# Redefining Scientific Thinking for Higher Education

## Higher-Order Thinking, Evidence-Based Reasoning and Research Skills

*Edited by*
Mari Murtonen · Kieran Balloo

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"The contributors to this timely book could not be more right in proclaiming that higher-order thinking should be a core value and goal of higher education. They perform a valuable function in bringing together under one umbrella the related constructs of critical thinking, scientific thinking, and argumentation, making it clear that scientific thinking is central to science but not confined to it. They also remind us that educators should pay as much attention to fulfilling the intellectual potential of young adults as they do to education earlier in life."

—Deanna Kuhn, *Professor of Psychology and Education,*
*Teachers College, Columbia University, USA*

Mari Murtonen · Kieran Balloo
Editors

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# Preface

Universities have the special task of producing and utilising knowledge that is based on reliable and unbiased principles. Hence, during their university education, students are expected to develop a set of skills that represents these principles. That is, students should learn how to make valid scientific judgements, informed by evidence and research. Graduates should then use these skills to deal with the complex responsibilities of their professional working lives. Current discussions about the importance of evidence-based decision-making and relying on scientific research results all refer to peoples' ability to think scientifically. Thus, this book frames the collection of higher-order thinking, evidence-based reasoning and research skills that students should develop during higher education as *scientific thinking*. The proposed new theory of scientific thinking comprises of: (1) criticality and basics of science, (2) epistemic understanding, (3) research skills, (4) evidence-based reasoning skills and (5) contextual understanding.

The development of scientific thinking, however, is not a straightforward process for all students. For example, during their research training, many students have difficulties understanding the basics of the scientific method and how knowledge is created. This book aims to convey the learning and development process of students' scientific thinking skills during higher education. The chapters of this book focus on the definition and development of scientific thinking in higher education, on problems that students face during learning, and on pedagogical ideas for how to support their learning processes.

In Part I of the book, *Components of Scientific Thinking in Higher Education*, a new theory of scientific thinking in higher education is proposed, then the subsequent chapters examine the different components of this new conceptualisation. In Chapter 1, Murtonen and Salmento make the case for a broad and cohesive theory of scientific thinking that encapsulates the higher-order thinking and research skills students should develop during higher education. Drawing on higher education teachers' conceptions of their students' scientific thinking, and the range of university-level thinking skills identified in the literature, they describe the fundamental components of this theory.

In Chapter 2, Salmento and Murtonen focus on why research skills and epistemic understanding are essential aspects of scientific thinking. They present a study on students' conceptions of scientific thinking, and their findings suggest that many students are aware of the role of research in developing these thinking skills, which, as they point out, emphasises the importance of incorporating research skills into the new broad theory of scientific thinking for higher education.

In Chapter 3, Hyytinen, Toom and Shavelson discuss how critical thinking forms the foundation for the development of scientific thinking skills. They provide a detailed definition and conceptualisation of critical thinking and review the focus of research into this domain. Hyytinen and colleagues highlight why it is important for students to develop critical thinking skills as useful skills in their own right, and in order to form scientific thinking skills more broadly. In making this argument, they discuss a curriculum alignment approach to enhancing critical thinking skills.

In Chapter 4, Shargel and Twiss describe a subcomponent of critical and scientific thinking called evidenced-based thinking, which represents the ways in which students understand how to use evidence to support their arguments. They present a case study in which a typology of evidence was taught to undergraduates in order to enhance their evidence-based thinking. Their findings focus on students' views about evidence and how their typology was useful for both understanding and enhancing this aspect of their scientific thinking.

In part II of the book, *Challenges for the Development of Scientific Thinking in Higher Education*, chapters are concerned with some of the hurdles that educators may face when attempting to enhance these skills. These chapters discuss the difficulties that students may experience and how these issues can then impact on the development of their scientific thinking skills. The chapters approach these difficulties from different perspectives, whilst also providing pedagogical suggestions for how to minimise these barriers.

In Chapter 5, Balloo describes how scientific thinking skills are likely to be developed through participation in research methods training courses, which means that difficulties with this training can cause barriers to the development of these skills. After reviewing some of the main difficulties raised in the research methods education literature, he presents a phenomenological investigation of the undergraduate experience of research methods training. His findings reveal that many of the difficulties experienced by students may not act as permanent barriers to their development of scientific thinking skills, so he provides some pedagogical suggestions for reducing potential issues.

In Chapter 6, Kiley describes some of the difficulties students may experience with understanding the concepts involved in learning to think scientifically or like a researcher. She suggests that an understanding of threshold concepts can be helpful for dealing with the potential challenges students may face. Kiley provides some pedagogical suggestions for making students more aware of relevant threshold concepts and liminality to assist them in developing some of the knowledge and skills required for successful scientific thinking.

In Chapter 7, Hosein and Rao argue that research methods training brings together disparate higher-order thinking skills to allow students to demonstrate their epistemic thinking within their discipline. However, through the use of acculturation theory, they contend that students demonstrate different levels of discomfort in engaging with research methods and overcoming discipline-specific threshold concepts that help them to develop higher-order scientific thinking skills, depending on whether or not they chose the discipline voluntarily. They provide some pedagogical suggestions for research methods courses to engage students with scientific thinking skills and overcome their disciplinary threshold concepts and episteme.

In the final part of the book, *Fostering the Development of Scientific Thinking in Higher Education*, chapters concern the larger-scale impact of scientific thinking as students become part of professional and academic communities. The chapters demonstrate how scientific thinking skills are formative in students' formation of an academic identity and may subsequently aid them in their professional practice. The frameworks presented here provide educators with ideas for how scientific thinking can be fostered.

In Chapter 8, Lehtinen, McMullen and Gruber consider the role that scientific thinking plays in experts' professional lives. They note that whilst many experts are not active researchers, they still need to draw on evidence-based recommendations in their decision-making. Thus, many experts face the challenge of needing adequate methodological knowledge to interpret the findings from scientific evidence that relate to their practice whilst being able to navigate the very different epistemic cultures of various research. They propose that the scientific thinking skills required to use evidence in professional practice should supplement the ways we distinguish experts from non-experts.

In Chapter 9, Wisker outlines a model of four quadrants of higher-order scientific thinking and research skills, which students are expected to develop whilst completing their capstone research projects. Drawing on previous research, as well as her own experience and practice, Wisker argues that research students progress from an initial state of dependence on their supervisor to developing higher-order intellectual, practical and writing skills that leads to them forming a researcher identity in the larger academic and scientific community.

Finally, in the concluding Chapter 10, Brew, Mantai and Miles present a student–staff partnership programme that was used to engage undergraduate students in research and inquiry as a means of fostering their development of scientific thinking skills. The model views universities as inclusive scholarly knowledge-building communities, and the programme is discussed in relation to a seven-year case study. The model provides the potential for scaling up an approach to enhancing scientific thinking at a large-scale whole-of-university level.

This book should provide readers with an understanding of why scientific thinking needs to be understood broadly and nurtured throughout higher education, so that society can benefit from having graduates with these skills. Student readers should become more able to recognise and evaluate their own scientific thinking skills, whereas educators will have a better awareness of how to support their students' development.

Tampere & Turku, Finland — Mari Murtonen
Guildford, UK — Kieran Balloo

# Contents

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**Angela Brew** is Emeritus Professor and previously Professorial Fellow in the Learning and Teaching Centre at Macquarie University, Australia. She is an elected Fellow of the UK's Society for Research into Higher Education (SRHE), a Life Member of the Higher Education Research and Development Society of Australasia (HERDSA) and an Australian Senior National Teaching Fellow.

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**Anesa Hosein** is a Senior Lecturer in Higher Education at the University of Surrey. She has worked in the higher education systems of the Caribbean and the UK. She has an eclectic collection of qualifications in areas of physics, engineering and education. Her career aim is to help people (students, lecturers, etc.) to achieve their intrinsic needs, namely of self-growth, which she has accomplished in a variety of research areas including academic practice, mathematics education, research methods, educational technology and academic mobility.

**Heidi Hyytinen** is a Senior Lecturer in University Pedagogy, at the University of Helsinki. As formal pedagogical training, she has completed the pedagogical qualifications required of teachers specified in the University Pedagogy. She has diverse teaching experience at the various levels of university education. Her research interests are students' conceptions of knowledge, critical thinking and performance-based assessment in the context of higher education. She received the best educational dissertation of the year award in 2015 from the Finnish Educational Research Association (FERA). She leads and co-leads several research projects on higher education.

**Margaret Kiley** is an Adjunct at the Australian National University. Her research and teaching interests relate to the education of future researchers. In addition to working in Further/Higher Education in Australia, Indonesia, Malaysia and the UK she has also presented workshops on research education nationally and internationally. A recent publication is: Taylor, S., Kiley, M., & Humphrey, R. (2017). *A Handbook for Doctoral Supervisors* (2nd ed.). Oxon: Routledge.

**Erno Lehtinen** is a Professor of Education at the University of Turku and Visiting Professor in the Vytautas Magnus University. He has worked in several universities in Finland, other European countries and the USA. His research has focused on cognitive and motivational aspects of learning, development of mathematical thinking, educational technology and new forms of expertise in rapidly changing working life. He has published about 400 scientific publications with more than 1800 citations (Web of Science). In 2009 he got the Oeuvre Award of the European Association for Research on Learning and Instruction.

**Lilia Mantai** is a Lecturer, Academic Lead in Course Enhancement, at The University of Sydney Business School, and has previously worked as a Senior Learning Designer at the Learning Innovation Hub and Academic Developer at the Learning and Teaching Centre, both at Macquarie University. She was awarded a Ph.D. for research on researcher development of doctoral students in 2017. Lilia is a Senior Fellow of the AdvanceHE/Higher Education Academy.

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**Heidi Salmento** is a Doctoral Student and Project Researcher at the University of Turku. She is the main developer of the pedagogical and technical solution, UNIPS.fi digital learning environment. Her areas of research include learning and teaching in higher education, the development of university students' scientific thinking and the pedagogical use of educational technology.

**Rebecca Shargel** is an Associate Professor of Education in the Department of Educational Technology and Literacy at Towson University in Maryland, USA. For the past ten years, she has taught courses related to research to both graduate and undergraduate students in the College of Education. Her research interests include teaching critical thinking, collaborative learning, religious education and curricular integration. In January 2019, she received the Innovation in Teaching Award for her work in evidenced-based thinking that is the subject of her chapter in this book.

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**Auli Toom** Professor of Higher Education, is the Director of the Centre for University Teaching and Learning, University of Helsinki, Finland. She is the Director of the PsyCo (Psychology, Learning and Communication) Doctoral Programme. She is Visiting Professor at the Institute of Education, University of Tartu, Estonia. Her research focuses on knowing, competence, expertise and agency amongst students and teachers in basic and higher education contexts. She leads several research projects on higher education and teacher education.

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# List of Figures

# List of Tables

# Part I

## Components of Scientific Thinking in Higher Education

# 1

# Broadening the Theory of Scientific Thinking for Higher Education

Mari Murtonen and Heidi Salmento

## Introduction

University education across all disciplines aims to produce thinking skills in students that reflect the principles and practices of scientific research and rigour. University graduates are expected to use these higher order thinking skills in their future jobs to solve the complex problems of today's world. By utilising these thinking skills, individuals are presumed to overcome the limitations of layman thinking, such as, gut feelings and non-scientific beliefs. They are supposed to use evidence-based reasoning by benefitting from the best research knowledge available related to the question at hand.

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Although the thinking skills described above are extremely important, there is no common theory or even an agreed name for these thinking skills in higher education. In this chapter, a new theory named *scientific thinking in higher education* is proposed that combines the former theories related to this subject and empirical results concerning university teachers' views of scientific thinking. This broad conceptualisation of scientific thinking builds on theories of the development of scientific thinking in natural sciences, the development of critical thinking in higher education, the theories of reasoning at different ages, and theories about the development of epistemological beliefs.

When looking at the history of scientific thinking, there have been many attempts to name, define and clarify what these skills are. According to Woolley et al. (2018), the above mentioned skills have been defined and named by many researchers and associations as scientific process skills, procedural skills, experimental and investigative science, habits of mind, scientific inquiry abilities, scientific reasoning skills, knowledge seeking behaviours with the coordination of theory and evidence, critical thinking skills, science process skills, basic skills, integrated skills, scientific literacy, and so on. Many of these have only concerned the natural sciences. The aim of this current work is to find something in common for all disciplines that are involved in university-level knowledge building. We base our suggestion on both previous research traditions on higher order thinking skills and empirical results depicting university teachers' views of their students' scientific thinking skills.

Kuhn, Amsel, and O'Loughlin (1988) state in the preface of their book, *The development of scientific thinking skills*, that "Skills in the coordination of theories and evidence are the most central and fundamental skills that define scientific thinking". That is also the starting point for our broader theory of scientific thinking in higher education. Attention will be especially focused on the "skills" element, since in the case of adult learners in university, the skills that need to develop in the scientific endeavour across the disciplines are very challenging. The name *scientific thinking* was selected here for the new theory because it best describes the features that are important and common across the disciplines.

In proposing a new, broader theory of scientific thinking, the word *science* itself may create a problem due to its connection to natural sciences. Therefore, an analysis of the term *science* is presented and we show how it can be used in a broader sense to describe the thinking skills used across all academic domains. We also elaborate on how the new theory can aid instruction, since scientific thinking skills are extremely important to teach students during university education.

## On the Meaning and Nature of "Scientific" Across Different Disciplines

### The Meaning and Usage of the Word Science

In many instances, the word *science* is often used as a synonym for *natural science*. This is especially the case in the English language. In some languages the term science is not so closely attached to the natural sciences. For example, the German word *Wissenschaft* includes the ideas of *knowledge* and *making*, so it has a much broader meaning than the English word science. While science can be understood to include only natural sciences, social sciences and formal sciences, "Wissenschaft also includes the humanities, art, philosophy, and religion, and refers to learning and knowledge in general, whether obtained through scientific or non-scientific means" (Wiktionary, n.d.).

Scandinavian languages have adopted the idea of German *Wissenshaft*, for example, the Swedish *vetenskap* includes the word "vet" meaning "to know" and *skap* referring to a specific area or domain. Accordingly, the Finnish word *tiede* originates from the words "to know" and the whole word has the same logic as the Swedish idea of a domain, so it is used more broadly to refer to all disciplines in university.

Although the English word *science* is prima facie connected to natural sciences, it is used in a broader sense in many situations. Searching for the names of disciplines, faculties and departments of universities on the Internet, terms such as educational sciences, human sciences, medical sciences, economic sciences and historical sciences sit side by side with more natural science ones. Additionally, the word science is visible in many journal names in disciplines that are not considered to be natural sciences. For example, in the area of education, the *International Journal of Educational Sciences* states that it "publishes manuscripts that have direct relevance to the principles of learning and teaching, the significance of quality education, the role of technology in education, application of psychological concepts to education, student health and wellness, the importance of curriculum development and sociology of education". Similarly, the journal *Educational Sciences: Theory & Practice* describes itself as "an international scientific journal for the publication of research and studies covering all aspects of education and education-related issues". Thus, it is apparent that the word science is already used very broadly in many situations and connected to many academic disciplines.

## Nature of Science in Different Disciplines

In addition to reflecting on the different usages of the word science, we should also question what science is and what it does in order to consider if it is suitable for a wider usage across disciplines. According to Hoover and Donovan (2011, p. vii), "science is about the reduction of uncertainty in a world of phenomena that are only partially knowable through observation". This is a common goal of many, if not all, university disciplines. Research in various domains aims at understanding reality better, overlapping the human restrictions, both in observation and thinking. It is not only the so-called "hard sciences" which observe material reality, but also the "soft sciences", such as social, economic and human sciences, that want to understand the world better. "Science is a process of thinking and asking questions", Hoover and Donovan continue (2011, p. 3), portraying a very broad conception of science, applicable to all disciplines in universities.

In addition to the goals of science, there can be various other factors that have an impact on our conceptions of science. According to Ziman (2000), science generates knowledge, but how this knowledge generation is done, where it is done and by whom, is not as clear as it used to be. The new picture of science is more complicated and not so sharply defined as the outmoded stereotype, which has not been replaced but enlarged by concepts such as cultural elements, individual acts and collective processes. Ziman sums up that the notion of the scientific "method" is thus seen to extend outside the laboratory to a whole range of social practices.

A further question concerns whether there are some general features or principles in common for all disciplines. Disciplinary differences must, of course, be taken into account, but we also argue that it is important to try to find some common ground, especially for educational purposes in higher education. In 1959, Snow gave his now famous Rede Lecture at Cambridge (see Snow, 1964) about "the two cultures", in which he suggested and warned that western society had been divided into two poles, scientific and non-scientific. The notion was studied further by Biglan (1973) and developed by Becher (1994), who proposed a model to divide the disciplines into hard pure (natural sciences), soft pure (humanities and social sciences), hard applied (science-based professions) and soft applied (social professions). Debates concerning the different types of science date back to the history of science and especially to the times when the "softer" topics were introduced to be included in science. When Darwin demonstrated that humans were not so distant from other animals in 1859 (see Darwin, 1979), entirely new methods of studying human beings arose (De Landsheere, 1988). The study of humans was related to the study of other natural phenomena, with the notion of the science behind it being more "scientific". For example, a long and intense debate about methodology in education (e.g. Smith & Heshusius, 1986) culminated in the 1970s, when the positivist ideal of quantitative methodology was heavily criticised by the interpretivist proponents of qualitative methodology. While these debates have at least partly faded now, and the more flexible mixed methods approach has become more popular (e.g. Johnson & Onwuegbuzie, 2004), there is still a lack of a common understanding about what science means and includes today.

