, regardless of discipline. Because in this study our focus was not on individual teachers' beliefs, we interpreted the discussions by paying attention to the shared understanding that developed during the discussions. A model of learning to think scientifically was created based on our interpretations. A summary of the methods in studies is presented in table 3.

Table 3. Summary of the methods used in the studies.

STUDY	PARTICIPANTS	DATA COLLECTION METHODS	DATA ANALYSIS
I THE ROLES OF EPISTEMIC UNDERSTANDING AND RESEARCH SKILLS IN STUDENTS' VIEWS OF SCIENTIFIC THINKING	University students (N = 145) representing different faculties (Humanities, Education, Medicine, Science and Engineering, Social Sciences, and Economics). 45 of the participants were first or second year students, 66 were third year students and 34 fourth, fifth or sixth year students	Anonymous paper-and-pencil questionnaire during lectures or seminars	Data- and theory-driven content analysis. Pearson's correlation test and a Mann–Whitney U-test Descriptive statistics were utilised to report the results
II BROADENING THE THEORY OF SCIENTIFIC THINKING FOR HIGHER EDUCATION	University teachers (N = 87) representing different faculties (Humanities, Education, Medicine, Science and Engineering, Law, Social Sciences, and Economics); 12 of the teachers did not mention their faculty	Anonymous paper-and-pencil questionnaire in pedagogical training seminars	Data- and theory-driven content analysis Descriptive statistics were utilised to report the results.
III UNDERSTANDING TEACHER EDUCATION STUDENTS' RESEARCH COMPETENCE THROUGH THEIR CONCEPTIONS OF THEORY	Teacher education students (N = 179). First- or second-year students (n = 114) and fourth- or fifth-year students (n = 65)	Anonymous paper-and-pencil questionnaire or anonymous online questionnaire	Data- and theory-driven content analysis Descriptive statistics were utilized to report the results
IV TEACHING UNIVERSITY STUDENTS TO THINK SCIENTIFICALLY: FOCUS ON EPISTEMIC UNDERSTANDING AND RESEARCH SKILLS	University teachers (N = 14) representing 6 faculties (Humanities, Medicine, Science and Engineering, Economics, Social Sciences, and Technology)	Focus group interviews in groups of 3–4 university teachers	Data- and theory-driven content analysis

2.5 Ethical Considerations

Ethical principles were followed during all phases of the research process. In all studies, participation was voluntary. All study participants were aware that they were participating in the research and gave their permission for the data to be used for research purposes. Before data collection, the participants were informed about the central purposes of the research, and the information provided was the same for all participants. The data were handled anonymously, and participants were informed in the data collection.

The participants in study I were university students representing different disciplines. Their courses were taught by university teachers participating in university pedagogical courses. Because teachers who are studying university pedagogy represent various disciplines, this was a way to reach students in many disciplines. This was important because the aim of study I was to understand students' conceptions of scientific thinking at the multidisciplinary level. The same was true for the participants of study II. Because the aim was to increase understanding of how university teachers, regardless of discipline, comprehend scientific thinking and how it develops, the teachers participating in university pedagogical courses were an appropriate target group. In addition, their strong interest in pedagogy was seen as a benefit for delving deeper into the topic. Of course, in the future, it would be important to explore novice teachers' conceptions as well.

The participants in study III were teacher education students. They were selected because the aim was to approach the phenomenon from the viewpoint of one specific discipline. Because the idea was to compare the conceptions of students in different phases of their studies, it was reasonable to select students who were studying the same study programme. Of course, it would be important to explore the same phenomenon also in other disciplines to achieve a disciplinary and multidisciplinary understanding of the topic.

The participants in study IV were teachers participating in university pedagogical courses. The reason for participant selection was the same as in study II. The aim was to explore the phenomenon at the multidisciplinary level, and expert teachers were assumed to be proficient in supporting their students' learning and thus capable of constructing a deep understanding of the learning process of scientific thinking. In addition, people feel more comfortable, and the discussion can become deeper, if participants in the focus group interviews are familiar with each other (see, e.g., Wilkinson, 2004).

The data for studies I, II, and III were transcribed after data collection, and participants' names were replaced with numbers as codes. The data for study IV were also transcribed after data collection, and a letter was assigned as a code for each group. A number was assigned to each group member, and the final IDs included the letter of the group (A–D) and the ID number (1–4).

Because the number of participants in study IV was small, and the number of teachers participating in certain university pedagogical courses is limited in each year, there is a higher risk of identifying the participants. This was taken into account when reporting the results, and careful attention was paid to avoid reporting anything that could cause harm to the participants. All data were saved in the university's secured network folder, and only the authors had access to the data.

The studies did not involve intervention in the physical integrity of the participants, deviation from informed consent, studying children under the age of 15 without parental consent, exposure to exceptionally strong stimuli, causing long-term mental harm beyond the risks of daily life, or risking participants' security (cf. Finnish Advisory Board on Research Integrity, 2019). Consequently, the studies did not require a Finnish ethics review.

3 Summary of the Main Findings

3.1 The Roles of Epistemic Understanding and Research Skills in Students' Views of Scientific Thinking (Study I)

The starting point of this doctoral dissertation was the need to better understand the phenomenon of scientific thinking in the university context. The basic idea was to deepen the understanding of how university students and teachers conceptualise what scientific thinking is and how it develops. The aim of study I was to explore the phenomenon from university students' (N = 145) point of view and examine 1) how university students conceptualise scientific thinking and 2) what roles epistemic understanding and research skills play in the students' views.

Students' conceptions of scientific thinking were explored by asking them to describe what they think that scientific thinking is. Their responses were classified in five theory-based categories: 1) Criticality and basics of science, 2) Epistemic understanding, 3) Research skills, 4) Evidence-based reasoning and 5) Contextual understanding. The categorisation was based on a theory of scientific thinking, which is explained in more detail in the next section. Data-driven categories were allowed to arise, but no additional categories were identified.