The aforementioned disciplinary differences do not indicate that there is a complete absence of common features shared by all domains. We assume there to be some general features, which is the reason for gathering these topics under the institution named university. Furthermore, today's science is not the same as it was in, for example, Snow's time, since interdisciplinary decision-making is more important than ever. According to Fung (2017, p. 77), "connecting across disciplines does not speak only to intellectual connections and discoveries, then, but to global and ethical awareness". University students need to learn to understand other disciplines and work together—grounding collaborative knowledge creation in the general principles of scientific thinking. Actions such as setting questions and hypotheses, criticality, epistemic understanding, reasoning, rigour and systematic use of methods are presumably very important in all disciplines in pursuit of the endeavour of trying to understand the world. With these thinking skills, students are equipped with the competences needed in complex problem-solving situations.

## The Need for a Broader Theory of Scientific Thinking in Higher Education

Even over 30 years ago, Kuhn et al. (1988) stated that "teaching of thinking skills has become a topic of widespread interest and concern", and that "science educators have long been in agreement that a major goal of science education ought to be fostering skills of scientific thinking" (p. 3). At the time of writing the current book, in the times of "alternative facts" and "fake news", that statement by Kuhn and colleagues is even more pertinent. However, the skills required to think should not be limited only to natural scientific issues, but should be applicable to all disciplines across universities that try to understand the world.

The theory of scientific thinking was originally developed for children's learning (e.g. Piaget, 1971; Kuhn, Iordanou, Pease, & Wirkala, 2008), and it has mainly concerned the learning of natural sciences. The methods of this tradition also originate in natural sciences by including physical tasks, for example, a task about inferring the effects on a pendulum when variables (length of a string and weight of balls) are manipulated (Piaget, 1971). These types of control-of-variables tasks are good for measuring certain reasoning abilities in natural science settings, but for more general scientific thinking, they are too restrictive. In their 2008 paper, Kuhn et al. proposed that the traditional control-of-variables strategy seems to be too narrow a view for studying scientific thinking. This is especially the case in higher education, where education should prepare students for the complex tasks of working life, and the problems of today's working life are not restricted to inferential tasks about physical objects. The control-of-variables theory is also too narrow when we use the word "science" to refer to all disciplines of universities. Furthermore, in university-level natural sciences, students need wider skills than just the ability to make inferences in certain clearly defined contexts.

Kuhn et al. (2008) suggest there are three aspects that are essential for students to master as a foundation for skilled scientific thinking: (1) The strategic aspects that involve the ability to coordinate effects of multiple causal influences on an outcome; (2) The mature understanding of the epistemological foundations of science, recognising scientific knowledge as constructed by humans rather than simply discovered in the world; and (3) The ability to engage in skilled argumentation in the scientific domain. The first aspect resembles the traditional idea of scientific thinking about controlling variables, but in a broader sense. The second factor referring to epistemic maturity and the third aspect relating to the ability to articulate arguments are especially in focus when considering scientific thinking in university across the disciplines in a broader sense.

Creating a new theory that collects all important aspects of the proposed broad scientific thinking in higher education must build on the work that we already know about these higher order thinking skills that are aimed at students in university education. However, one forgotten aspect is how the teachers of these students view scientific thinking. The teachers are in a central position to both recognise and enhance their students' learning. Thus, their views concerning both the nature and development of scientific thinking in different disciplines are central for this theory.

In the current chapter, by proposing a descriptive theory about scientific thinking, the focus is on what this type of thinking ability consists of, i.e. the nature of scientific thinking. Questions concerning the development of expertise on scientific thinking and the cognitive processes related to this development process, such as conceptual change and executive functions, and how to support these developmental processes are extremely important questions and topics for other papers (see other chapters in this book).

To describe the prospective components of scientific thinking, we will introduce the most prominent theories and studies of thinking in higher education, namely, theories on critical and epistemic thinking, and more general theories of traditional scientific thinking and reasoning skills. Also, more recent results in the domain of research methodological understanding are included, since they appear to be very important for scientific thinking in higher education. In addition, we present empirical results of how university teachers conceptualise scientific thinking and examine these empirical results in the light of the proposed components of scientific thinking.

## Redefining the Theory of Scientific Thinking for Use in Higher Education

### Critical Thinking and Understanding the Basic Principles of Science

Critical thinking has become a widely studied theory, perhaps because criticality has been seen as one of the most crucial factors in academic competence. According to Halpern (2013, p. 4), critical thinking is usually depicted as "the use of those cognitive skills or strategies that increase the probability of a desirable outcome. It is used to describe thinking that is purposeful, reasoned and goal directed". The following thinking skills are often mentioned as being elements of critical thinking: the ability to identify, reason, judge, analyse, evaluate and make decisions about assumptions (Hyytinen, Holma, Toom, Shavelson, & Lindblom-Ylänne, 2014). These cognitive skills are central in higher order thinking in university education.

Criticality can also be seen as a basic element of science itself. When looking at literature concerning attempts to define what science is, criticality is one of the basic principles which is usually mentioned. For example, Peirce (1877) differentiates the scientific method from other methods of knowing, namely, tenacity, authority and a method of intuitive inquiry. According to Peirce, criticality is an important factor in the scientific method. Haaparanta and Niiniluoto (2016) build on Peirce's conception of the scientific method, stating that science should be objective, public, critical, autonomous, self-corrective and progressive. In addition, the general principles of science such as those related to ethical questions must be taken into account in scientific processes. These basic principles can all be seen as important aspects of conducting research across the disciplines. Thus, university students should gain understanding of what these basics of science mean and how they can be applied to decision-making processes.

For the above-mentioned reasons, critical thinking is certainly a central skill in university education. However, theories of critical thinking alone seem to be too narrow for describing all of the higher order thinking skills that university students should possess while studying, and especially, after graduating. This is partly because, in many critical thinking theories, critical thinking skills are described as being a set of thinking skills possessed by an individual only. Although some theories mention that critical thinking skills can be enhanced through collaboration, the focus is still on the individual's internal processes. In working life, skills required to justify decisions and work collaboratively across a range of contexts are crucial, and thus the inner processes of an individual are insufficient for understanding what thinking skills are needed. Related to the idea of critical thinking being about an individual's internal processes, criticality is seen as an abstract process of thinking, while many higher order thinking skills are connected to an understanding of more practical processes, such as knowing how certain research methods can be used in enquiry processes. A corollary of these claims is that the ability to use empirical research results, that is, to use evidence-based thinking, is not emphasised in theories of critical thinking, despite being central skills in academic expertise.

## Epistemic Understanding: Ability to Understand that Knowledge Is Uncertain and Created by Humans

While critical thinking theories mostly focus on what people do with the information they receive, epistemic beliefs are more about people's beliefs about where the knowledge comes from and what the nature of knowledge is (e.g. Schraw, Bendixen, & Dunkle, 2002). Although epistemic beliefs and critical thinking are closely intertwined, they have had separate research traditions and clear differences can be found between the constructs.

Research on epistemic beliefs was initiated by Perry in the 1960s, and it has since become a prominent theory for explaining university students' development of higher order thinking skills. According to Perry (1968), students' conceptions of knowledge are likely to develop during university studies from black and white conceptions towards more relativist views, and finally, to commitment to certain knowledge. Research on epistemic beliefs since then has focused on questions such as what students think knowledge is, where knowledge comes from, and how it is constructed (e.g. Hofer & Pintrich, 2002; Ståhl & Mildén, 2017). Relationships between students' critical thinking and their epistemic beliefs have been found (Hyytinen et al., 2014).

Although acknowledged as very important by many researchers, epistemic beliefs appear to be very difficult to capture and measure (see Salmento & Murtonen in Chapter 2 of this book). This problem stems from the fact that few students are aware of their epistemic beliefs and thus asking about them may be very difficult for students to answer.

Kuhn et al. (2008) state that epistemic maturity, i.e. the ability to understand that knowledge is produced by people, should be an important part of theories of scientific thinking. Since both teachers and students include epistemic maturity as a factor in scientific thinking, and critical thinking theories note the role of epistemic maturity as an important factor of higher order thinking skills, this construct is likely to be an important component of scientific thinking in higher education.

## Research Skills Underpinning Science: Understanding How Knowledge Is Produced

To understand what science is without understanding the methods it draws on, is likely to be challenging. To develop an understanding about how scientific knowledge is constructed, and how reliable it is, a university student needs to learn: how the methods of their discipline can be and are used; the more general methods underpinning science; and how these methods and the knowledge constructed with them can be evaluated. All these skills together can be called research skills. On the basis of previous research (Balloo, Pauli, & Worrell, 2016; Murtonen, 2015), it seems that one of the most important aspects of developing a mature understanding of scientific knowledge, is being able to understand how knowledge is produced, maintained and reproduced in our society. Without understanding the basics of research methods (see e.g. Balloo, Pauli, & Worrell, 2018;

Murtonen, 2015), it is not possible to develop scientific thinking, that is, to understand academic knowledge and participate in evidence-based decision-making.

The critical thinking and epistemic maturity theories presented above mainly lack the notion of how research skills relate to the development of higher order thinking skills at university. Although critical thinking theories note the importance of being critical towards the origin of knowledge and epistemic belief theories emphasise the ability to understand that knowledge is constructed by humans, neither of these traditions incorporates the role that research skills play in students' development of thinking skills. This is pertinent, since the role and impact of research training for the learning of scientific thinking skills seems to be crucial; research has found epistemic beliefs to be connected to conceptions of research, indicating that epistemic beliefs cannot be separated from research training (Ponsiluoma & Murtonen, 2016).

Developing a mature understanding of the epistemological foundations of science requires an understanding of the methods that are used in knowledge construction. These methods are described with concepts that aim to explain how knowledge is created. For example, in social sciences, psychology, economics and education, some of these central concepts are empirical, theoretical, qualitative and quantitative. These concepts are constantly used by teachers of research courses in the behavioural sciences. The terms are usually introduced on introductory courses and after that it is often assumed that university students know what these concepts mean. However, these concepts are not easy for students to grasp (Murtonen, 2015; see also Balloo in Chapter 5 of this book); instead, they are complex in their nature, historically developed over a long period, and they contain vast amounts of information about the rules and principles of research. Similarly, debates about the nature of some of these concepts and theoretical constructs are still ongoing, for example, the methodological or even paradigmatic debate between qualitative and quantitative methods (e.g. Tashakkori & Teddlie, 2003; Johnson & Onwuegbuzie, 2004). Also, there is no single and commonly shared conception about research among university staff (Brew, 2001). Thus, understanding research methodology in combination with epistemic maturity and skills in critical thinking precedes the development of a broad understanding of science.

## Reasoning Skills: Evidence-Based Reasoning as the Basis for Knowledge Building

The very earliest studies concerning university students' higher order thinking skills were Lehman and Nisbett's (1990) studies about the effects that training has on reasoning. Studying undergraduates in the natural sciences, humanities and social sciences, they concluded that these skills can be trained. They also noted that statistical-methodological reasoning skills seem to be especially significant for the ability to think critically. These studies on reasoning highlight that university students take many courses on research methodology during their education and these are an essential part of their development of scientific and critical thinking. The critical thinking theories developed after that (see e.g. Behar-Horenstein & Niu, 2011), however, do not pay any attention to students' research training, but instead treat critical thinking as an abstract thinking skill of its own, detached from the methodological skills. We propose that evidence-based reasoning skills, research methodological skills, epistemic understanding and critical thinking are all closely intertwined and are important aspects of broad scientific thinking skills. It should also be noted that the use of these skills, such as reasoning skills, do not develop spontaneously during education, but should be deliberately targeted during instruction (Manolo, Uesaka, & Chinn, 2018).

Distinct from basic reasoning skills are skills in evidence-based thinking and evidence-based reasoning. In higher education settings, these are the skills that are particularly desirable to develop. The ability to make judgements based on research is extremely important in all disciplines. However, studies on these abilities in higher education are scarce, since most research focuses on children's development. Some of this research is also very promising for the domain of higher education. Chinn and Malhotra (2002) have developed the AIR (Aims, Ideals and Reliable processes)-model to analyse students' epistemic cognition, i.e. the cognitive processes related to epistemic beliefs, in cases where they evaluate information. By using this model, it is possible to separate out different factors in students' decision-making and justification processes. This model offers interesting ideas about epistemic understanding, but it also relates heavily to the question of reasoning. University students' epistemic beliefs have been extensively studied, but their epistemic cognition in evidence-based decision-making has not been examined.

## University Teachers' Views About Scientific Thinking

### Methods

Most of the theories about higher order thinking skills are based on premises defined by a researcher, i.e. what the researcher thinks a certain type of thinking consists of, as well as on empirical research examining whether this type of thinking can be found among the subjects of a study. Instead, we approached this from a different perspective; we asked the central actors in the development of higher order thinking skills, higher education teachers ($N = 87$), to describe what they think scientific thinking is and how it should develop during university studies. Teachers from all seven faculties at the University of Turku in Finland took part: Humanities ($n = 16$), Education ($n = 2$), Medicine ($n = 21$), Science and Engineering ($n = 21$), Law ($n = 3$), Social Sciences ($n = 5$), Economics ($n = 7$) and the remaining teachers ($n = 12$) were from unknown disciplines. All teachers were participating in university pedagogy training for teachers at the time the data was collected and were advanced level groups, i.e. they had studied at least a 10 ECTS basic course in university pedagogy. Due to small group sizes from 12 to 22 per year, the data was collected during consecutive years from 2011 to 2018.

The data was collected with paper and pencil in pedagogical training seminars by the first writer of this study, who also taught the 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. Participation was voluntary and participants were briefly told about the purposes of the research and that their data would be handled anonymously. The questionnaire was one A4 size paper having the instruction at the top of the page and rest of the single-sided page for answering. The average word count of teachers' answers was 92 and varied between 24 and 141 words.

The data was analysed using both theory and data-driven content analysis (see e.g. Green, 2004), meaning that the preliminary categories for the analysis were defined on the basis of the aforementioned theories of higher order thinking in higher education, but new categories arising from the data were also added. The theory-driven classification categories assumed on the basis of the previous theories were: (1) *critical thinking*, (2) *epistemic understanding*, (3) *research skills* and (4) *evidence-based reasoning*. In addition to the theory driven categories, the coders added data-driven categories in the preliminary analysis if responses could not be classified into the theory-driven categories. The suggested new data-driven categories were discussed between the researchers and one new category was selected and named as *Contextual understanding*. Also, many mentions of generic skills were coded, but we deemed this not to be a category of scientific thinking. Then, both researchers classified the data according to the agreed five categories. Both authors read all of the answers and coded 1 for each category if a notion of the above-mentioned classification categories was found and 0 if there was no mention of the categories. A teacher's answers could be categorised into more than one category if the notions met the criteria in more than one category. An inter-rater reliability check of codes for the whole five-category model was calculated resulting in 86% agreement between coders. Disagreements were discussed until consensus was obtained for each classification. Quotes below have been translated from their original Finnish into English.

## Teachers' Views

The first category, *Criticality and basics of science*, includes notions of criticality often involved in the general principles of science, such as, objectivity, questioning, reliability of information and the idea of advancing science. The following examples are responses coded into this category:

> Scientific thinking includes critical thinking and reflection, in other words, the ability to assess the reliability of knowledge and the capability to call into question knowledge (also the knowledge produced by oneself) and position the knowledge produced in different situations and from different perspectives in the field of academic discussion. (68)

> Students should become critical thinkers who are able to search information about the topic of their choice and to argue for their opinions and decisions based on scientifically studied knowledge. (70)

> Scientific thinking includes critical thinking, ability to reflect, assessing one's own and others' conceptions. (71)

> Objectivity: one should avoid letting one's prior conceptions affect the interpretation of observations in such a way that the interpretation becomes biased. (53)

> A person capable of scientific thinking understands according to which experiences and patterns of thought some claim is true or false. Thus, she is not held hostage by impressions or prejudices, but instead she can critically assess both claims about facts and different requirements concerning values and norms. She is familiar with key theories and their background and is always ready to learn. (57)

> Students should be able to critically interpret literature – that is to say, mostly others' research – and find the correct observations and conclusions and be critical towards one's own and others' research. (61)

The second category, *Epistemic understanding*, included responses emphasising the development of students' conceptions of knowledge and knowing. Some teachers described the changes that happen or should happen in students' epistemic understanding during university education. Responses referring to the development of more relativist thinking were also classified in this category. These type of responses included the idea of uncertainty of knowledge or they stressed the importance of understanding that knowledge and science are constructed and created by humans:

> Understanding that usually there is no right answer, there are many alternatives and the current knowledge forms a part of them, however, new research results may refute the current understanding. Courage to be creative and come up with new ideas. (49)

> Students' thinking and world view should be changed from black and white absolute thinking and repetition of "school truths" towards a more open way of thinking based on knowledge produced critically by research. Some parts of knowledge are immutable truths, however, the major part is mutable and uncertain. (70)

> …thus, the fact that the information is published in a scientific journal does not make the information valid. One has to also learn a certain kind of open-mindedness, in other words, to accept new knowledge that may challenge things that have been considered as facts. (75)

> …ability to consider how knowledge is produced, what factors affect the process and how the conceptions of the knowledge affect its position in the discipline. (73)

While describing scientific thinking, many teachers mentioned research skills as being a part of it or saw research as a learning process. The third category, *Research skills*, included these kinds of responses:

> A scientist has to be experienced in every aspect of the research process. It is necessary to be able to combine the strong knowledge base to applied and innovative research. Thus, 'scientific thinking' is an overall view which aims to produce and apply new research based knowledge. (41)

> Courses on research methods and statistical methods are a very crucial part of psychology studies. Their role might seem useless at first for someone whose dream is to become a psychologist. Nevertheless, the importance of these courses lies in the development of scientific thinking. A psychologist should be able to keep up with the latest research and evaluate it critically as well as utilise it in his/her work. (40)

> Scientific thinking includes 1) the ability to analyse existing problems from the framework of acknowledged theories of the field, 2) ability to produce knowledge by applying acknowledged research methods, 3) the ability to call things into question, in other words, having the required skills to call into question the solutions for problems, 4) skills to argue scientifically – that is to say, being able to give arguments for his solution's scientific foundations. (48)

The fourth category, *Evidence-based reasoning*, included responses emphasising students' abilities to make scientific and logical inferences, or the idea of deductive or inductive reasoning:

> Secondly, learning to justify claims logically and without gaps. What causes challenges is that one needs to know the assumption, i.e. what is known before, and one must recognise the claim that is aiming to be proven. Different chains of evidence are used to prove the claims. (25)

> Independence of thinking and ability to make conclusions is a crucial part of scientific thinking. (37)

> Students should develop to become critical thinkers who are able to search for knowledge and to justify their opinions and decisions based on knowledge produced by scientific research. (70)

> Understanding relativity and causal relationships and being able to analyse the factors that have an impact on events. (73)

Many teachers brought up the aspect of discipline-specific thinking that included the idea of expertise or the worldview typical for one's own discipline, also in connection to wider contexts. The fifth and final category, *Contextual understanding*, included responses describing a distinctive way of thinking that relates to the specific discipline, for example growing up to be a member of an expert community or participating in the activities of one's own field. Responses referring to conceptual change and combining theory and practice in one's own field were also placed in this category:

> Chemistry is (quite) an exact science, however, even in this discipline from time to time it is discovered that things are not quite as it had been thought; for example freons were considered wonder substances until it was discovered that they are the major cause of climate change. (42)

> In my field (history) the development of students' critical thinking should happen (and it indeed happens) in parallel with the development of discipline-specific competences, for example, through different data exercises. Critical thinking is a central part of the whole study process, not some

> skill that develops independently of the discipline-specific competences. The development of scientific thinking can be understood as field-specific (what one has to know or be able to adopt etc., certain competences related to theories etc.) but I perceive science also in this broader meaning. (71)

> Scientific thinking entails the ability to create something new (to contribute to one's discipline); thoughts, innovations… (54)

> In economics, teaching is large corporate-driven. Teaching contains large amount of theories, however, practice (such as assignments, business cases, etc.) is also increasingly integrated into teaching. Education should, after all, equip students with competences to operate in the business realm. (38)

In addition to these five categories, many teachers brought up the importance of learning various generic skills, such as information seeking skills, language skills, scientific writing skills, metacognitive skills, lifelong learning skills and broad overall thinking skills. Despite the importance of general skills, they were left out from the analysis in this chapter because they are closer to thinking skills in general rather than scientific thinking specifically.

## Disciplinary Differences

The most frequently used categories by teachers were *basics of science and critical thinking* ($n = 57$) and *research skills* ($n = 54$). About half of the teachers' responses were classified into the category *contextual understanding* ($n = 41$) and about one-third of teachers ($n = 22$) mentioned *epistemic understanding* ($n = 22$). We also explored how teachers' views of scientific thinking were divided across disciplines. Teachers' responses from the faculty of Education and Social sciences, and Law and Economics were combined for the analysis because of the small amount of teachers and the similarities in responses. The number of teachers' responses in each category by discipline is presented in Fig. 1.1. Since some of the teachers did not mention their discipline ($n = 12$), their data has not been included in the figure.

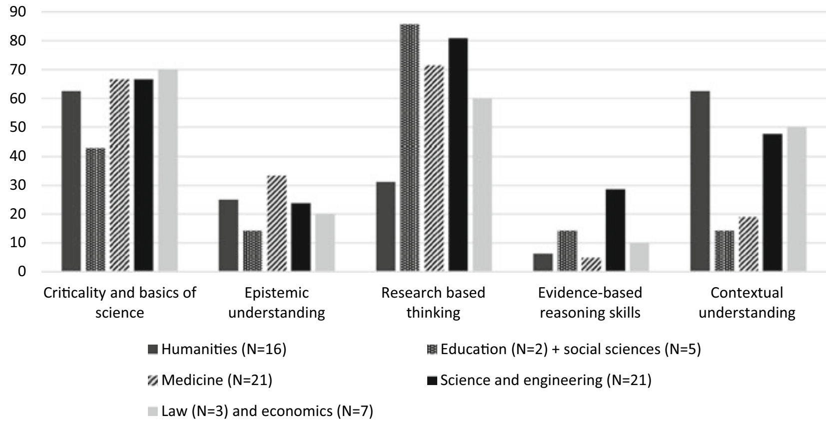


**Fig. 1.1** Teachers' views (% of the teachers) on scientific thinking by discipline

To ascertain whether there were disciplinary differences in teachers' responses, we looked at the percentage of teachers' views of scientific thinking in each category across different faculties (the percentage here refers to the percentage of teachers in each faculty). There were no big differences in the category *criticality and basics of science.* Teachers from the faculties of education and social sciences had fewer responses in this category than others, but the difference was quite small. The same result can be seen when looking at the category *epistemic understanding*. Teachers from all faculties, except the Faculty of Humanities, had a lot of responses coded as *research skills.* Only one third (31.3%) of them mentioned research when describing what scientific thinking is. About one-third (28.6%) of teachers in the Faculty of Science and Engineering emphasised *evidence-based reasoning*, which was more than what teachers from other faculties did. Teachers in the Faculty of Humanities had a lot of responses in the category *contextual understanding* (62.5% of the teachers) and the category was also popular in law, economics and science and engineering. Teachers from the faculties of education and social sciences had fewer mentions in this category than other faculty teachers.

The general conclusion here is that there were surprisingly few differences between disciplines, indicating that the theoretical model of scientific thinking proposed here can be used to analyse and describe teachers' views across the disciplines.

## The Proposed Theory of Scientific Thinking

Building on the theoretical and empirical work described above, a new, broader theory of scientific thinking is proposed here for use in higher education. The original theory of scientific thinking (Kuhn et al., 1988) provides a good basis for constructing a theory for the needs of higher education students. Combining it with other theories explaining the development of thinking skills during university education, specifically, theories of critical thinking (e.g. Halpern, 2013), development of reasoning skills (Lehman & Nisbett, 1990), epistemic maturity (Hofer & Pintrich, 2002), and understanding of research methodology (Murtonen, 2015), offers a wide basis for understanding the thinking skills expected to develop during higher education. On the basis of the empirical results presented in this chapter the theory we suggest here is also compatible with university teachers' views on what scientific thinking is.

We thus propose the following components to form the theory of broad scientific thinking in higher education (see also Fig. 1.2):

1. Critical thinking and understanding the basic principles of science
2. Epistemic understanding: understanding that knowledge is uncertain and created by humans
3. Research skills: understanding the research methods underpinning science: understanding how knowledge is produced
4. Evidence-based reasoning: scientific reasoning as the basis for knowledge building
5. Contextual understanding: disciplinary and more generic understanding in situating knowledge

In addition to the first four theory-driven categories described earlier in this chapter, the fifth category, *Contextual understanding*, refers to students' ability to situate constructed knowledge in certain contexts. Entwistle (2005) found that when asked about the most important learning out-

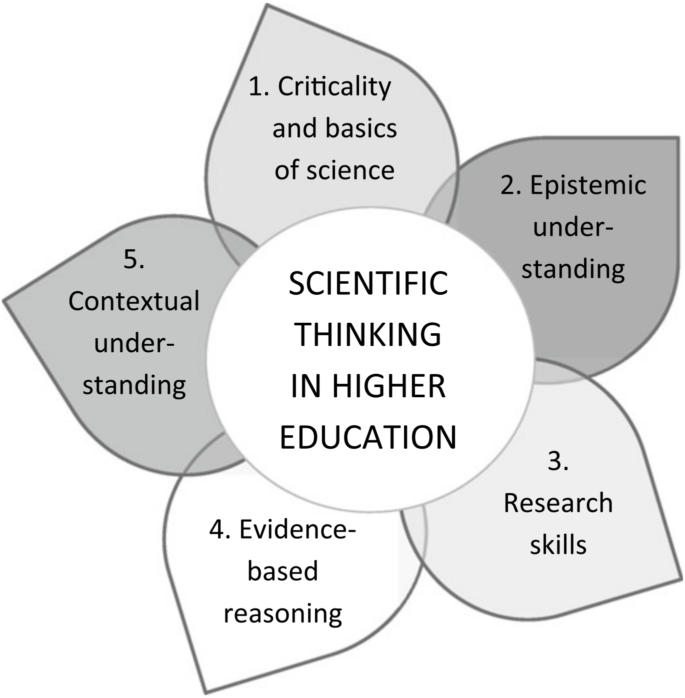


**Fig. 1.2** Components of scientific thinking in higher education

comes in university education, many teachers mentioned specific ways of thinking and practising which are typical to the discipline. Thus, higher order thinking skills cannot develop in a vacuum, but instead in a context that includes different layers: the close environment, such as the discipline or department, then, the broader context of the whole faculty and the whole university, and finally the international scientific community. This also sets a requirement for curriculum developers to not set too strict learning outcomes in order to allow the students to develop broad understanding (e.g. Murtonen, Gruber, & Lehtinen, 2017). Students need to understand that some questions are on the level of more common principles of science, and in other cases the problems may be more specific to their own discipline or even to some subdomain of it. The ability to situate questions in the right contexts affects the way these questions are answered. For example, if a student finds information claiming that using oil to heat houses does not increase the greenhouse effect, the student needs to understand that in addition to understanding oil as a source of energy, s/he needs to understand what information sources the claims are based on, and how inferences generally can be made from evidence. Students also need to understand how the contents of what they study are related to their later working life in order to understand their value and be motivated during their studies (e.g. Murtonen, Olkinuora, Tynjälä, & Lehtinen, 2008).

Together, these five categories form a new, broader theory of scientific thinking that can be used in higher education to understand and evaluate students' scientific thinking and how they develop these skills.

## Conclusions: Fostering the Development of Skilled Scientific Thinking

Equipping university students with important skills for their citizenship and working life today needs to include training in understanding and using research-based knowledge. Some pedagogical innovations have already strived for what we describe here as scientific thinking. For example, Problem Based Learning (PBL; e.g. Nieminen, Sauri, & Lonka, 2006) has been described as the pursuit of skills that use the scientific process as the basis for all learning. This type of pedagogical solution honours the collective knowledge-building and problem-solving processes of learning, and fosters the metacognitive abilities that further enable higher order thinking skills. The idea of PBL and other enquiry-based pedagogical solutions is to offer learners a realistic problem-solving situation where they can search for the solution through the principles and methods of scientific enquiry. Fung (2017, p. 61) states that this type of a process also empowers students to use enquiry skills to develop their own coherent story of who they are, what they can do and where they want to go. This strengthens students' agency, i.e. it makes them trust their own decisions to act responsibly in problem-solving situations. Agency has been stated as one of the most desirable learning outcomes of higher education (Eteläpelto, Vähäsantanen, Hökkä, & Paloniemi, 2013).

To reach an enquiry-based decision-making ability with strong agency, students need skills in scientific thinking. According to Fung (2017), a connected curriculum in which students' connections with research practices and practitioners, as well as with working life, helps students to build the necessary competences. The processes described above are very important for students' development of thinking skills during higher education. To ensure the direction of these developmental processes, the principles of broad scientific thinking should be paid attention to. Focusing on the development of critical thinking abilities, reasoning skills, epistemic maturity and understanding of research, within different contexts, creates the basis for academic expertise that is needed in society.

The components of the proposed theory of scientific thinking can be evaluated on an individual or collective level. In either case, there is a need to understand that scientific thinking is not a feature or a function of an individual person, but instead a collaborative phenomenon. Collaborative knowledge building has been shown to be crucial for the functioning of the communities of networked expertise (Hakkarainen, Palonen, Paavola, & Lehtinen, 2004). In the first petal of Fig. 1.2, *Criticality and basics of science*, it should be understood that critical thinking and other requirements are ways for a community to ensure that knowledge is as reliable as possible. *Evidence-based reasoning skills* (petal 4) are a further tool used to execute the requirements of petal 1. *Research skills* (petal 3) are a commonly agreed collection of instruments and rules for how to pursue new knowledge and use it for different purposes. *Epistemic understanding* (petal 2) is not only studied mainly on an individual level, but it can also be seen as a quality of a larger group of actors, and it can presumably be fostered in collective situations. Finally, *contextual understanding* (petal 5) binds scientific thinking both to the general broad idea of science and to the disciplinary context, which further sets tighter boundaries for all petals to be applied.

In the case of higher order thinking skills, such as broad scientific thinking, the highest levels most likely require meta-level understanding to be obtained. A university student needs to have metacognitive skills to understand his own thinking in order to be able to develop his thinking. Similarly, groups need metacognitive understanding of their goals and actions in scientific thinking to be able to guide those in the right direction.

The role of a shared metacognitive regulation (Iiskala, Volet, Lehtinen, & Vauras, 2015) in collaborative knowledge building is crucial for the success of the groups in developing understanding of scientific functioning. Although broad scientific thinking can be observed on an individual level, there is always a collective element involved.

The proposed broad theory of scientific thinking in higher education tries to fulfil the gap that has existed in higher education research and practice by offering a theoretical tool to approach this important set of thinking skills. Responses from all five categories were present in all disciplines, indicating that the proposed theory can be used across domains. Thus, the proposed components of the theory of scientific thinking in higher education are common to all faculties and disciplines.

Explicating the phenomenon of scientific thinking with five subcomponents gives a method for studying students' understanding and the development of it, and as a result, this kind of study informs instruction about how to support the development of scientific thinking. The proposed theory does not only suggest a definition for this abstract thinking ability, but binds the thinking skills to the practical research methods that underpin the scientific method. To this end, the theory does not only offer tools for analysing students' thinking, but also provides ideas for pedagogy about how to foster the development of scientific thinking. Making the generic skill of scientific thinking explicit to students, and attaching it to the concrete, discipline-based research methods, gives students the readiness to monitor and develop their own ability to think scientifically.

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# 2

# The Roles of Epistemic Understanding and Research Skills in Students' Views of Scientific Thinking

Heidi Salmento and Mari Murtonen

## Introduction

University students' views of the higher order thinking skills that they should develop during their education are crucial for their education to be successful. We perceive scientific thinking here as a wide phenomenon that consists of five components, based on an analysis of university teachers' responses to a question about what they think scientific thinking is (see Chapter 1 by Murtonen & Salmento in this book). The components are: (1) *Criticality and basics of science*, (2) *Epistemic understanding*, (3) *Research skills*, (4) *Evidence-based reasoning* and (5) *Contextual understanding*. Critical thinking and reasoning skills are likely to be more familiar to students,

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so in this chapter we wanted to focus more on epistemic understanding, i.e. beliefs about knowledge and knowing (including aspects of both personal epistemology and epistemic cognition), and research skills.

Epistemic questions about the nature of knowledge (what knowledge and knowing is) and the source of knowledge (where knowledge and knowing comes from) are very central in higher education. As Strømsø, Bråten, Britt, and Ferguson (2013) argue, research-based teaching that has been highlighted as the cornerstone of university teaching requires an understanding of the nature of knowledge. What we claim here is that understanding the nature and sources of *scientific knowledge* and *scientific knowing* are crucial, especially in a university context. What we call *epistemic understanding* means understanding that beliefs and conceptions about scientific knowledge and scientific knowing are strongly related in scientific thinking. We suggest that, as a cornerstone of scientific thinking, epistemic understanding must be related to research skills, which we believe to be another foundation for scientific thinking.

## The Role of Epistemic Understanding in Teaching and Learning in Higher Education

Half a century has passed since William Perry started the research tradition of *personal epistemology* that refers to beliefs about knowledge and knowing, also known as *epistemic beliefs*. Perry was interested in the development of his students' cognitive thinking processes and his studies revealed that students' understanding of knowledge often changes from dualistic "black and white views" towards relativism, and finally, to a committed view. His book, *Forms of Intellectual and Ethical Development in the College Years: A Scheme* (Perry, 1970), opened the door to the field for many researchers. A lot of research has since been done to continue Perry's work and still, fifty years later, personal epistemology is an integral part of research concerning students' learning and thinking processes. Because a lot of research has been done in the field, several different theories and models exist (Kelly, 2016; King & Kitchener, 2002). A review article by Hofer and Pintrich (1997) about the history of research concerning epistemic beliefs shows that there is a lot of conceptual variation and differences between definitions and terminology used for the phenomena (e.g. epistemic or epistemological beliefs, personal epistemologies and epistemic development, see also Sandoval, Greene, & Bråten, 2016). When reviewing edited books about the topic published this century, two of them, *Personal Epistemology: The Psychology of Beliefs About Knowledge and Knowing* edited by Hofer and Pintrich (2002) and *Personal Epistemology and Teacher Education* edited by Brownlee, Schraw, and Berthelsen (2011), use the term *personal epistemology*. Another term, *epistemic cognition* has also been chosen as an umbrella term in the most recent work in this area—*Handbook of epistemic cognition* edited by Greene, Sandoval, and Bråten (2016).