When examining students' conceptions, about half (51.7%) emphasised critical thinking skills and understanding the basic concepts of science as an important part of scientific thinking. Statements related to epistemic understanding of science were found in only a few of the students' responses (8.2%). Strengthening the need for a theory of scientific thinking in university context, about one-third (31.3%) of the students mentioned research and methodology skills in their descriptions of scientific thinking. Research skills are not often included in scientific thinking theories, perhaps because of contextual differences in theories. For example, research skills often lack from theories that focus on children's scientific thinking. About one-fifth (21.1%) of the students mentioned evidence-based reasoning or inference skills in their responses. Contextual understanding, meaning understanding the discipline-specific way of thinking in relation to wider contexts, was recognised only in some (12.9%) of the students' responses.

Based on assumptions about the fundamental role of research and methodology skills and epistemic understanding in scientific thinking, these aspects were explored in more detail. Conceptualising research skills as part of scientific thinking was not typical for first-year students (only 12.9% of the first-year students mentioned research skills), but the number of conceptions of research skills seemed to increase rapidly after the first year (50% of second-year students and at least 30% of students in all the further study years mentioned research skills). Some of the responses were declarative, meaning that students mentioned some core details of scientific research. Some of the responses were procedural, i.e., related to doing (for example conducting research and participating in the research process). Some of the responses were interpreted as including an understanding of the epistemic nature of scientific knowledge. In these responses, research and methodology skills were combined with epistemic understanding. Despite the low number of student responses related to epistemic understanding of science, the results strengthened our assumption about the link between research skills and epistemic understanding in scientific thinking.

3.2 Broadening the Theory of Scientific Thinking for Higher Education (Study II)

The aim of study II was to deepen understanding of the phenomenon of scientific thinking in higher education by exploring university teachers' conceptions of the development of their students' scientific thinking. University teachers' (N = 87) were asked to describe what they think scientific thinking is and how it develops. Theory- and data-driven content analysis was conducted to explore what are the most central elements of scientific thinking in the university context. A suggestion of theory of scientific thinking was created based on the analysis. The aim was not to create a theory of scientific thinking in any specific field of science. Instead, the goal was to find out what are the elements of scientific thinking that are common to all disciplines.

The theory-driven analysis was based on classifying teachers' responses into categories arising from previous scientific thinking theories. The theory-driven categories were (1) criticality and the basics of science, (2) epistemic understanding, (3) research skills, and (4) evidence-based reasoning. The suggested theory is a combination of previous scientific thinking theories and an extra category that arose in the data-driven analysis, which we named (5) contextual understanding. The theory of scientific thinking was suggested to consist of these five elements (figure 1).

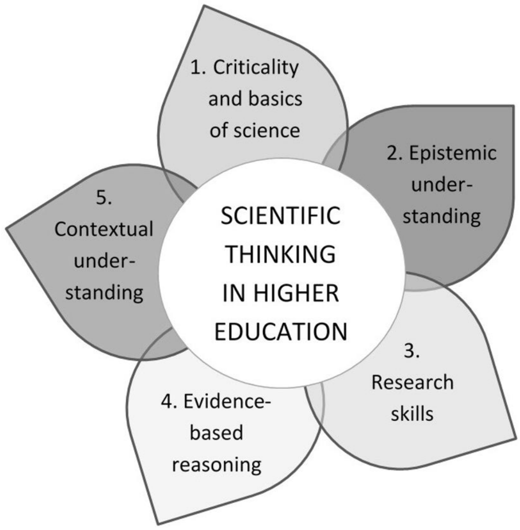

Figure 1. Theory of scientific thinking in higher education.

The teachers' responses were grouped into these categories. As in study I, the categories were not exclusive, and one response could be categorized into several categories. The most common categories among teachers were critical thinking and the basics of science, research and methodology skills, and contextual understanding. About one-fourth of the teachers emphasised the role of epistemic understanding of science and some evidence-based reasoning. The number of teachers' responses is presented in figure 2. To illustrate the differences between teachers' and students' views of scientific thinking, students' responses from study I were included in the figure. When comparing the results, the percentual amount of teachers' responses classified in the categories was higher than the percentual amount of students' responses in all the categories, except the category evidence-based reasoning.

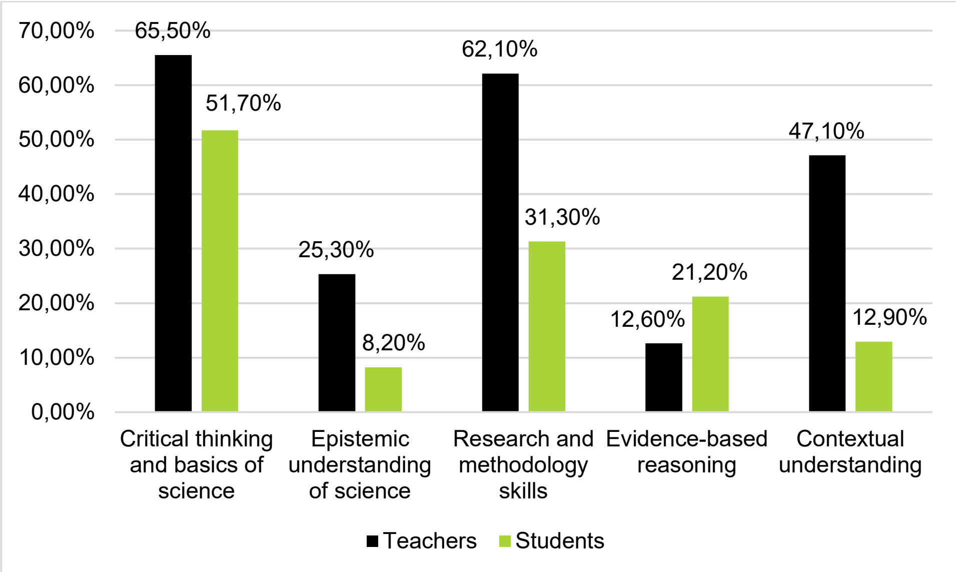

Figure 2. Teachers' conceptions of scientific thinking (study II) combined with students' conceptions of scientific thinking (study I).

3.3 Understanding Teacher Education Students' Research Competence Through Their Conceptions of Theory (Study III)

The results of studies I and II strengthened assumptions about the fundamental role of research skills in scientific thinking. Both teachers and students emphasised the importance understanding the basics of science, including the basic scientific concepts. In study III, the aim was to deepen the understanding of students' research competence by exploring how they understand one of the fundamental scientific concepts, the concept of theory.