What does it mean to perceive epistemic understanding from the student's perspective? According to Perry's (1968) theory, a simplified example about what happens in university students' epistemic understanding during their education would be as follows: at the beginning of their studies, students often see knowledge as black and white and hope that after graduation they know all the facts and have all the knowledge needed in their field. Teachers are expected to have all of this knowledge and the "right" answers to students' questions. Epistemic understanding starts to develop when students face different and contradictory research during their studies and begin to understand the uncertainty of knowledge. Students start to question the simplicity of knowledge and realise that even teachers and books do not necessarily have the right answers to their questions, and that the knowledge teachers and books have, is also limited and uncertain. Finally, students start to understand the relativity of knowledge. At the highest level of epistemic understanding, one develops a commitment to certain knowledge on the basis of his or her own judgements.

What we claim here is that without the development of epistemic understanding, learning the scientific way of thinking is impossible. Additionally, it is known that epistemic understanding develops slowly (e.g. Hofer & Pintrich, 1997) and this is why we argue that epistemic understanding should receive more attention at the university level.

According to previous research, personal epistemology is connected to many central aspects of teaching and learning, for example, motivation, metacognition and self-regulated learning (Hofer & Pintrich, 1997;

Trevors, Feyzi-Behnagh, Azevedo, & Bouchet, 2016; Muis, 2007; Muis, Chevrier, & Singh, 2018). Personal epistemology is also known to be connected to critical thinking, conceptual change, scientific reasoning and scientific argumentation skills (Hofer, 2016; Nussbaum, Sinatra, & Poliquin, 2008), all of which are important in higher education. All of these factors also arose in our study on university teachers' views of scientific thinking (see Chapter 1 in this book). The development of epistemic understanding is often linked with age and educational experience (Kuhn & Weinstock, 2002) and many studies have shown that there are clearly positive relationships between these factors (Hofer & Pintrich, 1997).

Because of the assumption that development in epistemic understanding happens during early adulthood, and in the context of formal education, exploring university students' epistemological understanding is naturally important. Also, the specific task of university education in equipping students with the highest possible thinking skills requires attention on the development of these skills. Thus, research is needed about how university teachers could support the development of their students' epistemic understanding. However, as Weinstock and Roth (2011) state, there is not a lot of research about possible methods for fostering students' epistemological development.

When looking at epistemic understanding from the viewpoint of university teachers, what happens in practice when moving through the levels of Perry's scheme is that the teacher's role as an authority and the source of truth changes towards a model of being an expert who can search for knowledge and solve problems. At the same time, the student's role as a passive receiver of information changes towards becoming an active agent who is creating new knowledge (Moore, 2002). Research has shown that personal epistemology is connected to approaches to teaching and learning (for examples see Strømsø & Bråten, 2011, pp. 58–59). It is also known that teachers' own epistemic beliefs may affect their teaching and thus, students' learning (Brownlee et al., 2011; Feucht, Brownlee, & Schraw, 2017; Madjar, Weinstock, & Kaplan, 2017; Marra & Palmer, 2011; Sandoval, 2003, 2014; Schraw, 2012; Sinatra & Taasoobshirazi, 2018; Strømsø and Bråten, 2011; Yadav, Herron, & Samarapungavan, 2011). For example, teachers' epistemic cognition may impact on students' understanding of complex and controversial issues (Bråten, Muis, & Reznitskaya, 2017).

Strømsø and Bråten (2011) suggest that it is important to offer possibilities for teachers participating in university pedagogical training to become aware of the influences of personal epistemology in teaching and learning. According to Brownlee, Ferguson, and Ryan (2017), availing epistemic cognition should be a goal of teaching and also, a goal of teacher education. Marra and Palmer (2011) highlight that at a faculty level, in addition to the content of teaching, pedagogical choices may also have an effect on students' personal epistemologies. Berland et al. (2016) emphasise the significance of supporting students to engage in scientific practices. They recommend a practice-based approach to science and highlight the importance of participating in scientific knowledge construction through learning by doing.

## Context Sensitivity of Epistemic Understanding

Measuring epistemic beliefs is methodologically challenging and still, after 50 years of research, a valid way of measuring epistemic beliefs has yet to be found (see e.g. Strømsø et al., 2013). Many impressive models and questionnaires have been developed (e.g. the Epistemological Questionnaire [EQ] by Schommer, 1990, and modelled on that, the Epistemic Beliefs Inventory [EBI] by Schraw, Bendixen, & Dunkle, 2002). However, even these questionnaires tend to be limited because of the complex and sophisticated nature of epistemic beliefs (Hofer, 2016). Yet, the research field of epistemic understanding is expanding all the time and new methods and approaches are continuing to be found. A relatively new perspective in this research proposes that epistemic understanding may be more context-sensitive than traditionally expected (e.g. Brownlee et al., 2017; Hofer, 2016, 2017; Merk, Rosman, Muis, Kelava, & Bohl, 2018).

The original research on personal epistemology (Perry, 1970), and most of the research in the field after that, have focused on individuals' epistemic beliefs as being domain-general (Yadav, Herron, & Samarapungavan, 2011). However, further research has presented the idea that individuals have both domain-general and domain-specific epistemic beliefs, or personal epistemologies (see e.g. Hofer, 2000, 2016; Muis, 2004). As Merk et al. (2018) explain, an individual may have beliefs about knowledge in general that differ from his or her beliefs on knowledge in some specific domain. Bråten, Strømsø, and Samuelstuen (2008) suggested that, in addition to a domain-general level, there is a topic-specific level as well. In line with this research, other recent research on personal epistemology has given hints that the nature of epistemic cognition or personal epistemology may be more context-sensitive and sophisticated than previously has been thought (Brownlee et al., 2017; Hofer, 2016; Merk et al., 2018).

## Research Skills as Broadly Understood

Learning the scientific way of thinking is one of the central aims of university education. Students are expected to learn how scientific knowledge is produced, used, and justified in our society. However, despite the significant resources that universities put into research methodology courses, many students do not achieve this goal (Murtonen & Lehtinen, 2003). Understanding scientific research is challenging and research skills are not easy for students to learn (Balloo, Pauli, & Worrell, 2016; Murtonen, 2015; Murtonen, Olkinuora, Tynjälä, & Lehtinen, 2008). For example, students face difficulties in understanding the most central concepts concerning research (Balloo, Pauli, & Worrell, 2018), such as the terms empirical, theoretical, qualitative and quantitative (Murtonen, 2015). In addition, they have problems understanding the necessity for research skills in working life (Murtonen et al., 2008). Yet, understanding the basics of research is crucial (Balloo et al., 2018; Kuhn, 2009; Murtonen, 2015; Murtonen et al., 2008), and as we claim here, together with epistemic understanding, it can build a base for scientific thinking. The link between epistemic understanding and scientific activities has also previously been made by other authors (see e.g. Berland et al., 2016; Kuhn, Arvidsson, & Lesperance, 2017).

We see the role of research in scientific thinking as being multidimensional, consisting of different levels. In this chapter, when we talk about *research skills* we mean: (1) understanding of the most central concepts of scientific research and research methodology (declarative level); (2) skills to conduct research and participate in scientific knowledge construction (procedural level); and (3) understanding the nature of scientific knowledge (epistemic level). The epistemic level includes: (1) understanding the source of scientific knowledge, i.e. that scientific knowledge is pursued through scientific research by researchers using different research methods; and (2) the nature of scientific knowledge, i.e. that scientific knowledge is also uncertain, unstable and created by people, but that the trustworthiness is pursued with the aid of certain rules and principles. We think that reaching a certain declarative level, i.e. understanding the most central concepts, is crucial for being able to move to the procedural level. That is, being able to conduct research. However, understanding these complex concepts cannot be learnt without connection to practical examples. We claim that the first two levels can be acquired by university students at the end of their studies, but what may often be the missing part is the epistemic level that is needed to really understand scientific knowledge and reach the scientific way of thinking. Furthermore, reaching the first two levels is already very advanced and it is possible that for many students the epistemic level actually comes later with maturity and experience. To deepen understanding of university students' views of scientific thinking, we present a study that aims to explore: (1) how students conceptualise scientific thinking; and (2) what roles epistemic understanding and research skills play in their views.

# Methods

## Participants

The participants of this study were undergraduate and postgraduate university students ($N= 145$) representing six faculties of the University of Turku, Finland: Humanities ($n = 18$), Education ($n = 4$), Medicine ($n = 20$), Science and Engineering ($n = 42$), Social Sciences ($n = 45$) and Economics ($n = 16$). Forty-five of the participants were first or second year students, 66 were third years and 34 were fourth, fifth or sixth year students. The data was collected anonymously with paper and pencil during lectures or seminars by teachers who were participating in university pedagogical training. The instruction for students was to describe what they think scientific thinking is and how it develops during university education. Participation was voluntary and students were briefly told about the purposes of research and that their data will be handled anonymously. The average word count of students' responses was 57 and responses varied between 11 and 107 words.

## Data Analysis

To explore students' views of scientific thinking, a content analysis was performed based on our research exploring university teachers' views of students' scientific thinking (see Murtonen & Salmento in Chapter 1 of this book). As with our research with teachers, the content analysis in this study was also conducted with both theory and data-driven methods. In this study, five theory-based categories were used that were the result of the study with the teachers: (1) *Criticality and basics of science*, (2) *Epistemic understanding*, (3) *Research skills*, (4) *Evidence-based reasoning* and (5) *Contextual understanding*. Data-driven categories were allowed to arise, but after the first round of tentative classifications of the whole data, no additional categories were identified.

All of the responses referring to critical thinking and responses including the basic idea of science, like objectivity and questioning were classified into the first category, *criticality and basics of science*. Responses including thinking about the development of conceptions of knowledge and knowing were classified into the second category, *epistemic understanding*. Responses describing the changes that happen or should happen in students' epistemic understanding during university education, as well as responses referring to the development of relativist thinking, were classified into this category. These type of responses included the idea of uncertainty and lack of stability of knowledge or they stressed the importance of understanding that knowledge and science are constructed and created by humans. Responses emphasising research as being a part of scientific thinking were classified into the third category, *research skills*. Responses referring to scientific reasoning skills were classified into the fourth category, *evidence-based reasoning*. Additionally, responses focused on the idea of deductive or inductive reasoning were also classified into this category. Finally, responses that included the idea of expertise or a worldview typical for one's own discipline, also in connection to wider contexts, were classified into the fifth category, *contextual understanding*. The criteria for categorisation is explained in more detail in the previous chapter by Murtonen and Salmento.

Students' responses were read and analysed by identifying whether they mentioned these categories when describing what they think scientific thinking is. Each student's answer could be categorised into more than one category. For the final analysis, the first author analysed all data and the second author analysed about half (56.6%) of the responses. An inter-rater reliability was calculated on the data resulting in 83% agreement. Disagreements about classifications were discussed between the two researchers until a final agreement was reached for each case.

The data was coded and entered into the IBM SPSS statistics program. An ID-number was given for each student to guarantee the anonymity of participants. Variables were also created for background information including faculty and study year. Excerpts were translated from Finnish into English. Pearson's Correlation analyses were conducted to explore possible connections between categories. Additionally, a Mann–Whitney *U*-test was used to explore epistemic understanding in relation to other aspects of scientific thinking.

# Findings

## Students' Views of Scientific Thinking

About half of the students' responses (51.7%) were categorised into the category *criticality and basics of science* and this was also the most common category. About one third (31.3%) of the students mentioned *research skills* when defining what scientific thinking is. This is significant, because traditionally, research skills have not been included in theories of scientific thinking. This endorses our assumption about the key role of research skills in the phenomena of scientific thinking. What was interesting, was that despite our assumption of *epistemic understanding* being a cornerstone of scientific thinking, only a few of the students' responses (8.2%) included thoughts about epistemic understanding. On the other hand, these responses are highly valuable because the question we asked of students was very general, so mentioning epistemic understanding tells us something about the sophisticated nature of these students' scientific thinking conceptions. About one fifth (21.1%) of the students saw scientific thinking as being related to *evidence-based reasoning*. Only a few of the students (12.9%) made statements related to *contextual understanding*. These were more prevalent in teachers' responses (see Chapter 1 in this book).

To determine how students' views of scientific thinking were distributed across disciplines, we looked at the number and percentage of students' views about scientific thinking in each category across different faculties. The percentage here refers to the percentage of students in each faculty (e.g. if looking at the first bars of Fig. 2.1, 22.2% of students' responses in the Faculty of Humanities and 75% of students' responses in the Faculty of Medicine have been categorised into the category, *criticality and basics of science*). The results show no clear differences between the disciplines in the *epistemic understanding* category, but differences were shown in *research skills*. More than half (62.5%) of the students in economics and half of the students in medicine (50%) saw research as being a part of scientific thinking, and only 20–30% of the students in other disciplines showed these kinds of views. Even though the main focus was on the categories of epistemic understanding and research skills, the other categories show

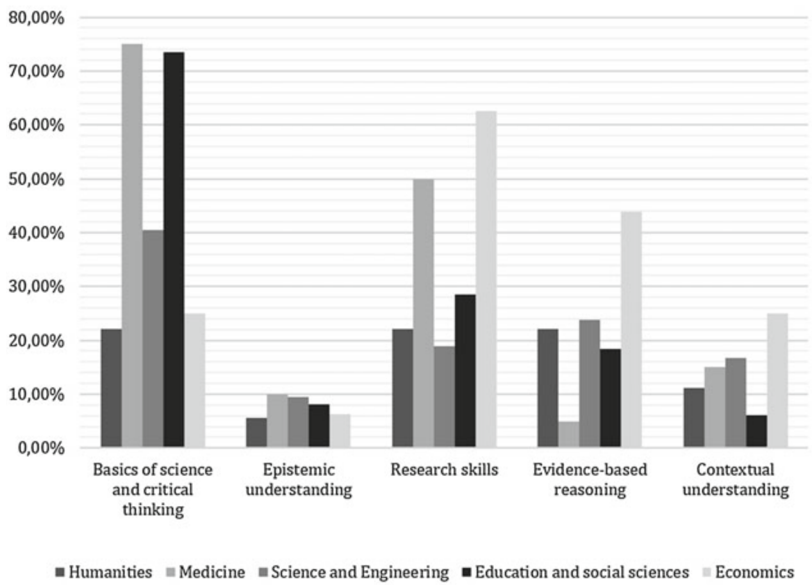


**Fig. 2.1** Students' views (% of the students in discipline) of scientific thinking

interesting differences too, and are for that reason also presented in Fig. 2.1. For example, there are notable differences in students' conceptions of *criticality and basics of science* and *evidence-based reasoning*.

## Differences in Students' Scientific Thinking Conceptions by Phase of Study

When looking at the role of *epistemic understanding* in students' scientific thinking by the phase of study, there were no clear differences between students in different study years. When looking at Fig. 2.2 it appears that epistemic understanding increases along the study years (except for fifth year students or higher). Fourth year students' responses included more aspects of epistemic understanding than others did, but because of the small total amount of responses in this category, no conclusions can be drawn. However, there seems to be a trend towards the theoretical claim by Perry (1968) that students understand epistemological aspects better

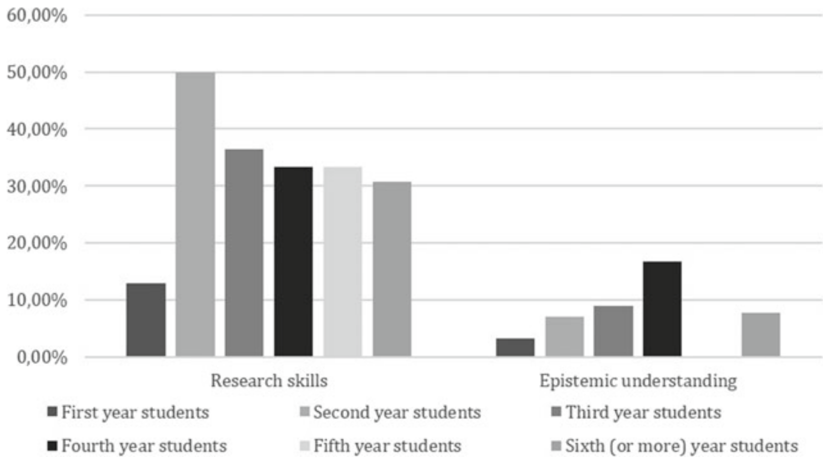


**Fig. 2.2** Epistemic understanding and research skills in students' scientific thinking conceptions by the phase of study

in their later years of education. When looking at the role of *research skills* in students' conceptions of scientific thinking, the analysis revealed that only some (12.9%) first year students understood research as being a part of scientific thinking. The amount of conceptions of research skills seems to increase after the first year, which is quite rational, since students only become acquainted with research methods in their first year, and after that they will learn to use them more actively. However, the difference is quite remarkable and at least one-third of students in all further study years included research in their descriptions of scientific thinking. These results clearly show that students see research methods as being a part of scientific thinking.