In this study, teacher education students (N = 179) were asked to describe what they think that the concept of theory means. Some of the participants (n = 114) were first- or second-year students (referred here as early-stage students), and some (n = 65) were fourth- or fifth-year students (referred here as graduating students). Some of the responses showed an understanding of the concept of theory in a scientific context, but many of the answers did not. Many of the responses were more related to 'everyday thinking' and did not show any kind of understanding of the scientific meaning of the concept of theory. These students seemed to combine the concept of theory with practical thinking in everyday life, for example, explaining practice, being a solution to a problem, or being a fact or truth. This kind of non-scientific conception was typical for early-stage students (65.4% showed non-scientific conceptions) but also for graduating students (44.10% showed non-scientific conceptions).

The responses that showed an understanding of the concept in the scientific context were explored in more detail, and different levels for explaining the concept were found. Some of the students described the concept at the *declarative level*. They used some terms that were related to science, for example the term scientific. Some of the students described the concept at the *procedural level*. They showed an understanding of where theories come from and what they can be used for. Their answers were related to research and "doing." Some of the students described the concept at the *declarative level*. They showed understanding, for example, that theories are pursued through scientific research by researchers using different research methods, and that although theories are created by following strict scientific practices, theories are not certain truths. Differences between the student groups are presented in figure 3.

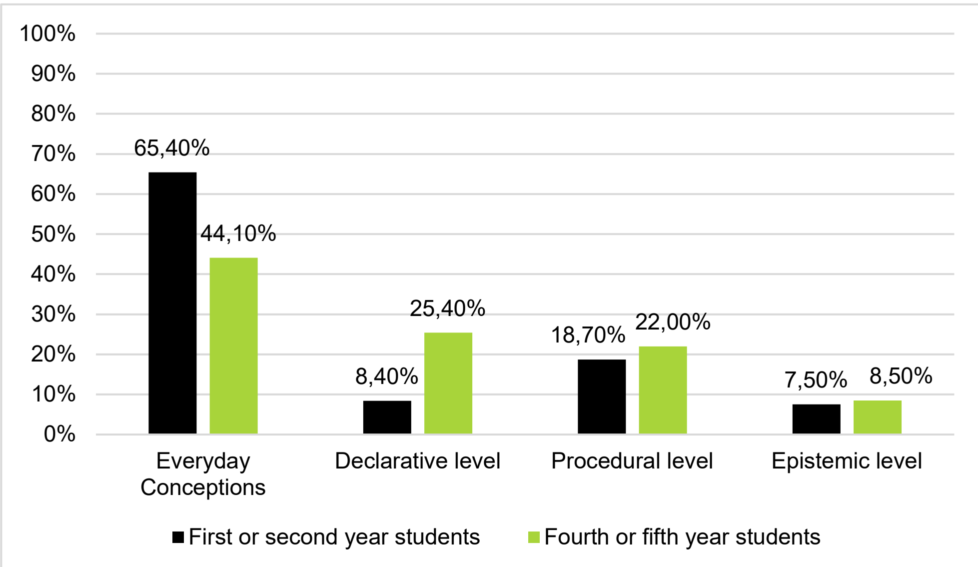

Figure 3. Differences in conceptions of theory between first- and second-year students and fourth- and fifth-year students.

3.4 Teaching University Students to Think Scientifically: Focus on Epistemic Understanding and Research Skills (Study IV)

Studies I and II increased understanding of university students' and teachers' conceptions of scientific thinking. Critical thinking and understanding the basics of science were emphasied by students and teachers. The role of research and methodology skills was shown to be fundamental, and the results of study II strengthened assumptions about the intertwined relationship of epistemic understanding and research skills in scientific thinking. The intertwined relationship between research and epistemic understanding was also shown in study III. The most advanced descriptions of the concept of theory included a combination of these. In addition, contextual understanding, meaning understanding the discipline-specific way of thinking related to wider contexts was emphasised by university teachers. These findings raised questions about how all these thinking skills are related and what actually is included in the process of learning to think scientifically. The aim of the study was to explore what critical phases in the process of learning to think scientifically university teachers identify and what is the role of epistemic understanding and research skills in it.

Four essential phases were found, and the process of learning to think scientifically was visualized based on the phases. The first phase, understanding the difference between scientific knowledge and knowledge in general, was based on teachers' observation that the epistemic nature of science is often unfamiliar to people. Regardless of the discipline, teachers brought up examples of how people often want to see things simple, hope to find some truths, and become confused about why there are so many theories. This kind of thinking is familiar in everyday life, and we proposed that understanding the difference between these ways of thinking might be a starting point moving forward in the learning process toward scientific thinking.

The second phase, understanding the basics of the scientific research process and research methodology, was based on the teachers' agreement that students need to have a basic understanding of the scientific research process and research methods to be able to understand and interpret scientific knowledge. As a link to epistemic understanding of science, teachers stressed that the nature of the scientific knowledge construction process might be hard to understand for students who expect to find truths from research. A combination of the first and second phases is needed, for example, to distinguish scientific research from fake studies. The view of the significance of understanding the basics of scientific research process and research methodology was shared by teachers across disciplines.

The third phase, figuring out the idea of scientific way of thinking: receiving readiness to think scientifically, was based on the interpretation of teachers' discussions of relevant learning goals for students. The teachers pondered that instead of expecting students to learn to conduct "real scientific research," they should be ready for scientific thinking. Received readiness means that students are able to recognize scientific knowledge from other kinds of knowledge, know how scientific knowledge is created, understand the value of different perspectives, and have basic skills to interpret and apply scientific knowledge.

The fourth phase, learning to express scientific thinking and identifying oneself as a scientific thinker (figure 4) was based on development of scientific communication skills. Teachers saw that students often need encouragement for expressing their thinking. In conclusion, it was suggested that the combination of epistemic understanding and research skills is the heart of developing scientific thinking. Each phase demands more developed epistemic understanding and research skills than previous phases. Thus, it would be important to ensure that students achieve at least the two first phases, preferably also the third and even fourth during their university education.

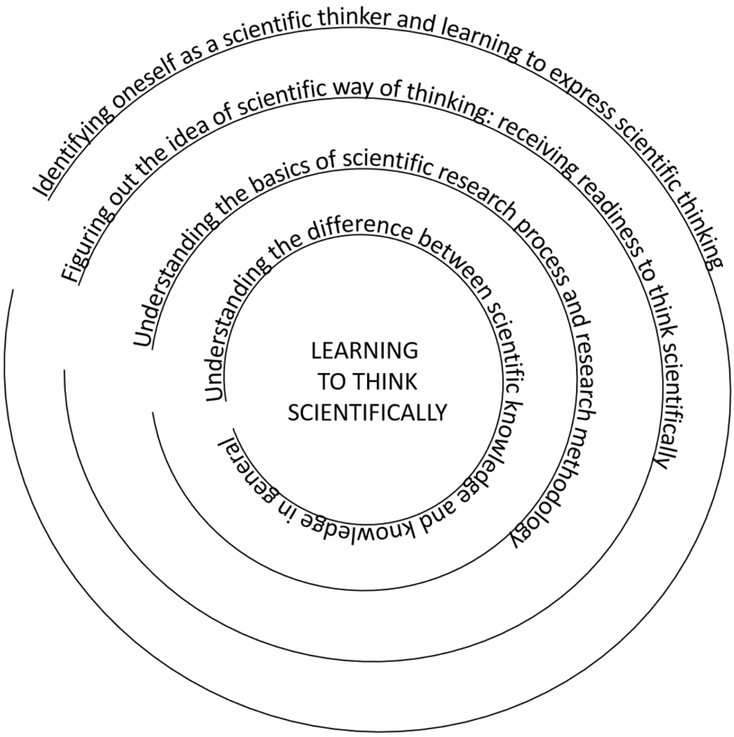

Figure 4. Process of learning to think scientifically. Although the phases are expected to follow each other, there are likely overlaps in the achievement of the phases.

4 Discussion

The aim of this dissertation was to increase the understanding of learning and teaching scientific thinking at universities by exploring 1) What are the central elements of scientific thinking in the university context conceptualised by university students and teachers, 2) What kind of connections between epistemic understanding and research skills can be identified in students' and teachers' conceptions of scientific thinking in the university context, and 3) What kind of conceptions university teachers have of promoting university students' scientific thinking. The questions will be discussed in light of the findings of the studies. In addition, theoretical, pedagogical, and practical implications will be presented in the chapter to provide tools for promoting learning and teaching scientific thinking in universities. Finally, the limitations of this study and directions for future research will be discussed.

4.1 Elements of Scientific Thinking in the University Context

By exploring university teachers' and students' conceptions of what scientific thinking is, studies I and II aimed to create an overview of the main elements of scientific thinking in the university context. According to the results of both studies, the main elements of scientific thinking are (1) the basics of science and critical thinking, (2) epistemic understanding, (3) research and methodology skills, (4) evidence-based reasoning, and (5) contextual understanding. The elements were mentioned by teachers and students representing several faculties. Some elements were emphasised more in certain faculties than in others, but remarkable differences were not found. Thus, it was suggested that these elements form a theory of scientific thinking that can be generalised to most disciplines at university.

There were differences in the emphasis that teachers and students gave to different elements. The basics of science and critical thinking were a popular category in both teachers' and students' views. However, although critical thinking often comes to people's minds in relation to science and scientific research (see, e.g., Sinatra et al., 2014), it does not mean that they understand critical thinking in the context of scientific thinking. In everyday life, critical thinking is sometimes considered simply as opinion (see, e.g., Kuhn, 1999), not as an ability to identify, reason, judge, analyse, evaluate, and make decisions about assumptions, as is understood in the higher education context (see, e.g., Halpern, 2013; Hyytinen et al., 2014; Hyytinen et al., 2019). The same phenomenon was identified by teachers in study IV, and they brought out that critical thinking is often connected to choosing right or wrong answers. This is describing the link between epistemic understanding and critical thinking that has been identified also in previous studies (see, e.g., Greene et al., 2018).

The development of epistemic understanding as a part of developing scientific thinking was described by about one-third of the teachers. Only a few of the students discussed the idea of developing epistemic understanding in their responses. The low number of students' responses may refer to the fact that perhaps they do not yet comprehend the nature of knowledge as a component of scientific thinking (see, e.g., Khishfe, 2022). On the other hand, epistemic understanding might have been more identifiable through more advanced methods. Thus, for example, focus group interviews would work when exploring the phenomenon in more detail in future research. However, the fact that teachers and students spontaneously discussed epistemic understanding was interpreted as a sign of its important role in scientific thinking in the university context.

The role of research skills was also shown to be significant in teachers' and students' conceptions of scientific thinking. In addition, the number of teachers who described research skills as part of scientific thinking was higher than the number of students. Some of the descriptions were more advanced than others. Some of the students mentioned research, some described research as process of producing scientific knowledge, and some saw research as an active scientific knowledge production process conducted by people. Building on Perry's theory (1970, see the introduction of this work), the latter conceptions refer to more advanced conceptions than the first ones and were interpreted to be epistemic in the nature. Here came the first assumption about the intertwined relationship of epistemic understanding and research skills in scientific thinking. The relationship between these will be discussed more detailed in chapter 5.2.

In addition to above mentioned scientific thinking skills, both teachers and students identified inference skills an element of scientific thinking. Moreover, a discipline-specific way of thinking or the worldview typical for one's own discipline (named in the studies as contextual understanding) was also identified as part of scientific thinking by both teachers and students, but was emphasised more by teachers. This is also understandable, because as more experienced members of the scientific community, teachers likely comprehend the discipline-specific way of thinking better than students and are able to relate it in other contexts. Although the suggested theory of scientific thinking in higher education does not cover all the thinking skills that university students are expected to learn, it aims to direct attention to issues that are relevant for the development of scientific thinking. Thus, the main advantage of the results of studies I and II was to find the elements that should be explicitly supported when teaching university students to think scientifically. Because there is a broad research tradition behind each of the five elements, exploring all of them more detailed in one dissertation would have been challenging for theoretical, methodological and practical reasons. The aim of this dissertation was to increase understanding of scientific thinking in universities as research-based academic institutions, and attention was paid especially to the methods with which scientific knowledge is produced (scientific research) and the nature of scientific knowledge (epistemic understanding of science). The relationships between of all the five elements would be interesting to explore in more detailed in the future research.