## The Role of Epistemic Understanding in Students' Views of Scientific Thinking

Our study exploring university teachers' views of scientific thinking (presented in Chapter 1) showed that about one quarter of university teachers described the development of epistemic understanding when defining what they think scientific thinking is. When looking at the phenomena from the students' perspective, the amount of responses in the current study was much smaller (only 8.2% of the students referred to epistemic understanding). Despite this low number, these responses are significant and reveal relevant aspects of students' epistemic understanding. The question we asked of students was very general (what scientific thinking is and how it develops during university education) and thus, spontaneously mentioning epistemic understanding portrays quite advanced scientific thinking conceptions. To understand these students' thinking processes, we looked at the responses that included aspects of epistemic understanding in more detail. In their responses, some of the students stressed the development of their thinking process moving from a "black and white" view towards a broader understanding of knowledge:

> Scientific thinking develops in University by learning to think critically. Perspectives are expanding and knowledge and science are no longer so unambiguous and black and white. (94)
> Questioning the 'general facts' - > understanding also one's own subjectivity - understanding that things are never black and white. (09)
> Awareness of different theories and understanding that things aren't black and white. (06)

There were thoughts about (un)certainty of knowledge and students wrote about the complex and ambivalent nature of knowledge:

> Recognising that nothing can be known for sure. Everything is basically just a theory and a complex sum of variables and probabilities. (40)
> Thinking develops during studies when a student acquires more knowledge and learns to understand and endure the contradictions and uncertainties related to knowledge. (107)
> During my studies I have learned to understand how few things I really know/understand. (42)

Some of the students criticised the "exact truths":

> Scientific thinking differs from religious thinking, for example, by not believing in the explanatory truths of everything, it is more about finding solutions through exact studies. (14)

> Questioning one's own thinking and thoughts of what reality is and what is true in the world. (15)
> Students become familiar with scientific thinking immediately at the beginning of university studies. All the teaching is based on the latest research and things are not seen as ultimate truths. (24)

Some questioned the omniscience of authority and they understood that authorities, like teachers or books, do not have all the knowledge, and the knowledge they do have is also uncertain and unstable:

> In the first year of study, one takes everything that is taught as "truth". Then you learn that things can and must be questioned even if they were taught by some more educated person. This kind of criticism I have learned especially from other students who have disagreed and discussed with the lecturer during lectures. (06)
> You don't just 'fire opinions' without reflection and things are not swallowed blindly, even if they come from a 'certain' source. (90)

There were also discussions about the ambiguous nature of knowledge; students stressed that science and scientific knowledge are constructed and created by humans:

> Science is overrated when people forget that they have created it themselves. It was meant to challenge God (in the west). Now that God is not as important, we believe in science. But is it merely a need of believing or is it really the truth? (24)
> The term 'scientific' itself relates to a set of rules or procedures used to make some evaluation, for instance, what is true and what is real? Scientific thinking develops by way of doing scientific research. Scientific thinking can also develop from critical evaluation and analysis of scientific journals and coming up with an independent conclusion about those scientific articles/journals. (66)
> Scientific thinking is interpretation of things through philosophies of science. Usually the subject is some phenomenon in the world observed by humans. Methodology, epistemology and ontology always have an impact on scientific thinking. (90)

## The Role of Research Skills in Students' Views of Scientific Thinking

The study presented in the previous chapter revealed the huge role of research in university teachers' views of scientific thinking. When looking at the same phenomenon from the students' perspective, the finding was in line with teachers' views. To deepen our understanding of the role of research in students' views, we looked at the responses in more detail. The responses were analysed and three different levels, *declarative, procedural* and *epistemic* were found. Many responses included thinking at all of these levels were not exclusive. Furthermore, the categorisation helps to perceive the different aspects in students' thinking and the following examples are provided to clarify the overall picture. Many of the students mentioned some core details of scientific research, like objectivity, repeatability and justifiability and saw that scientific thinking is based on research and theories. They referred to the most central concepts of scientific research and research methodology. These kinds of responses show understanding of research at a *declarative level.* The following are examples of students' responses from this point of view:

> Understanding of what is good research and theory. (07)
> Scientific thinking is the process of extending one's knowledge by learning a theory based on observation. (25)
> Scientific thinking is objective, abstract level thinking, whose goal is to produce facts. Scientific thinking develops as students familiarise themselves with theories, research, and scientific literature. (138)
> Scientific thinking is based on research and scientific sources, and it should be justifiable. (94)
> Learning the different phases in the research process for its part guides towards scientific thinking. (17)
> Scientific thinking refers to the ability to examine things critically and objectively. It requires the ability to understand different phases of the research process, particularly the significance of research hypotheses. It is crucial to have a good command of scientific terminology in order to be able to read scientific texts and publications. (125)
> In scientific thinking one uses scientific facts as the basis for understanding and is able to view things critically and approach them from various points

> of view. This skill develops in university studies as one explores scientific research, its principles, and its methods. (135)
>
> Through scientific thinking it is possible to conduct plausible scientific research which can be reproduced by others, withstands critique, and applies carefully chosen methodology. (88)

Some students referred to skills to conduct research and participate in scientific knowledge construction. They saw research as a learning process or noted that scientific thinking develops when participating in or conducting research. Some of them emphasised the active role of the student and the significance of scientific essays or thesis. The following are examples of responses showing understanding of research at the *procedural level*:

> In particular, conducting research is likely to enhance scientific thinking as one explores literature and the results of one's own research have to be assessed and compared with the results of prior studies. (127)
>
> Scientific thinking is critical, argumentative, and research-based. Furthermore, being familiar with scientific methods (for example, through conducting research) in order to evaluate knowledge and research objectively is part of scientific thinking. Scientific thinking develops as one learns conducting different kinds of research, critical thinking is taught (what is good research, etc.), and by doing (own essays). (122)
>
> In scientific thinking knowledge is based on observations made in research. This means that the effect of individuals' prior conceptions should be minimal and it should be possible to change one's conceptions in light of new knowledge. In the university context the development of this type of thinking is fostered by the fact that everyone has to participate in doing research in some way and read scientific articles. (130)
>
> Scientific thinking is critical thinking formed on the basis of research and sources that is usually taken into use in academic research. Scientific thinking becomes broader and more demanding during university studies as we learn research skills and acquire new information about the research topics. (123)
>
> For me scientific thinking means being able to give a positive or negative opinion about some specific topic, but also becoming familiar with research procedures and understanding them. It is also very related to carrying out research for some paper, conference or thesis. (28)

Some students wrote about applying the scientific knowledge and emphasised the significance of interpreting and utilising research. There were reflections about the source and nature of scientific knowledge. Some responses showed that understanding scientific knowledge is pursued through scientific research by researchers using different research methods and that scientific knowledge is also uncertain, unstable and created by people. These are examples of this kind of responses at an epistemic level:

> Scientific thinking is, in my opinion, an ability to utilise scientific research results, interactions, broader issues, and to maintain a critical approach. It develops through reading scientific texts and writing scientific essay assignments. (119)
>
> Scientific thinking develops significantly during studies as one becomes familiar with different methods used in research and different approaches to understand the world. Scientific thinking also develops through exploring scientific practices. (101)
>
> At university the scope of thinking becomes broader, and especially searching for information and evaluating it becomes more critical; how the information is acquired, what kind of research is conducted or what kind of reasoning is used, etc. (19)
>
> Scientific thinking develops by way of doing scientific research. Scientific thinking can also develop from critical evaluation and analysis of the scientific journals and coming up with an independent conclusion about those scientific articles/journals. (51)
>
> Justified and argumentative. Knowledge is trialled and as correct as possible, but it is always possible to refute it. It develops as one is dealing with scientific knowledge and research and aims to write scientifically. The theoretical basis of how scientific community works is learned through taking courses. (134)
>
> During university studies, as more information is received, the student is increasingly more able to examine claims that are presented to him/her and their veracity. (43)
>
> Scientific thinking is based on the information stemming from theories and research. During university studies students learn to look critically at research and examine the research methods and, for example, the research settings used in them. Also, the connection between theory and practice becomes clearer. (10)

> Upon beginning university studies one usually understands the role of scientific thinking in research; research requires not only logical and rational, but also open-minded (not closed), interpretations of the world. University studies deepen the scientific interpretation characteristic of the major and minor studies, and they also deepen the scientific mode of thinking in general. (87)
>
> Is able to comment on the validity of knowledge and research, to evaluate how knowledge affects the future. (47)

## Epistemic Understanding and Research Skills in Relation to Other Aspects of Scientific Thinking

To gain more detailed information about the different aspects of scientific thinking, we explored the connections between the categories. To analyse how our classification categories were connected to each other, we conducted Pearson's Correlation analyses between all categories. There were only a few statistically significant correlations. It must also be noted that since a student's answer could be categorised into more than one category, some of the categories, such as basics of science and critical thinking were popular, i.e. many students' responses were categorised into these categories, which explains connections between the other popular categories. The categories most related to our research questions in this study were the *research skills* and *epistemic understanding*, which had a weak statistically significant positive correlation ($r = 0.17$, $p = 0.038$). This is theoretically interesting, since it means that those students who paid attention to epistemic understanding also more often mentioned research as an important factor of scientific thinking. To expand our understanding of the relationship between epistemic understanding and other aspects of scientific thinking we looked at students who showed epistemic understanding and students who did not show epistemic understanding and explored what other aspects of scientific thinking were included in their responses.

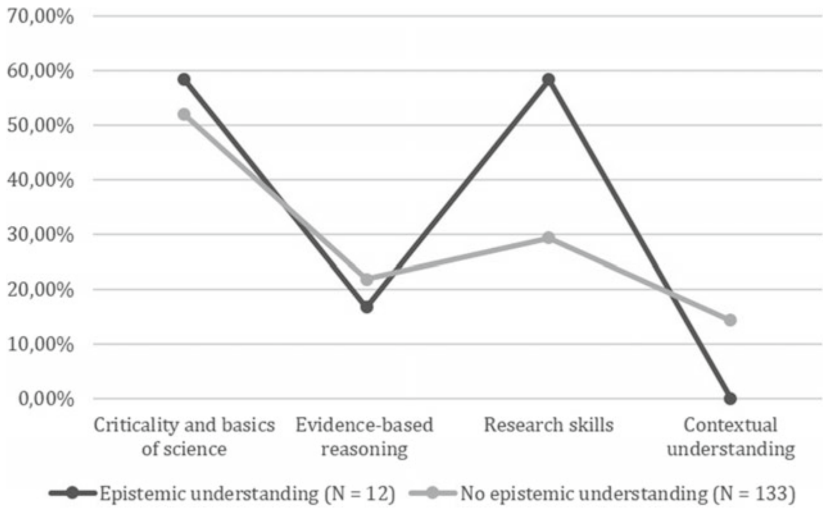


**Fig. 2.3** Epistemic understanding in relation to other aspects of scientific thinking

Figure 2.3 shows that students who showed epistemic understanding when describing scientific thinking had also most often mentioned research skills (58.33% of the students with epistemic understanding). The difference between groups (students who mentioned epistemic understanding and students who did not) was explored with an independent samples Mann–Whitney *U*-test. There was a statistically significant difference between the student groups, $U(143) = -2.085$, $p = 0.039$. Other than this finding, there were no notable differences, considering the small number of students mentioning epistemic understanding. However, according to this analysis, epistemic understanding and research skills often seemed to appear together, which supports our assumption about the relationship between these.

## Discussion

The aim of this study was to determine the role of epistemic understanding and research skills in university students' views of scientific thinking. According to our previous research (Murtonen and Salmento in Chapter 1 of this book) university teachers have wider views of scientific thinking than former scientific thinking theories suggest. The results of this current study are in line with that, and when approaching the phenomena from the students' perspective, the same five aspects of scientific thinking applied as a classification scheme.

According to our findings, understanding the basics of science forms a foundation for the whole concept of scientific thinking. The category *criticality and basics of science* was most popular among students and the same result was found when looking at teachers' views (Chapter 1 in this book). From the viewpoint of teachers, the role of *research skills* shown to be a fundamental part of scientific thinking. Now, when expanding this viewpoint and looking at the same phenomenon from university students' perspectives, the results are in line with teachers' views; students across the disciplines see research as an important part of scientific thinking. This is notable because "research" has not been included in traditional scientific thinking theories. However, the finding that students see research skills as a part of scientific thinking does not mean that all of these students *have* research skills, e.g. skills to understand and conduct scientific research. As previous studies have shown, learning of these skills is challenging and students face a lot of difficulties (Balloo et al., 2016; Murtonen, 2015; Murtonen & Lehtinen, 2003; Murtonen et al., 2008). In this current study, the approach was different and the results do not show the "negative side", such as the challenges and problems students face. What is important in our findings is that many of the students conceptualised research as a part of scientific thinking and some of the views were quite advanced. In the light of the results, *research skills* should not be ignored in scientific thinking theories anymore, especially in the university context.

When looking at the rest of the scientific thinking categories, students described fewer aspects of *contextual understanding*, but more aspects of *scientific reasoning* compared to teachers (see Chapter 1 in this book). This is understandable because university teachers, as professional scientists, must have broader views of scientific thinking than most of the students, and they look at students' development from the viewpoint of working life, which emphasises more generic skills.

Endorsing our assumption about the link between epistemic understanding and research skills, our findings showed that students who paid attention to epistemic understanding also often showed research skills in their responses. At the university level, where teachers are usually also researchers, their epistemic understanding is likely to be affected substantially by research. From the perspective of our interest in exploring epistemic understanding and research skills as cornerstones of scientific thinking, at first it appeared quite surprising that only a few of the students' responses included thoughts about *epistemic understanding*. On the other hand, awareness of one's own conceptions of knowledge and knowing is something that cannot be taken for granted (e.g. Strømsø & Bråten, 2011), and from that point of view, the low number of responses is actually quite understandable. The question we asked of students was very general and thus, mentioning epistemic understanding shows quite advanced views of scientific thinking.

When studying higher order thinking skills, like scientific thinking in this study, the difficulty is finding methods that help researchers measure these complex phenomena. As we know, this problem is especially prominent while measuring epistemic understanding (e.g. Strømsø et al., 2013). It is also possible in the current case that the method did not succeed in revealing the epistemological understanding students have and the small amount of students mentioning epistemic understanding might result from problems with the method. Another possible explanation is that very few students really are able to consider epistemic understanding as part of scientific thinking. To ascertain whether the former explanation is true, we plan to develop this method in further research. If the latter reason explains the results, we need to pay much more attention to the role of epistemic understanding in teaching and learning in higher education. Despite this, analysing the responses of students who showed epistemic understanding revealed a lot of relevant information about their thinking processes. Despite the fact that epistemic understanding did not appear often in students' responses, we still believe it plays a significant role in scientific thinking. Findings from the teachers' data (Chapter 1 in this book) endorses this interpretation. We assume that the nature of epistemic understanding is so sophisticated that awareness of it is challenging to perceive and this might be the major reason for the small amount of responses in this category. Promoting the idea of context-sensitive epistemological beliefs (e.g. Brownlee et al., 2017; Hofer, 2016; Merk et al., 2018), what arose from our analysis of scientific thinking conceptions was the idea that it might be necessary to separate *scientific epistemic understanding* from *general epistemic understanding*. This is something we need to study more in the future.

## Pedagogical Implications

The role of epistemic understanding is important in scientific thinking and we argue that more attention should be paid to increasing both university teachers' and students' awareness of epistemic understanding. Other researchers (e.g. Strømsø & Bråten, 2011) have also come to the same conclusion. Epistemic understanding should be particularly discussed in university pedagogical courses, because previous research has shown that teachers' own epistemic beliefs may affect teaching and thus, also students' learning (Brownlee et al., 2017; Marra & Palmer, 2011; Strømsø & Bråten, 2011). In addition to individual teachers and courses, the significance of epistemic understanding should be reflected at a university level, for example in curriculum work. As Marra and Palmer (2011) claim, the pedagogical choices at a faculty level may affect students' personal epistemologies. Awareness of epistemic understanding can help both teachers and students to reflect on their own conceptions of knowledge and knowing and thus, support them to develop these conceptions (Feucht et al., 2017). Developing one's own epistemic understanding is crucial because of its connections to motivation, metacognition, self-regulated learning, critical thinking, conceptual change, scientific reasoning and scientific argumentation skills (Hofer, 2016; Hofer & Pintrich, 1997; Nussbaum, Sinatra, & Poliquin, 2008; Trevors et al. 2016).

Additional attention should be paid to supporting students' understanding of scientific research by showing them how research is related to their other thinking skills. The results of this study showed a connection between epistemic understanding and research skills, and this link has also been observed by others (see e.g. Berland et al., 2016; Kuhn et al., 2017). We think that understanding the most central concepts of scientific research and research methodology (declarative level) and skills to conduct research and participate in scientific knowledge construction (procedural level) are requirements for understanding the source and nature of scientific knowledge (epistemic level). In an ideal case, students would all reach these levels during university education, but the reality is that not all students reach the epistemic level. Increasing awareness about epistemic understanding and immersing students even more in scientific activities could help them to better understand their conceptions and thus, be able to develop those like Berland et al. (2016) stated before.