4.2 An Intertwined Relationship Between Epistemic Understanding and Research Skills in Scientific Thinking

As discussed in the previous chapter, an assumption about an intertwined relationship between epistemic understanding and research skills arose when analysing the results of study II. ln that study, only a few of the students expressed an understanding of the development of epistemic understanding as a part of scientific thinking, but those who did also emphasized the significance of research skills in scientific thinking. The connection between epistemic understanding and research skills has been noted also by other authors (see e.g., Lederman, 2019 to read more). Similar tendency was found also when exploring university students' conceptions of the concept of theory in study III. In that study, the students with the most advanced scientific conceptions of the concept of theory also showed an understanding of the epistemic nature of the concept in the context of scientific research. The analyses were based on students' written open-ended responses to a questionnaire. More advanced methods would probably deepen the understanding of the topic. In the future, the phenomenon could be explored in more detail by conducting individual or focus group interviews that would allow for a deeper understanding of students' thinking (see, e.g., Wilkinson, 2004).

Support for the assumption about the intertwined relationship between epistemic understanding and research skills was also found in study IV, when university teachers' thinking about the process of learning to think scientifically was explored. The analysis of the teachers' focus group discussions revealed four critical phases in the development of scientific thinking. Some of the phases were interpreted as more advanced than others, and the process of learning to think scientifically was visualised as an expanding spiral. The phases were as follows: 1) understanding the difference between scientific knowledge and knowledge in general, 2) understanding the basics of the scientific research process and research methodology, 3) understanding the scientific way of thinking: achieving readiness to think scientifically, and 4) learning to express scientific thinking and identifying oneself as a scientific thinker. Although there are likely overlaps between the phases, reaching each phase enables moving toward the next one. To progress in the process, both epistemic understanding and research skills must be developed. Despite the need for further research on the relationship between epistemic understanding and research skills, the study IV results provide a starting point. The visualisation could also be expanded in future research by exploring the role of other elements of scientific thinking in more detail. The focus group interview method was experienced as a good method for deepening the understanding of the topic because it allowed teachers to construct their understanding of the phenomenon together (see, e.g., Wilkinson, 2004). The advantage of multidisciplinary groups was the possibility for teachers to compare disciplinary differences and similarities, which led to fruitful discussions. For example, when some of the teachers gave examples of typical perceptions that students often have about their discipline, other teachers began to find similar ones from the perspective of their own discipline. Despite the fact that the examples were related to discipline-specific knowledge, the epistemological idea behind the examples was the same. These kinds of observations were used as foundation when building the visualisation of the phases of learning to think scientifically as a result of this study. In the future, the phenomenon could also be explored at the disciplinary level. However, the multidisciplinary design was functional for the purposes of this study, which aimed to explore the disciplinary-generic elements of scientific thinking.

4.3 Effective Promotion of the Development of Students' Scientific Thinking in Universities

The aim of all the studies was to deepen our understanding of how the development of students' scientific thinking can be promoted in universities. The results indicate that despite the considerable work done to support the development of students' scientific thinking, more attention should be paid to explicitly teaching scientific thinking skills to students. The results of studies I and II revealed the central components that should be consciously paid attention to when teaching students to think scientifically. Many of the elements, such as critical thinking, research, and methodology skills and inference skills, are mentioned in the curriculum. In addition, the central scientific concepts are often described as learning outcomes, at least in methodology courses. Although many students learn these skills, many do not (see, e.g., Murtonen, 2005, 2015). In addition to the need to ensure that students achieve basic research skills, more attention should be explicitly paid to the development of epistemic understanding of science (see, e.g., Lederman & Lederman, 2019). In light of the findings of the studies, consciously combining them in teaching could promote the development of both.

In study IV, many teachers described what kind of (mis)conceptions people usually have about their field of study. Most of the conceptions were related to epistemological thinking, and regardless of their discipline, the teachers discussed that students often believe that science will give them the truth about things. This is a typical challenge for the public's understanding of science (see, e.g., Sinatra et al., 2014; Sinatra & Hofer, 2016) that is understandable, because if the nature and origins of scientific knowledge are foreign to people, it is unreasonable to expect them to understand. Thus, the first stage of learning to think scientifically was proposed to understand the difference between scientific knowledge and knowledge in general. It might sound obvious, especially for university teachers, who often are also researchers and thus, presumably familiar with scientific ways of thinking. However, many students arrive at university without a scientific background, and their epistemological thinking is based on knowledge in general instead of scientific knowledge. Because the nature and origins of scientific knowledge differ fundamentally from the nature and origins of knowledge in general, it might be confusing for students to try to understand where scientific knowledge comes from and how to approach it. A general (mis)conception of scientific knowledge is that it just appears from somewhere or is discovered in the world (see, e.g., Sandoval, 2005) and offers objective truth of things (see, e.g., Sinatra & Hofer, 2016). Thus, it is important to explicitly discuss the differences between scientific knowledge and knowledge in general with students.

In addition to helping students understand the empirical and tentative nature of scientific knowledge (see, e.g., Sandoval, 2005), it is important for them to learn how scientific knowledge is produced. This was also identified as the second critical phase for the development of scientific thinking by university teachers in study IV. This includes understanding basic scientific concepts, basic scientific research methods, and the basic scientific research process. Understanding the basic concepts of science might be a starting point for the development of research competence and, more broadly, for scientific thinking, as concluded in study III. Thus, it is important for teachers to ensure that their students have learned the central scientific concepts and be aware of the possible barriers they face in learning research skills to help them overcome the barriers (Balloo, 2019). If students do not understand the self-corrective nature of scientific knowledge and scientific knowledge production as an active process, they might be confused about what they are expected to do with the existing knowledge and how to combine it with their own scientific work, such as essays or a thesis. Thus, the development of epistemic understanding should be consciously promoted hand in hand with research skills learning.

In light of the results of the studies, it is suggested that when epistemic understanding in science is developed, and students have learned to understand the central scientific concepts, basics of research methodology and basic research skills, they are ready to face Perry's (1968) stages 4, 5, and 6 that open the way for relativistic understanding of the world. Achieving this phase is relevant for an additional learning goal, which is commitment to knowledge. In study IV, the third phase was named understanding the scientific way of thinking: achieving readiness to think scientifically. In this phase, students overcome the confusion of multiple theories and perspectives and begin to understand their value. by Perry (1968) and later by other authors (e.g., Kuhn et al., 2017), the development of an advanced understanding of scientific knowledge demands active studying and practicing in a scientific community, which is crucial for the development of expertise (Lehtinen et al., 2019). Thus, it is important to put effort into ensuring that all university students learn basic research and methodology skills and to explicitly support the development of their epistemic understanding of science.

Scientific argumentation skills have been identified as an important part of scientific skills in previous studies (see, e.g., Kuhn, 2010; Kuhn & Lerman, 2021; Kuhn & Modrek, 2022; Nussbaum et al., 2008). This arose in the results of study IV, and skills for expressing scientific thinking were identified as advanced scientific thinking skills. Teachers identified that their students face challenges in expressing their own thinking in theses or essays. The reasons identified were found to be epistemological. One explanation for this challenge was that students might be uncertain about how scientific knowledge should be applied. If they believe that their previous scientific knowledge is certain, they might be confused about why they should edit their knowledge and how to do it. Again, the findings encourage teachers to explicitly explain to students the scientific knowledge production process and the epistemic nature of scientific knowledge. In addition, explaining the difference between opinions in everyday life and interpreting research results in the theoretical framework is important for students. This kind of discussion might help students better understand the nature of scientific knowledge and to comprehend how scientific knowledge can be applied. The moment when students start to comprehend themselves as scientific thinkers and learn to produce scientific thinking (phase 4 in study IV) is presumably similar to Perry's (1968) second 'epistemological crisis,' which is making a personal commitment to expert knowledge (Perry's stages 5, 6, and 7). This means constructing a personal worldview that is based on conscious 'acts of choice and orientation in a relative world' (Perry, 1968, p. 36). Although most students do not achieve this phase during their studies, university education can offer a good foundation for achieving this phase later. Overall, the aim of university education is to provide students with a good base for the development of expertise that can develop further with deliberate practice in working life (see, e.g., Lehtinen et al., 2019). Perhaps scientific thinking should be approached in a similar way. Instead of trying to educate 'ready scientific thinkers,' we should help students construct a good foundation for their further development of scientific thinking.

4.4 Conclusions

By exploring university teachers' and students' conceptions of scientific thinking, this dissertation aimed to increase understanding of teaching and learning scientific thinking at universities. A theory of scientific thinking was formed based on the results of studies I and II, observations about challenges in understanding the concept of theory were made in study III and critical phases in learning to think scientifically were identified in study IV. Despite the studies together managing to increase understanding of scientific thinking in the university context, there are limitations, and also a need for future research to deepen understanding of the topic.

Since there are no prior studies on the topic, the aim of this dissertation was to start constructing understanding of the phenomena and the data provided answers to the research questions concerning students' and teachers' conceptions. Different types of methods, such as interviews, would have probably revealed more about students' and teachers' conceptions, especially about epistemic understanding. Thus, more advanced research methods are needed in future research when exploring the topic in more depth. For dealing with a complex and multifaceted phenomenon, a mixed- and multi-method approach would help to deepen understanding of it in the future (see e.g., Hyytinen et al., 2020). The focus group interview method was found to fit well for the purposes of study IV and it could be utilised also in future research. There are some theoretical limitations in this work. Since there are broad research traditions behind each of the elements of scientific thinking found in this research, it was not possible to concentrate on all of them in detail. However, selecting two of them, namely research skills and epistemic understanding, was justified by the context of the study. In the future, it would be important to explore also the other elements, or the combination of them in scientific thinking more depth. In addition to the need to explore the elements of scientific thinking with more detail and with more advanced methods in the future, the next step could be moving from exploring conceptions of scientific thinking towards empirically testing the theories that were developed in this work,based on students' and teachers' conceptions of scientific thinking. This would provide more concrete ideas on how to efficiently support the development of university students' scientific thinking.

Pedagogical implications based on the results of this work have been already presented in previous sections. Some points will be discussed here to summarise them: 1) Crucial in all the sub-studies was that teachers really put emphasis on fostering the development of their students' scientific thinking, but there should be more explicit discussion about what kind of way of thinking students actually are expected to learn and why. For example, if students don't comprehend what to do with research skills in working life, they might not understand the relevance of learning them. Thus, it could be good to discuss with students that even if they do not become researchers, they need basic research skills to understand and be able to utilise scientific knowledge in their future positions. 2) Another pedagogical implication that arose in this research is the need to explicitly observe how students understand the most important scientific concepts. Because same concepts might differ in their meaning in a scientific context and in everyday life, helping students to identify their everyday conceptions might help them to learn the scientific ones. 3) In addition to increasing explicit discussion of scientific thinking with students, it would be important to consciously put effort on it also in the university and faculty levels, as well as in smaller units.

Overall, universities play a fundamental role in producing scientific knowledge and educating future scientific thinkers. University teachers are doing valuable work when supporting their students in learning scientific thinking skills. Providing tools for seeking, understanding, evaluating, and interpreting scientific knowledge is the best that university education can offer for future experts and for society. Despite that scientific thinking skills are globally identified as one of the most central learning goals of university education, there is no clear understanding how this process is expected to happen. Instead of expecting students to learn scientific thinking skills implicitly, considerably more attention should be paid to explicitly teaching scientific thinking to students. This is also the main argument of this doctoral dissertation.

List of References

Abd-El-Khalick, F., & Lederman, N. G. (2023). Research on teaching, learning, and assessment of nature of science. In *Handbook of research on science education* (pp. 850–898). Routledge.

Aristeidou, M., & Herodotou, C. (2020). Online citizen science: A systematic review of effects on learning and scientific literacy. Citizen Science: Theory and Practice, 5(1), 1-12. https://doi.org/10.5334/cstp.224

Balloo, K. (2019). Students' difficulties during research methods training acting as potential barriers to their development of scientific thinking. In M. Murtonen & K. Balloo (Eds.), *Redefining scientific thinking for higher education: Higher-order thinking, evidence-based reasoning and research skills* (pp. 107–137). Palgrave Macmillan. http://doi.org/10.1007/978-3-030-24215-2_5

Balloo, K., Pauli, R., & Worrell, M. (2018). Conceptions of research methods learning among psychology undergraduates: AQ methodology study. *Cognition and Instruction*, *36*(4), 279–296. https://doi.org/10.1080/07370008.2018.1494180

Barzilai, S., & Zohar, A. (2016). Epistemic (meta) cognition: Ways of thinking about knowledge and knowing. In *Handbook of epistemic cognition* (pp. 409–424). Routledge.