## Further Research

Despite the long history of research on epistemic understanding, there are still many questions in the field. In addition to problems with measuring conceptions of knowledge and knowing (e.g. Strømsø et al., 2013), more information is needed about how students' epistemological development could be fostered (Weinstock & Roth, 2011). Thus, research is needed to explore how university teachers could better support the development of their students' epistemic understanding. Also, pedagogical interventions could be done to explore the changes that happen in teachers' own conceptions. In line with other researchers who have noted the context-sensitive nature of epistemic understanding (e.g. Brownlee et al., 2017; Hofer, 2016; Merk et al., 2018), we think that the nature of epistemic understanding is more sophisticated than previously claimed. Thus, there might be a need for separating *scientific epistemic understanding* from *general epistemic understanding*. To clarify this, we see that the nature and sources of scientific knowledge differ a lot from the nature and sources of general knowledge, so the foundation of these must be different. This is also something that needs to be explored in future research.

As with the study with teachers (Chapter 1 in this book), the components of the theory of scientific thinking were represented by the students of all disciplines. This indicates that the theory of scientific thinking that we have proposed is applicable to describing and analysing students in all disciplines. Some nuances may appear between the disciplines that need to be studied more carefully in the future.

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# 3

# Enhancing Scientific Thinking Through the Development of Critical Thinking in Higher Education

Heidi Hyytinen, Auli Toom and Richard J. Shavelson

## Introduction

Research publications, policy papers and reports have argued that higher education cannot only facilitate learning of domain-specific knowledge and skills, but it also has to promote learning of thinking skills for using that knowledge in action (e.g. Greiff et al., 2014; Shavelson, 2010a; Strijbos, Engels, & Struyven, 2015). The focus on critical thinking arises, in part, because of higher education's responsibility for preparing individuals to think, reason and cope in and change with an uncertain, continuously and rapidly fluctuating personal and working life (Bok, 2006;

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Jenert, 2014). The knowledge and skills students need and consequently should be taught in higher education are thus changing; more emphasis needs to be placed on higher-order domain-general or generic skills, such as analytical reasoning and evaluation, problem-solving, argumentation, written communication (e.g. Shavelson, 2010b; Tremblay, Lalancette, & Roseveare, 2012; Zahner & Ciolfi, 2018) and collaborative multidisciplinary work (Muukkonen, Lakkala, Toom, & Ilomäki, 2017). As a part of this discussion, critical thinking is now considered a key component of scientific reasoning and a capability to be enhanced in contemporary higher education.

While there is growing consensus on the importance of critical thinking in higher education, the same, however, does not hold true for questions concerning the processes of implementing critical thinking in teaching and learning in programmes (cf. Arum & Roksa, 2011). While several tips and exercises for how to teach scientific argumentation or reasoning can be found, the literature says surprisingly little about pedagogical principles of integrating critical thinking coherently in teaching and learning. The challenge in intertwining learning of critical thinking to domain-specific courses requires systematic and long-term work processes throughout a student's higher education studies in multiple different kinds of course contexts and themes. The development of critical thinking consisting of a variety of skills requires support, continuous feedback and long-term practice. Yet this is a challenge given the pedagogical organisation of higher education focusing on domain-specific knowledge competencies throughout the degree-programme curricula.

In this chapter, we begin by elaborating on the definition of critical thinking and presenting justifications for teaching critical thinking. Our first aim is to understand the characteristics of critical thinking based on current research, and what it means for teaching students to think critically in higher education. We do so from the viewpoint of scientific thinking. We then turn to teaching and learning. The second aim is to outline the role of curriculum and assessment in developing and implementing critical thinking in classrooms and academic programmes. The third aim is to suggest future teaching research and practice in higher education. The goal is to deepen our understanding of how to enhance students' critical and scientific thinking.

## What Is Critical Thinking and How Does It Relate to Scientific Thinking?

Critical thinking has been considered a foundation for participating in democracies for centuries, since the time of Socrates. It has been singled out as vital in growing up to be a genuinely autonomous and participating citizen of the modern society and one of the most important competencies for citizens of the twenty-first century. It has also been emphasised as the most important competence universities are expected to cultivate in students during higher education (Arum & Roksa, 2011; Halpern, 2014). Research on critical thinking is currently being pursued in at least two areas using very different approaches. One area is philosophical analysis of critical thinking. It focuses on the definition and justification of critical thinking as a theoretical concept. The second area is empirical analysis. It focuses on how individuals understand the nature of knowledge, how they construct and use knowledge, and what kinds of skills and strategies they utilise in the critical thinking process. In other words, empirical research focuses on the descriptive elements, and attempts to investigate how things are in the real world. For example, in the field of higher education, empirical research on critical thinking has focused on the development of critical thinking skills (e.g. Arum & Roksa, 2011; Kuhn, 2005), while philosophical analyses have concentrated on the normative elements of the prevailing theorisation of critical thinking (e.g. Holma & Hyytinen, 2015). The descriptive questions express an understanding of what something is, but they do not include an evaluation of how things should be. In contrast, the normative questions, such as what is the most adequate conception of knowledge, have been the central goals of the philosophical approach. Although philosophical and empirical analyses of critical thinking differ from each other, in educational research on critical thinking, the normative and descriptive elements of research are intertwined (Holma & Hyytinen, 2015). The descriptive assumptions of critical thinking become normative in nature when these assumptions are regarded as goals of education and are thus promoted and assessed in the various phases of the educational path (cf. Hopmann, 2007).

There are various definitions of critical thinking in educational research. Common to these definitions is their view of critical thinking as a purposeful self-regulatory judgement about what to believe and to do (e.g. Ennis, 1991; Facione, 1990; Halpern, 2014). However, critical thinking cannot be regarded as just any thinking aimed at deciding what to believe and do (Bailin, Case, Coombs, & Daniels, 1999). Such thinking can be naïve, rash or even careless. For example, one can come to believe on the basis of irrelevant reasons. Dewey's (1910, p. 9) analysis, the precursor to the modern critical thinking tradition, defined critical thinking as "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends". This suggests that thinking must meet some appropriate *standards* if it is to be regarded as critical thinking, for example, attempting to assess the evidence relevant to the belief or to the task (Bailin et al., 1999). Critical thinking, then, is conceptually connected to the epistemological ideal of rationality. Rationality requires the possibility of having some criteria or standards for evaluating beliefs and knowledge (Holma & Hyytinen, 2015).

Dewey (1941) called these standards warranted assertions. In Dewey's (1941, p. 172) words, all knowledge "The position which I take, namely, that all knowledge, or warranted assertion, depends upon inquiry and that inquiry is, truistically, connected with what is questionable (and questioned) involves a sceptical element, or what Peirce called 'fallibilism'". In a similar vein, it has recently been noted that critical thinking is conceptually connected to the epistemological concept, fallibilism (Holma & Hyytinen, 2015). According to Holma and Hyytinen (2015, p. 10), fallibilism implies that "all human knowledge is uncertain, coheres with the evolutionary understanding of knowledge: the bodies of knowledge we now have may be mistaken and are thus possibly subject to revision, but they have, nevertheless, survived the process of evolution to this point; as such, they provide the best available starting point for how to proceed at the present moment with respect to further inquiry".

Another common way to conceptualise critical thinking is to enumerate thinking skills (Bailin et al., 1999; Fisher, 2011). For example, Fisher (2011, p. 8) listed the following skills:

> identify the elements in a reasoned case, especially reasons and conclusions;
> identify and evaluate assumptions;

> clarify and interpret expressions and ideas;
> judge the acceptability, especially the credibility, of claims;
> evaluate arguments of different kinds;
> analyse, evaluate and produce explanations;
> analyse, evaluate and make decisions;
> draw inferences; produce arguments. (see also Ennis, 1993; Halpern, 2014)

However, critical thinking cannot be explained solely with the notion of a set of skills (e.g. Bailin et al., 1999; Holma, 2015); one who acquires a set of critical thinking skills does not use them all in a particular situation for one reason or another. It follows that it is not enough for one to possess the skills to assess the relevance of beliefs or knowledge, but one also needs to have the willingness to do so (Halpern, 2014; Hyytinen, 2015). American Philosophical Association's "Delphi report" (Facione, 1990) and the consensus statement regarding the ideal critical thinker conclude that critical thinking is a combination of various dimensions of cognitive skills and affective dispositions. The cognitive skills include a purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, inference, and found an explanation. The affective dispositions include open-minded, fair-minded and flexible in evaluation, willingness to reconsider, honesty in facing personal biases, diligence in seeking relevant information, reasonableness in the selection of criteria. Critical thinking is thus constituted by a variety of cognitive skills and dispositions to meet complex demands that make it possible to assess, evaluate, synthesise and interpret relevant information that is associated with a situation, and apply that information to solve a problem, to decide on a course of action, to find an answer to a given question or to reach a well-reasoned conclusion (Shavelson, Zlatkin-Troitschanskaia, & Mariño, 2018). It involves open-minded and self-regulated thinking about alternative solutions and perspectives as well as possible consequences. Educating critical thinkers means working towards this ideal. For the purposes of this chapter, the distinction between cognitive skills (i.e. procedural knowledge) and affective dispositions is theoretically important.

Researchers differ on the question of whether critical thinking is a general or generic skill that can be taught and applied across science disciplines or whether it is domain-specific (Bailin & Siegel, 2003; Banta & Pike, 2012; Barrie, 2006; Oljar & Koukal, 2019; Shavelson, 2018). In addition, there is research evidence that academics' views on teaching generic skills, such as critical thinking, vary (Barrie 2006, 2007). According to Barrie's (2006, 2007) phenomenographic analysis, some academics do not agree that teaching of generic skills is their responsibility. They assume that students have these skills already when they enter university. In addition, while for some academics this seems to be an issue of personal skills that are not related to domain-specific knowledge, others claim that critical thinking skills let students make use of or apply domain-specific knowledge (Barrie, 2006, 2007). Some academics have even claimed that critical thinking depends on domain expertise and thus cannot be assessed outside of the content of the discipline (see debate in Fischer, Chinn, Engelmann, & Osborne, 2018).

We are thus led to a complex question. If we deny the possibility of developing more general critical thinking that can be transferred from one science domain to another, how can we promote it is as a vital competence for participating as a citizen in democratic society (Shavelson, 2018)? The interpretation of critical thinking as domain-specific in nature leads to the idea that critical thinking is all only for experts. This notion is inconsistent with the basic idea of the modern critical thinking tradition which promotes critical thinking as a foundation for participating in democracies and thus applicable for all citizens. However, it seems to us that this kind of dichotomy is unnecessary. Learning to think critically is a complex process in which both domain-specific knowledge and generic thinking skills are needed (Hyytinen, Toom, & Postareff, 2018). Critical thinking demands the use of both declarative and procedural knowledge; i.e., students need some knowledge about the phenomenon before they can think about it critically. However, students need, at the same time, to possess necessary procedural and strategic knowledge to apply that declarative knowledge in context (Halpern, 2014; Hyytinen & Toom, 2019; Segalàs, Mulder, & Ferrer-Balas, 2012). In a similar vein, Bailin and Siegel (2003) have pointed out that although critical thinking is always connected to a particular context and it involves, to some extent, domain-specific knowledge, it does not follow that nothing general can be said about this issue. To a certain extent, the core elements of critical thinking are generalisable and applicable across different domains (cf. Siegel, 1991; Oljar & Koukal, 2019). However, it seems reasonable to suggest there are domain-specific differences as to what critical thinking skills and dispositions are promoted during university studies.

There are several ways to interpret scientific thinking and critical thinking and their relationship. In general, scientific thinking and critical thinking overlap considerably with the demand for evidence for knowledge claims and action. However, on the one hand, in the Finnish higher education context, the term scientific thinking is a more commonly used term than critical thinking and sometimes these terms are used interchangeably. In this view, critical thinking is understood as a sub-component of the general competence of scientific thinking. However, on the other hand, critical thinking can be understood as a foundation for scientific thinking, following that scientific thinking is perceived as a narrower concept. In this view, scientific thinking is used to describe evidence-based thinking in science, social science, humanities, education and business. This kind of view is emphasised in Europe, but not in the USA. In this chapter, we understand critical thinking in a broader sense. We view critical thinking as extending to the natural and social sciences and the humanities with an understanding of the unique application in each theoretically and methodologically (cf. Niiniluoto, 1980, 1984; Trigg, 2001).

## Why Do University Students Need to Be Able to Think Critically?

Scientific research is intended to produce new information and new understandings and to explain the world around us. However, this does not mean that research can provide certain or final answers (cf. Niiniluoto, 1999). Research is an ongoing process of correcting and refining current conceptions and theories. The same kind of open-minded attitude is required from university students. University teachers in Western countries hope that students are engaged actively not listening passively, accepting everything they see and hear. Rather students are encouraged to think actively, to ask questions and to consider the reasons behind the arguments presented. Academic education cannot thus consist of information on a subject major only, but must also include the thinking skills for using that information. Students need to think critically to construct and situationally apply knowledge and understanding.

Critical thinking is needed to theoretically and conceptually elaborate on the phenomenon being investigated, to gather and assess relevant scientific data and information, to use abstract scientific ideas to interpret them effectively, to come to well-reasoned scientific conclusions and solutions, testing them against relevant criteria and standards, as well as to communicate effectively with others in proposing solutions to complex scientific problems and understanding relationships between theory and practice (Niiniluoto, 1980, 1984, 1999; Paul & Elder, 2008). Critical thinking also goes with inquiry and encourages thinking rather than accepting what told. "The heart of education lies exactly where traditional advocates of a liberal education always said it was – in the processes of inquiry, learning and thinking rather than in the accumulation of disjointed skills and senescent information", as APA's Delphi report (1990, p. 2) sums up.

It is not surprising that critical thinking is promoted as an educational ideal (Arum & Roksa, 2011; Halpern, 2014). Critical thinking is essential as a tool of inquiry and learning and vice versa. Thus, it forms the foundation for scientific thinking. As such, critical thinking is also a liberating force in education and a powerful resource in one's professional and personal life (APA's Delphi report, 1990). While not synonymous with personal traits, critical thinking can be grasped in terms of intellectual resources (see Bailin et al., 1999). Critical thinking is not something inborn either; we can learn to think critically and teach it (Halpern, 2014). Critical thinking skills are also so-called transferable skills needed beyond academia, i.e., in the working world and civic life (e.g. Hyytinen et al., 2018; Shavelson, 2010a).

Critical thinking has been found to be an essential factor for university students in progressing successfully through their studies (Arum & Roksa, 2011; Badcock, Pattison, & Harris, 2010; Utriainen, Marttunen, Kallio, & Tynjälä, 2016). Problems with critical thinking and reasoning may not only affect the quality of learning, but the inability to think critically can cause significant delays in studies (Arum & Roksa, 2011). Although the importance of teaching critical thinking is widely promoted, there is evidence that higher education students differ in their ability to think critically (e.g. Arum & Roksa, 2011; Evens, Verburgh, & Elen, 2013; Hyytinen, Nissinen, Ursin, Toom, & Lindblom-Ylänne, 2015; Hyytinen, Löfström, & Lindblom-Ylänne, 2017; Hyytinen et al., 2018). While many students progress in these skills during their university studies, Arum and Roksa (2011) found that many students do not learn to think critically during university education.

In summary, university students need, at least, to be able to think critically to engage reasonably in democratic society, to do science, and to pose questions and problems as well as evaluate knowledge independently rather than repeating what has been told. Critical thinking captures the essential thinking and reasoning skills and thus forms a basis for scientific thinking. Critical thinking has also been found to be essential for learning and progressing in higher education and it can be learned as an intellectual resource.

## Teaching Critical Thinking in a Way that also Develops Scientific Thinking and Academic Competence

Educational researchers agree on the features of learning activities that would promote learning to think critically. These features include: facing open-ended problems, encountering real-world complexity, utilising multiple knowledge sources, developing knowledge artefacts to explicate thinking, utilising collective efforts and group resources instead of favouring individual student work, integrating rich use of modern technologies into the work processes (e.g. Bereiter, 2002; Brooks & Everett, 2009; Marton & Trigwell, 2000; Mills-Dick & Hull, 2011; Phielix, Prins, Kirschner, Erkens, & Jaspers, 2011), and teamwork, project work and multidisciplinary collaboration (Denton & McDonagh, 2005). Moreover, a number of pedagogical models have been suggested for promoting critical thinking. This includes problem-based learning (Dunlap, 2005; Hmelo-Silver, 2004), project-based learning (Bell, 2010; Helle et al., 2006), inquiry-based learning (Hofstein, Shore, & Kipnis, 2004), learning by design (Healy, 2008; Vartiainen, Liljeström, & Enkenberg, 2012), cooperative learning (Gillies, 2004), short novels and discussion borne out of the problems/questions encountered in narrative fiction (Tomperi, 2017) and concept maps (see Ruiz-Primo, Schultz, & Shavelson, 2001). In this way students encounter the complexity of the phenomena being explored, search and evaluate a variety of knowledge sources, define the core problems to be solved, and based on thorough elaboration, formulate justifications for the solutions based on the knowledge sources.