Brew, A., & Mantai, L. (2017). Academics' perceptions of the challenges and barriers to implementing research-based experiences for undergraduates. *Teaching in Higher Education*, *22*(5), 551–568. https://doi.org/10.1080/13562517.2016.1273216

Brew, A., & Saunders, C. (2020). Making sense of research-based learning in teacher education. *Teaching and Teacher Education*, 87, 102935. https://doi.org/10.1016/j.tate.2019.102935

Bråten, I., Strømsø, H. I., & Samuelstuen, M. S. (2008). Are sophisticated students always better? The role of topic-specific personal epistemology in the understanding of multiple expository texts. Contemporary Educational Psychology, 33(4), 814-840. https://doi.org/10.1016/j.cedpsych.2008.02.001

Brownlee, J., Ferguson, L., & Ryan, M. (2017). Changing teachers' epistemic cognition: A new conceptual framework for epistemic reflexivity. *Educational Psychologist*, *52*(4), 242–252. https://doi.org/10.1080/00461520.2017.1333430

Brownlee, J., Schraw, G., & Berthelsen, D. (2011). Personal epistemology in teacher education: An emerging field of research. In J. Brownlee, G. Schraw, & D. Berthelsen (Eds.), *Personal epistemology and teacher education* (pp. 3–22). Routledge.

Böttcher, F., & Thiel, F. (2018). Evaluating research-oriented teaching: A new instrument to assess university students' research competences. *Higher Education*, *75*(1), 91–110. https://doi.org/10.1007/s10734-017-0128-y

Donovan, T., & Hoover, K. R. (2013). *The elements of social scientific thinking* (pp. 1–208). Cengage Learning.

Brew, A. (2001). Conceptions of research: A phenomenographic study. Studies in Higher Education, 26 (3), 271–285. https://doi.org/10.1080/03075070120076255

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology*, *110*(8), 1084–1111. http://doi.org/10.1037/edu0000263

Halpern, D. F. (2013). *Critical thinking across the curriculum: A brief edition of thought and knowledge*. Routledge.

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research*, *45*(1–2), 85–95. https://doi.org/10.1016/j.ijer.2006.08.006

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140. https://doi.org/10.3102/00346543067001088

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education*, *104*(4), 641–666. https://doi.org/10.1002/sce.21575

Hyytinen, H., Holma, K., Toom, A., Shavelson, R., & Lindblom-Ylänne, S. (2014). The complex relationship between students' critical thinking and epistemological beliefs in the context of problem solving. *Frontline Learning Research*, *2*(5), 1–25. https://doi.org/10.14786/flr.v2i4.124

Hyytinen, H., Postareff, L., & Lindblom-Ylänne, S. (2020). Challenges in exploring individual's conceptions of knowledge and knowing: Examples of research on university students. In E. Kallio (Ed.), *Development of adult thinking: Interdisciplinary perspectives on cognitive development and adult learning* (pp. 177–190). Routledge. https://doi.org/10.4324/9781315187464

Hyytinen, H., Toom, A., & Shavelson, R. J. (2019). Enhancing scientific thinking through the development of critical thinking in higher education. In M. Murtonen & K. Balloo (Eds.), *Redefining scientific thinking for higher education: Higher-order thinking, evidence-based reasoning and research skills* (pp. 59–78). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-24215-2_3

Hyytinen, K., Nissinen, K., Kleemola, K., Ursin, J. & Toom, A. (2023). How do self-regulation and effort in test-taking contribute to undergraduate students' critical thinking performance? *Studies in Higher Education*, https://doi.org/10.1080/03075079.2023.2227207

Khishfe, R. (2022). Improving students' conceptions of nature of science: A review of the literature. *Science & Education*, 1–45. https://doi.org/10.1007/s11191-022-00390-8

Koerber, S., & Osterhaus, C. (2019). Individual differences in early scientific thinking: Assessment, cognitive influences, and their relevance for science learning. *Journal of Cognition and Development*, *20*(4), 510–533. https://doi.org/10.1080/15248372.2019.1620232

Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review*, *96*(4), 674–689. https://doi.org/10.1037/0033-295X.96.4.674

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher*, *28*(2), 16–46. https://doi.org/10.3102/0013189X028002

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education*, *94*(5), 810–824. https://doi.org/10.1002/sce.20395

Kuhn, D., Hemberger, L., & Khait, V. (2017). Argue with me: Argument as a path to developing students' thinking and writing. Routledge.

Kuhn, D., Amsel, E., O'Loughlin, M., Schauble, L., Leadbeater, B., & Yotive, W. (1988). *The development of scientific thinking skills*. Academic Press.

Kuhn, D., Iordanou, K., Pease, M., & Wirkala, C. (2008). Beyond control of variables: What needs to develop to achieve skilled scientific thinking? *Cognitive Development*, *23*(4), 435–451. https://doi.org/10.1016/j.cogdev.2008.09.006

Kuhn, D., & Pearsall, S. (2000). Developmental origins of scientific thinking. *Journal of cognition and Development*, 1(1), 113-129. https://doi.org/10.1207/S15327647JCD0101N_11

Kuhn, D., & Lerman, D. (2021). Yes but: Developing a critical stance toward evidence. *International Journal of Science Education*, *43*(7), 1036–1053. https://doi.org/10.1080/09500693.2021.1897897

Kuhn, D., & Modrek, A. S. (2022). Choose your evidence. *Science & Education*, *31*, 21–31. https://doi.org/10.1007/s11191-021-00209-y

Kuhn, D., & Weinstock, M. (2002). What is epistemological thinking and why does it matter? In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 121–144). Routledge. https://doi.org/10.4324/9780203424964

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, *84*(1), 71–94. https://doi.org/10.1002/(SICI)1098-237X(200001)84:1<71::AID-SCE6>3.0.CO;2-C