Focusing on a single teaching method, such as problem-based learning, however, is not adequate. Rather, how we use the various pedagogical methods is more crucial than the methods themselves. If higher education is to contribute to the development of critical thinking, the whole teaching-learning environment needs to be purposefully designed to that end (Arum & Roksa, 2011; Halpern, 2014). Moreover, teaching critical thinking needs to be built by combining both bottom-up (i.e. student-driven) and top-down (i.e. teacher-driven) approaches to teaching (Neisser, 1967) as well as by modelling reasoning or using realistic and authentic dilemmas and tasks (Shavelson, 2018). Teaching and learning need to be intertwined in solving real scientific mono- or multidisciplinary problems and questions. According to Bailin et al. (1999), teaching critical thinking should contain at least the following three components in a variety of learning situations in order to support the growth of students' intellectual thinking and to reach the core of critical thinking:

1. Engaging students in dealing with tasks that require reasoned judgement or assessment.
2. Helping students develop intellectual resources for dealing with these tasks.
3. Providing an environment in which critical thinking is valued and students are encouraged and supported in their attempts to think critically and engage in critical discussion.

Learning occurs when teaching critical thinking is explicitly embedded in several courses throughout the curriculum and provides feedback that informs students as how to improve and build their critical thinking skills (e.g. Abrami et al., 2008; Arum & Roksa, 2011; Halpern, 2014; Krolak-Schwerdt, Pitten Cate, & Hörstermann, 2018; Shavelson, 2018).

The development of critical thinking also requires teaching and learning activities that support metacognitive monitoring of thinking processes (Halpern, 2014; Virtanen & Tynjälä, 2018). Arum and Roksa's (2011) longitudinal study showed that putting significant effort into studying, having teachers who hold high expectations and share collective responsibility for learning, and offer courses that require rigorous academic work, are associated with improved performance on tasks requiring critical thinking, complex reasoning and written communication. Teaching that involves student collaboration and interaction has been shown to support the acquisition of critical thinking, problem-solving, and decision-making (Virtanen & Tynjälä, 2018). In contrast, lecturing and working alone were negatively related to learning such skills. Furthermore, teaching critical thinking can fail if it is not connected to disciplinary knowledge and practices (Samarapungavan, 2018).

Teaching students to think critically, then, requires holistic approaches that unify subject-matter learning, critical thinking and metacognitive skills. One challenge associated with this holistic view is for teachers to realise that the question is one of *how to teach* and not just *what to teach.* Yet higher education teachers are not necessarily well prepared to teach and assess critical thinking in a way that best supports the growth of students' understanding and reasoning skills. The evidence shows that there is a huge variation between teachers (Ayala et al., 2008; Barrie, 2006, 2007; Shavelson, 2018). Most teachers, then, will have to learn to teach differently.

A related challenge is that teachers resist change. From the holistic perspective, teachers need incentives to take risks in changing. Otherwise, why would they change what they know "works": teaching declarative knowledge top down?

## Anchoring Critical Thinking to the Curriculum

The discussion concerning teaching critical thinking could easily remain abstract or focus on certain specific teaching methods, assignments, taxonomies or tools. This is not our intent. More attention should be paid to the coherence of the curriculum and systematic integration of learning critical thinking throughout students' studies. Virtanen and Tynjälä's (2018) research showed that learning to think critically is a long process involving various teaching methods. An ability to think critically needs to be practised in multiple different contexts, on various tasks, combining theory and practice, alone, and together with others, and over time (cf. Arum & Roksa, 2011; Virtanen & Tynjälä, 2018). Students learning to think critically depends on how critical thinking is taught; students learn what they do (Biggs & Tang, 2009). Consequently, teaching critical thinking needs to be aligned at a programme level. This means that learning to think critically should be expressed in learning outcomes, and its learning needs to be taken into account systematically in teaching methods, students' assignments and in assessment aligned with learning outcomes (cf. Abrami et al., 2008). It is important that such learning is integrated in domain-specific courses; otherwise, it might remain separate and superficial in its core aspects.

Addressing critical thinking solely in a specialised course or relying solely on one specific teaching method is inadequate (Virtanen & Tynjälä, 2018). Moreover, the risk is that teaching critical thinking will remain an incidental or isolated topic, if not integrated into learning goals, various teaching practices and assessment in courses across the curriculum. The same risk appears if teaching decisions are left up to individual teachers of varying views of what is important to teach in their classes and how to do so. Successful integration at the curriculum level involves collaboration between teachers. Teachers need to be ready to synchronise their courses among each other in a way that supports the attainment of learning outcomes (Arum & Roksa, 2011; Jenert, 2014).

Critical thinking is an important part of scientific thinking, since it captures the core thinking and reasoning skills as described earlier. It also paves the way for students to progress in their higher education studies and enhance their academic competence. At the individual teacher level, critical thinking needs to be integrated into teaching goals, student in and out of class activities, and outcomes. At a department or institutional level, critical thinking needs to be integrated into the curriculum across teachers, courses within and across departments (cf. Arum & Roksa, 2011; Toom, 2017).

## Conclusion

The aim of teaching students to think critically is consistent with the epistemological ideal of rationality (Holma & Hyytinen, 2015; Oljar & Koukal, 2019). Critical thinking can be understood as a life skill that is applicable across disciplines (Oljar & Koukal, 2019). A critical thinker needs to have knowledge of what is reasonable, the thinking skills to evaluate and use that knowledge, as well as dispositions to do so (Facione, 1990; Halpern, 2014; Hyytinen et al., 2015). Critical thinking also makes possible the assessment, evaluation, synthesis and interpretation of relevant scientific theories and empirical knowledge. It is context and action-oriented in solving problems, deciding on a course of action, reaching well-reasoned conclusions and solutions, testing them against relevant criteria and standards and communicating them effectively to others (Niiniluoto 1980, 1984; Paul & Elder, 2008; Rapanta, Garcia-Mila, & Gilabert, 2013; Shavelson, 2010b). This is all necessary if we want to educate skilful, competent students in an academic domain as well as educate them to become autonomous citizens of the twenty-first century and develop their scientific thinking skills.

Students begin to learn to think critically when their teaching is explicitly integrated into one domain-specific course. But to be effective it needs to be integrated into courses throughout the curriculum. Critical thinking is learned when domain-specific, procedural and self-regulative knowledge are connected with each other, as well as when teaching and learning activities set tasks for students to construct knowledge and skills in complex situations. Students need to put significant effort into learning to think critically, by studying and working alone and together (e.g. Arum & Roksa, 2011; Muukkonen et al., 2017; Samarapungavan, 2018; Toom, 2017; Virtanen & Tynjälä, 2018).

Critical thinking, then, should be recognised as an important outcome of higher education; curricula and course outlines should be aligned to produce this outcome. This is the only way to prevent critical thinking teaching from becoming incidental in a random selection of courses. In order to provide sufficient coverage and alignment, study programmes need to be viewed as a whole. Teachers need to recognise that they have an individual and a collective responsibility for teaching students to think critically. Teachers also need to have a clear understanding of what critical thinking is and why it is important to teach. They should have the pedagogical competence to integrate thinking to various disciplinary topics and utilise a variety of teaching and assessment methods to enhance it. Finally, teachers need administrative and peer support in developing pedagogical competencies that enable them to ingrate the elements of critical thinking and reasoning in their teaching practices (Arum & Roksa, 2011; Jenert, 2014).

We have a lot to learn about teaching and learning to think critically. For example, a complex issue still to be understood is how students' critical thinking develops during higher education when it is anchored to the curriculum. Is the development process faster than what is currently the case? What kind of associations can be found between student learning to think critically, teachers' teaching and characteristics of learning environment? How do students learn the skills related to critical and scientific thinking, how do they progress in these skills and how does the mastery of certain skills enhance mastery of others? In addition, we might ask, what are the threshold skills and dispositions that should be learned during higher education? That is, which qualities are necessary for becoming and being a critical thinker in school, at work, and throughout life? Furthermore, how do domain-general or domain-specific competencies impact critical thinking, and what kind of variation–if any–can be found between the domains? How do all these factors influence higher education in students' thinking and reasoning skills? Finally, we need to understand similarities and variations in the pedagogical competencies to teach critical and scientific thinking among academics in different disciplines and support teachers in developing these competencies.

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# 4

# Evidenced-Based Thinking for Scientific Thinking

Rebecca Shargel and Lisa Twiss

## Introduction

If universities are to produce educated citizens, then professors are tasked with teaching scientific thinking skills, including formulating and supporting arguments with credible evidence. Our concern is that students are inundated with information and frequently lack the skills to discern between reliable and unreliable sources. Though they are accustomed to reading sources online, we noticed that they tend to believe written information without questioning. In order to navigate complex problems and make informed choices in both their academic and personal lives, they must develop competencies in *evidenced-based thinking*. Particularly, as university students begin their undergraduate studies, they need to cultivate the skills to search for evidence, evaluate it, and then use it in their

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arguments; these tripartite skills make up our definition of evidenced-based thinking, which is an important component of scientific thinking.

Our purpose is to highlight an approach to evidenced-based thinking through an innovative pedagogy which was part of the research discussed in this chapter. As a result of learning and using a typology of evidence, students' grew in their understanding and use of evidence to support arguments. We provide recommendations for instructors who seek to incorporate this new pedagogy into their teaching of university courses.

## Critical Thinking

As Hyytinen, Toom, and Shavelson discussed in Chapter 3 of this book, critical thinking can be defined in many ways (Lai, 2011) and involves complex skills to follow reasons and evidence, question information, tolerate new ideas and clarity of thought, and interpret information and perspectives (Pascarella & Terenzini, 2005). It is one important dimension of scientific thinking because with critical thinking, students learn to become competent at skilled argumentation, a foundational tenet of scientific thinking. The Association of America Colleges and Universities adds to the definition of critical thinking such skills as "inductive and deductive reasoning, identifying assumptions and hypotheses, drawing conclusions, extrapolating inferences and understanding implications" (Liu, Mao, Frankel, & Xu, 2016, p. 678). Paul and Elder's (2006) work specifies approaches that critical thinkers use inside and outside the classroom. They emphasise thinking "aimed at well-founded judgement, utilizing appropriate evaluative standards … to determine the true worth, merit, or value of something" (Paul & Elder, 2006, p. xx). Fisher (2007) sees critical thinking as evaluative thinking which requires students to reason in order to produce an argument that supports "a belief or course of action" (p. 13). Put simply critical thinking is "the art of taking charge of your own mind" and life (criticalthinking.org, para. 13).

## Importance of Critical Thinking

Why is critical thinking so valuable? Critical thinking is a foundational cornerstone of scientific thinking that provides students with abilities to weigh up and evaluate information in order to make sound judgements. Today, more than ever, this is important as students are inundated with information and need critical faculties to evaluate the vast information that they consume. Without thinking critically, they are unable to examine multiple sides to an argument. They may also fall prey to false, distorted, or biased information which could result in rash decision-making. Moreover, critical thinkers are essential to perpetuating a democracy because they carefully weigh options prior to voting and make decisions based on reasons and evidence, rather than just impulse (Paul & Elder, 2006).

## University Students and Critical Thinking

The ability to think critically is considered one of the most important goals of higher education (AAC&U, 2011; Bok, 2006; Hyytinen, Holma, Toom, Shavelson, & Lindblom-Ylänne, 2014) and fundamental to scientific thinking because bringing forth reasoning and evidence are key skills in developing skilled argumentation.

In a survey by the Association of America Colleges and Universities, 95% of chief academic officers believed that critical thinking is a top learning outcome for university graduates, only second to writing (AAC&U, 2011). Despite the high premium put on critical thinking in higher education, many studies demonstrate that many students do not develop critical thinking skills during their studies in university (Bok, 2006; Pascarella, Blaich, Martin, & Hanson, 2011). For example, Arum and Roksa's (2011) large-scale study demonstrated that many undergraduates show "no statistically significant gains in critical thinking, complex reasoning, and writing skills for at least 45 percent of the students in [their] study" (p. 36).

Critical thinking, as a subset of scientific thinking, has also become a goal for an entire university campus. Faculty at Washington State University (WSU) lamented students' lack of critical thinking (Condon & Kelly-Riley, 2004) and this deficit became evident in faculty's assessment of undergraduate student writing. In order to improve students' critical thinking skills, faculty used grant funds to create a critical thinking framework to apply across subjects throughout the university (Condon & Kelly-Riley, 2004). Faculty developed a framework which included key critical thinking skills such as problem identification, establishment of a clear perspective, and recognising alternative perspectives, and identifying evidence. The framework was disseminated to hundreds of instructors resulting in clearer expectations and goals for teaching critical thinking across a range of disciplines. This new framework helped them design their assignments to include the aforementioned critical thinking skills.

Like faculty of WSU, we found that many of our own students lacked critical thinking skills, which has problematic implications for their overall development of scientific thinking skills. This problem was the catalyst for the study presented in this chapter. When faced with the task of articulating arguments and evidence in reading, first-year university students struggled to provide sufficient evidence to support an argument. For example, "Jane" read two articles, one for class size reduction and the other against it. When attempting to provide evidence for the advantages or disadvantages of class size reduction, Jane cited one statistic from the Tennessee STAR project[1] about how reducing class size improved test scores for third graders (Biddle & Berliner, 2002). She could not provide any more details to support her argument.

Compounding this problem, despite the existence of frameworks such as those developed at WSU (Condon & Kelly-Riley, 2004) is that many university faculty do not have the tools to *teach* critical thinking; in fact studies have demonstrated that both school teachers and university professors lack knowledge of how to teach critical thinking (Alwehaibi, 2012). We noticed that many first-year students' courses employed exclusively lecture and lower level tasks; in parallel seminar classes, we find that our colleagues emphasised locating articles, citing them correctly and produc-

[1]The Tennessee STAR project was a large-scale research study that examined the correlation between reducing class sizes and student achievement. It found that there were positive effects in reducing class size. The intervention occurred in the 1980s in the American state of Tennessee and this longitudinal study measured students' progress through the end of their secondary education (in US terms, twelfth grade).

ing a correctly formatted paper more of a priority than teaching students how to use evidence to support an argument.

We also found in the departmental data (technology department, state university), that breaks down grades within the final papers, that several years prior to our intervention, students, numbering in the hundreds across dozens of sections, scored lowest in critical thinking. In this chapter, we provide a pedagogical tool, a typology of evidence that we used to foster analytical thinking about the sources that students were reading.

## Evidenced-Based Thinking

One important aspect of critical thinking is evidenced-based thinking. Evidenced-based thinking and decision-making skills are at the core competencies of a university education. Evidenced-based thinking involves locating appropriate sources for writing research papers and developing arguments. We derive this concept from the literature on critical thinking that identifies locating and using evidence as a discrete skill of critical thinking (Lai, 2011; Pascarella & Terenzini, 2005).

Evidenced-based thinking is part of critical thinking which involves identifying, evaluating, and using evidence. Though critical thinking has many aspects, we identified teaching the skill of *evidenced-based thinking* as our focus for first-year undergraduate students.

How does this pursuit, examination, and use of evidence connect to scientific thinking? "By promoting scientific thinking, educators can ensure that students are at least exposed to the basic tenets of what makes a good argument [and] how to create their own arguments…" (Schmaltz, Jansen, & Wenckowski, 2017, p. 1). Students must learn to formulate arguments supported with evidence that they locate, evaluate, and then utilise. In Fig. 4.1, we present evidenced-based thinking as a nestled skill inside of critical thinking and scientific thinking. These skills are not only nestled inside of each other, but they are dependent upon one another. Critical thinking fits into the greater picture of scientific thinking, particularly because it gives students the ability to reason logically by using evidence to skilfully develop arguments.

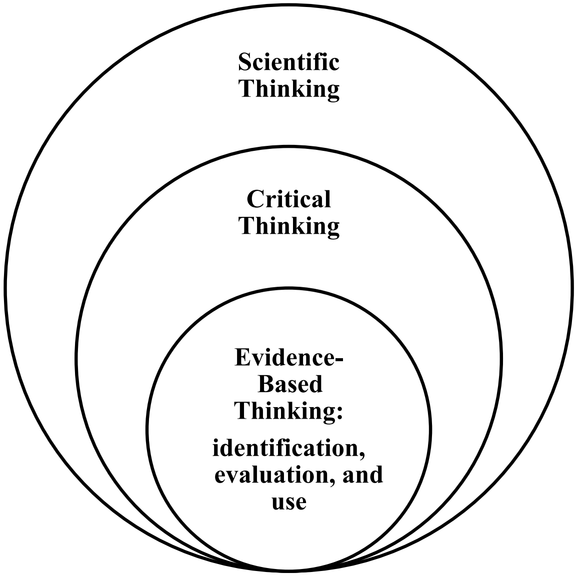


**Fig. 4.1** Relationship between evidenced-based thinking and scientific thinking

## Context for the Study

In order to sharpen the focus on critical thinking, so students could develop their scientific thinking skills, we designed our course to emphasise the use of evidence to support arguments. The entire course was geared towards students writing an argumentative research paper, where they used evidence to support arguments of their choice. They selected controversial topics related to education; their topics spanned several fields and included areas such as educational technology, single-sex education, disciplinary policies, or inclusion of special needs students.

We created a number of in-class and out-of-class activities and readings for students to practise the skill of using evidence to support their claims. Among other sources, students learned to locate evidence in research studies through the university's databases, as well as reputable news articles. Students also learned to evaluate sources through such criteria as the author's credentials, date of publication, audience, and biases. Moreover, they identified arguments and counterarguments and formulated their own arguments based on their readings. They also watched videos, debated, and participated in simulated investigations where the use of evidence was imperative to make sound conclusions. These activities, and the course itself emphasised the practice of skilled argumentation, a key aspect of scientific thinking.