Lederman, N. G. (2019). Contextualizing the relationship between nature of scientific knowledge and scientific inquiry: Implications for curriculum and classroom practice. *Science & Education*, *28*, 249–267. https://doi.org/10.1007/s11191-019-00030-8

Lederman, N. G., & Lederman, J. S. (2019). Teaching and learning nature of scientific knowledge: Is it déjà vu all over again? *Disciplinary and Interdisciplinary Science Education Research*, *1*, 1–9. https://doi.org/10.1186/s43031-019-0002-0

Lehman, D., & Nisbett, R. (1990). A longitudinal study of the effects of undergraduate training on reasoning. Developmental Psychology, 26 (6), 952–960. https://doi.org/10.1037/0012-1649.26.6.952

Lehtinen, E., McMullen, J., & Gruber, H. (2019). Expertise development and scientific thinking. In M. Murtonen & K. Balloo (Eds.), *Redefining scientific thinking for higher education: Higher-order thinking, evidence-based reasoning and research skills* (pp. 179–202). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-24215-2_8

Leung, J. S. C. (2020). Students' adherences to epistemic understanding in evaluating scientific claims. *Science Education*, 104(2), 164-192. https://doi.org/10.1002/sce.21563

Lorencová, H., Jarošová, E., Avgitidou, S., & Dimitriadou, C. (2019). Critical thinking practices in teacher education programmes: a systematic review. *Studies in Higher Education*, 44(5), 844-859. https://doi.org/10.1080/03075079.2019.1586331

Merk, S., Rosman, T., Muis, K. R., Kelava, A., & Bohl, T. (2018). Topic specific epistemic beliefs: Extending the theory of integrated domains in personal epistemology. *Learning and Instruction,* 56, 84-97. https://doi.org/10.1016/j.learninstruc.2018.04.008

Muis, K. R., Trevors, G., Duffy, M., Ranellucci, J., & Foy, M. J. (2016). Testing the TIDE: Examining the nature of students' epistemic beliefs using a multiple methods approach. *The Journal of Experimental Education*, *84*(2), 264–288. https://doi.org/10.1080/00220973.2015.1048843

Murtonen, M. (2005). University students' research orientations—Do negative attitudes exist toward quantitative methods? *Scandinavian Journal of Educational Research*, *49*(3), 263–280. https://doi.org/10.1007/s10734-008-9113-9

Murtonen, M. (2015). University students' understanding of the concepts empirical, theoretical, qualitative, and quantitative research. *Teaching in Higher Education*, *20*(7), 684–698. https://doi.org/10.1080/13562517.2015.1072152

Murtonen, M., Olkinuora, E., Tynjälä, P., & Lehtinen, E. (2008). "Do I need research skills in working life?"—University students' motivation and difficulties in quantitative methods courses. *Higher Education*, *56*, 599–612. https://doi.org/10.1007/s10734-008-9113-9

Nussbaum, E., Sinatra, G., & Poliquin, A. (2008). Role of epistemic beliefs and scientific argumentation in science learning. *International Journal of Science Education*, *30*(15), 1977–1999. https://doi.org/10.1080/09500690701545919

O'Connor, G., Fragkiadaki, G., Fleer, M., & Rai, P. (2021). Early childhood science education from 0 to 6: A literature review. *Education Sciences*, *11*(4), 178. https://doi.org/10.3390/educsci11040178

Perry, W. (1968). *Patterns of development in thought and values of students in a liberal arts college: A validation of a scheme* (Final Report, Project No. 5-0825, Contract No. SAE-8973). Department of Health, Education, and Welfare.

Perry, W. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. Holt, Rinehart & Winston.

Piaget, J. (1971). Genetic epistemology. New York:W.W. Norton.

Rutjens, B. T., Van der Linden, S., & Van der Lee, R. (2021). Science skepticism in times of COVID-19. *Group Processes & Intergroup Relations*, *24*(2), 276–283. https://doi.org/10.1177/1368430220981415

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634–656. https://doi.org/10.1002/sce.20065

Sandoval, W. A., Greene, J. A., & Bråten, I. (2016). Understanding and promoting thinking about knowledge: Origins, issues, and future directions of research on epistemic cognition. *Review of Research in Education*, *40*(1), 457–496. https://doi.org/10.3102/0091732X1666931

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*(3), 498–504. https://doi.org/10.1037/0022-0663.82.3.498

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life?. *Science Education,* 104(5), 873-894.

Sinatra, G. M., & Hofer, B. K. (2016). Public understanding of science: Policy and educational implications. *Policy Insights from the Behavioral and Brain Sciences*, *3*(2), 245–253. https://doi.org/10.1177/2372732216656870

Sinatra, G. M., Kienhues, D., & Hofer, B. K. (2014). Addressing challenges to public understanding of science: Epistemic cognition, motivated reasoning, and conceptual change. *Educational Psychologist*, *49*(2), 123–138. https://doi.org/10.1080/00461520.2014.916216

Strømsø, H., & Bråten, I. (2011). Personal epistemology in higher education: Teachers' beliefs and the role of faculty training programs. In J. Brownlee, G. Schraw, & D. Berthelsen (Eds.), *Personal epistemology and teacher education* (pp. 54–67). Routledge.

Thiem, J., Preetz, R., & Haberstroh, S. (2023). How research-based learning affects students' self-rated research competences: Evidence from a longitudinal study across disciplines. *Studies in Higher Education*, *2023,* 1–13. https://doi.org/10.1080/03075079.2023.2181326

van der Graaf, J., van de Sande, E., Gijsel, M., & Segers, E. (2019). A combined approach to strengthen children's scientific thinking: Direct instruction on scientific reasoning and training of teacher's verbal support. *International Journal of Science Education*, *41*(9), 1119–1138. https://doi.org/10.1080/09500693.2019.1594442

Wilkinson, S. (2004). Focus group research. *Qualitative Research: Theory, Method, and Practice*, *2*, 177–199.

TURUN
YLIOPISTO
UNIVERSITY
OF TURKU

Painosalama, Turku, Finland 2023

ISBN 978-951-29-9533-2 (PRINT)
ISBN 978-951-29-9534-9 (PDF)
ISSN 0082-6987 (Print)
ISSN 2343-3191 (Online)