## Typology of Evidence

To structure evidenced-based thinking, we developed a typology of evidence. This provided language to categorise and to discern between types of evidence that they would use in their research papers. We taught students to identify five different types of evidence in order for them to understand different types of purpose and value of evidence. The types of evidence included:

- Statistical: Evidence from statistical studies that emphasised numbers
- Qualitative: Evidence from observational research with small numbers of participants
- Anecdotal: Stories coming particularly from vetted news sources as well as from their own personal experiences or those of others they knew
- Legal: Evidence from laws or court cases
- Expert opinion: Evidence from an expert in the field

The typology provided students with areas of focus for their sources. For example, when reading empirical studies, they learned to discern between statistical and qualitative evidence. They built their arguments on the findings of such studies. In addition, when reading news stories, they gleaned anecdotal evidence to support their arguments. For making arguments about the legal dimensions of schooling, they referenced laws or court cases.

This typology was developed to help alleviate students' confusion about the different types of evidence. First-year students who had training using evidence beyond personal opinions were habituated to look for statistical evidence and were not aware of other types of evidence early on in the semester. We realised that their sole reliance on statistical evidence was limited. In order to broaden the palate of viable sources of evidence, we created a typology to serve as a menu from which they could select different types of information in order to support their arguments. It also served as a lens to look for and understand information beyond statistics. The types of evidence could be applied to a variety of disciplines.

Underlying implementation of the framework was a belief that students would learn to think more critically if they have practise "solving problems, synthesizing data, and evaluating evidence as a regular part of their coursework" (Lemons, Reynolds, Curtin-Soyden, & Bissell, 2013, p. 53). In addition, we corroborated with the idea that university professors need more "systemic direct instruction aimed at developing effective critical thinking skills" (Alwehaibi, 2012, p. 193). We believe that this framework provides an intentional teaching strategy to instruct students in evidenced-based thinking in order for students to more skilfully argue their points and develop competencies in scientific thinking.

## The Case Study

This study focused on the use of the typology of evidence and its influence on students' evidenced-based thinking and ultimately scientific thinking It explored university students' understandings of evidence to support their arguments and occurred over the course of four discrete fifteen-week semesters, from the autumn of 2014 through the spring of 2016. Each section was comprised of approximately 20 students enrolled in eight sections totalling 160 students. This study was approved by Towson University's Institutional Review Board. We explored these questions:

1. In what ways did students describe different types of evidence?
2. How did students use evidence?
3. How did students' thinking about evidence shift over the semester?

## Methodology

Data were collected through the following sources, focus groups, observation, and student work. In addition, we observed students' learning of the typology during in-class discussion and activities. We collected written work in the form of ongoing short writing pieces. In addition, students completed midterm and final papers; the midterm was their literature review as a work-in-progress and subsequently, the final paper was the completed literature review in its final form. One significant piece of writing occurred at the end of the semester, when students composed a letter to an incoming first-year student describing the different types of evidence and substantiating them with examples from their own final papers. Students also described the types of evidence they relied most on to support their arguments in their final papers. They responded to these questions:

- What does it mean to use evidence to support an argument?
- What types of evidence could one use to write a paper?
- Give an example of the best evidence that you used in your paper to support a reason. Explain why this is the best evidence and how you used it in your paper to support your thesis.

As a smaller sample of each class, we traced the perceptions of students, who volunteered to participate in focus groups. Each semester, approximately seven students per section, with two or three sections participating at a time, volunteered to participate in two focus groups, one in the middle of the semester with the second at the end of the semester. In total there were 62 students who participated in these focus groups (out of 160 total in the study). In these focus groups, we asked students questions about the types of evidence they found most reliable for their midterm and final paper; these were audio-recorded and transcribed. Questions included:

- Have you used evidence in your life recently? If so, how?
- What was the best evidence that you found from your paper to back up your thesis and why did you choose that as the best evidence?

We employed a constant comparative method (Merriam & Tisdell, 2016) for coding the data. We imported the data from focus group transcripts and students' written work into *NVivo10*, a qualitative research software. We assigned codes to tag phrases and sentences in both transcripts and students' work in order to triangulate data. Over time, those codes were consolidated into categories, and out of those categories, themes that addressed the research questions were developed.

## Findings

Students' descriptions and preferences of the types of evidence detailed below suggests that they began to develop a deeper understanding of different types of evidence as well as valued what each type of evidence could bring to an argument. By learning and using the typology, students broadened their horizons by learning to seek information from different sources, such as stories, laws, and qualitative research. They overcame their prior inclinations and preferences with regard to information and they improved their abilities to argue skilfully, which is a core component to scientific thinking. The findings below show that in some cases students' preferences changed over the course which indicated that they appreciated the appeal of logic as well as emotion.

### Describing Statistical Evidence

Students described the different types of evidence and most frequently referred to statistical evidence. We found that students relied mostly on qualitative and statistical evidence more than the other types. They found statistical evidence trustworthy and described it as: "hard facts", "solid", "unbiased", "tested", and "data". Many had prior experience with statistics in their education prior to university. One student reflected, "In high school there were always statistics, statistics, and statistics!" She remembered that her teachers emphasised statistics as viable proof and she, like many others, entered university predisposed to perceiving statistics as reliable. Another student reflected: "The best evidence I used in my paper was statistical because statistical evidence tends to use numbers and graphs that are easy to read and gives you a clear perspective of the information presented". Statements like these revealed that, for some students, the appeal of statistical evidence was their preference to read numerical displays of information because they found it clear. Enthusiasts favoured statistics because they favoured numerical displays such as charts and tables over text.

Many students who favoured statistical evidence described themselves as "numbers or math people" or "visual learners". Some of these students' expressed their faith in statistics in their repeated refrain: "numbers don't lie". While some had learned to question the absolute reliability of statistical information, particularly if they had enrolled in a course in statistics, most began the semester seeing them as "true".

Additionally, students reported that statistical evidence was unbiased and "shocking," meaning surprising and attention-grabbing, and generalisable to other situations. For example, one student claimed statistical evidence was indisputable with "only one way to interpret it". According to another student "with statistical information, it's more clear cut and you are able to generalise from it; it is easier for the reader to understand numbers versus a story".

## Describing Qualitative Evidence

The second most frequently described type of evidence came from qualitative research. Students described qualitative evidence as personal and based on human experience. They appreciated the researcher's role in observing and interviewing participants. To exemplify, one student described how she found qualitative evidence appealing because of its holistic dimensions of the interviewer being able to see the participants' expressions and body language as further cues to feelings behind the words:

> Qualitative evidence is most reliable to me. I believe this because qualitative allows researchers to hear what participants really think and believe. The participants don't have to choose how they feel from a list of choices [as in survey research]--they can just speak freely. The researcher can also examine things like body language and facial expressions to help better grasp

the participant's emotions. The researcher gets to physically observe the environment in which they are researching.

Not only did she appreciate researchers' ability to "read" participants' feelings but also contrasted the authenticity of collecting information from interviews as opposed to forced answers in a survey format. Like the aforementioned student, many others appreciated the authenticity of a qualitative researcher since the researcher can observe participants in their natural setting and can see their behaviour and expressions within their everyday lives.

One of our most unexpected findings was that students described gathering qualitative research by stepping into the shoes of the researcher. Students frequently used the word "you" to describe the researcher. For example, one student noted, "I like in qualitative [research] you're able to interact with them [participants] on a personal level". In contrast, those same students described statistical research, using the third person "they", when describing quantitative researchers, students used the second person "you" when describing qualitative researchers. We found their use of "you" in describing qualitative researchers to indicate that they identified with qualitative researchers—perhaps even filling their shoes by imagining themselves enacting the role of a qualitative researcher by observing and interviewing participants.

Some students also recognised the benefits of qualitative research when it came to understanding data. For example, one student described the best evidence in her final literature review, which argued for the benefits of one-to-one computer learning for academic achievement. She remarked that in reading this particular qualitative research study, the researchers observed students using technology. In her opinion, this provided evidence that was superior to statistical studies focused on improved student learning. She found the observational aspect of qualitative researcher superior to tables and charts because that demonstrated a more meaningful representation of improved student learning through technology. According to the participant, "The researchers got to see… how the students got excited and showed their peers what they did on their computers. You can't do that with numbers."

## Describing Anecdotal Evidence

Personal stories and accounts of first-hand witnesses were the primary descriptors of this type of evidence, which appealed to them, particularly because they appreciated the perspectives of those telling the stories. Students said they could identify with the personal stories and found them convincing and supportive of their arguments. For example, one student researched zero tolerance policies, which denotes strict punishments for acts committed in schools, whether students acted out of intention or forgetfulness. To introduce his argument, he relied upon a news story about a fourth-grade boy who kissed a girl in the school playground and was then suspended.

> I thought this [story] was powerful because it showed that nine year olds kissing is not a viable reason for the boy to be suspended. This anecdotal evidence supported my thesis because I think that the policy of zero tolerance is harsh [by punishing children for] minor incidents.

He found this example persuasive and used it in his final paper to make the case that those zero tolerance policies are misused and overly punitive.

## Describing Expert Opinion and Legal Evidence

Compared to statistical, qualitative, and anecdotal evidence, students did not provide rich definitions for expert opinions nor legal evidence. We observed that students were familiar with the concept of legal evidence, particularly as seen in television shows that showed characters dealing with the law.

We speculate that students' lack of mentioning expert opinion and legal evidence was most likely a result of our emphasis on empirical research and the qualities of statistical and qualitative research. However, the data showed that some students appreciated expert opinions because they found that seasoned professionals had good advice on the topic at hand. A few did use legal evidence, particularly by citing laws dictating policy in education, particularly when researching special education, but few referenced this at all in their reflection on the best evidence used in their papers.

When students described evidence, they also explained the appeal of different types. For the most part, statistical and qualitative evidence most appealed to them. This was because they believed statistics contained "hard facts" and "the truth", and qualitative evidence, with its direct involvement with participants, was valuable in regards to feeling more connected to the research. Students also valued anecdotal evidence, especially from news sources, because they found personal stories the most compelling.

## Uses of Evidence

As mentioned earlier, the culminating assignment for the seminar was an argumentative research paper. Participants in this study talked about their experience learning about how to evaluate sources. They also shared how they used information from a variety of sources to support their arguments. Findings from this research showed that students used evidence in two ways: supporting an argument and combining types of evidence to make an even stronger argument. These findings show the development of students' scientific thinking in that they increased their sophistication around ways to support an argument through the use of evidence. Moreover, these findings showed students' changing notions of evidence and highlighted their thinking about their own thinking about evidence.

**Supporting an Argument**. One way students demonstrated evidenced-based thinking was through their use of evidence to support their argument. Students reported that in high school, prior to this course, they were accustomed to 'drop in' a few quotes from an online source, such as Wikipedia or cursory glances from Google, with little discernment. Some admitted that in high school, they habitually inserted "random quotes" from the Internet.

Yet, in our class, many contrasted their prior habits to this newfound sensibility; they described using facts and arguments from research studies to bolster their arguments in their papers. They learned to become more deliberate at mining research articles for information to support their arguments. They perused news sources to find stories that would make their arguments more compelling. They demonstrated a new sensibility to hunt for credible sources to support their ideas.

They explained their process of gathering information by using the phrase "back up" to indicate gathering information to support their points. For example, "I usually 'go for' [pursue] quantitative evidence, because it has numbers and statistical evidence to *back up* what they [the researchers] are saying".

**Combining Types of Evidence**. By the end of the semester, students found that combining sources strengthened their argument and helped them build a stronger case. They acknowledged that sometimes one type was not enough on its own, and that a better argument was made when multiple types of evidence were used. One student explained how qualitative and quantitative evidence each bring value to an argument:

> I believe that qualitative and quantitative evidence go hand in hand. I think that quantitative evidence provides concrete numbers that … can determine something generally. But then you have the question left of *why* and that's … where qualitative research comes in hand. Because then you can talk to individual [participants in a study] and figure out why.

This student found that statistical evidence provided generalisable information but that qualitative evidence gave more insight into the reasons behind a phenomenon.

Whereas students initially thought that *one* piece of strong evidence could support their argument, students began to use evidence in complementary ways. They began to recognise how statistical evidence might convince some people of an argument, particularly those who are numbers-driven. Yet, adding anecdotal evidence, too, could capture the attention and persuade those who are more attracted to personal accounts. Over the course of a semester, this combining of evidence became more of a common practice for our students.

Some students even noted that one type of evidence could serve as a launching pad for another. For example, one student explained that a qualitative study could serve as a basis for a larger quantitative study. She illustrated it in this way:

> [Let's say] that there was a qualitative study about students' attitudes about homework. In this study a teacher went into [a] student's home and inter-

> viewed them about homework. Whatever information she got from that research, she could create a quantitative study. That would then grow it into a bigger study that could help her then generalise to the general population.

Here the student noticed that a qualitative study could serve as a starting point for a larger study. This student intuited a process of mixed methods research, whereby one type of study could then be used as a basis to investigate further.

## Shifting Notions of Evidence

Students' notions of evidence shifted as some began the course unaware that types of evidence even existed. For example, a student noted: "I used to think of evidence as all the same. I never knew there were different types of evidence. But then [this course] taught me that there's more than just evidence. There are types, like qualitative, anecdotal. Like a bunch of different types." Furthermore, students notions of evidence shifted as they increased their questioning and became more sceptical of information. They also moved beyond solely relying on statistics and enlarging their scope of evidence. Prior to our course, students admitted that they often believed what they were told or what they read. As a result of learning and practising using the typology of evidence, students no longer accepted evidence at face value; they began to question it more and seek more information to confirm the veracity of a statement. Over the course of the semesters, students began to question different types of evidence. We were impressed by a dramatic shift in their perceptions from complete faith in statistics to overt questioning of them. For example, a student argued that the use of computer tablets benefits students' learning in the classroom. She found that qualitative studies provided her more meaningful evidence than statistical studies because:

> Observing students using technology is better than having numbers [because in qualitative research] … the researchers got to see their [the participants'] reactions and how quickly they adapted. They see how a lot of students get excited and show their peers what they did on their tablet. You can't [show that excitement] with numbers. Also, surveys could be confusing. If you're a

> kid and your answer is not on the survey-- you could get confused. [But] If you are interviewing them, they can tell you exactly what they are thinking.

Here, the student rejected statistical evidence and chose qualitative evidence as she found that observational data documenting students' excitement and peer interactions provided richer information than numerical evidence. Moreover, the same student questioned the viability of survey research since she speculated that the mode of data collection could have confused the young participants. She preferred collecting data through interviews over surveys and defended interviewing as a direct pipeline into participants' thoughts.

Students' attitudes towards statistical evidence changed. Whereas students expressed early on in the semester in their focus groups that statistics were the "truth" or "hard facts," over time they became drawn to other types of evidence such as those found in qualitative research; as a result students shifted away from their sole reliance on numbers. Students began the course unfamiliar with qualitative or anecdotal evidence. To illustrate one student said:

> In the beginning of the semester, I was [in favour of] quantitative and statistical evidence. I respond to numbers very well and I felt like that was the best form and the most valid way to present evidence. But, throughout the semester, I've really come to appreciate qualitative and legal evidence a lot more because I feel that's more applicable to every day.

In addition, they became more sceptical of what they read. Though many admitted at the end of the semester that they began the course very gullible, believing that every source is right, over time as they researched their topics, they began to question arguments and their sources. For example, one student stated: "It's important in life that you don't just fall under their charm. You are not just believing everything you're told. You're [an] educated, ethical person within society". Indeed, this student and others began to think more critically as they began questioning sources and sought out viable evidence to use for their arguments. This evidenced-based thinking also transferred this questioning stance towards everyday life and interactions, particularly in their attitudes towards information that their friends posted on social media.

Students admitted to entering the course with little experience in judging or evaluating sources. They tended to trust their teachers, peers, or authors with no scepticism. However, the seminar course challenged them to evaluate information for themselves. One student claimed she was no longer as gullible as she used to be and many others changed as a result of the course and their exposure to a variety of perspectives, sources, and vocabulary. Students admitted that they were susceptible to believing others. For example, one student reflected:

> I used to just believe everything I heard but I wouldn't really look into it. Now, I see how important evidence is and how some evidence is reliable while other evidence is not reliable. I've learned…when I hear something and it seems [suspicious] I know to look more into it instead of just believing it.

This student explained that she discerned between reliable and unreliable evidence and that she no longer accepted others' words at face value. Her scepticism propels her to further investigate the evidence she finds suspicious.

Finally, students finished the semester with a completely different perspective about what skilled argumentation means. They were in a much stronger position to embark in scientific thinking because they had the skills to provide reasons and evidence to skilfully argue their points.

> Before this seminar, I thought of evidence in only legal or investigative terms but now I think of it as a means to a quality paper, or quality argument. And I can now tell the difference between a credible source and a non-credible source. And I just think, when you're more aware of things having evidence or not having evidence. Like you're willing to gain a better understanding of something, rather than just hearing a fact and saying, 'Okay, that's a fact.' You're more thinking in broader terms of things.

## Discussion

Based on these findings, we believe that evidenced-based thinking should be taught as an ongoing process. The participants in this study shared a range of experiences, definitions, perceptions, and preferences when it came to readings, arguments, and evidence. One class session dedicated to evidenced-based thinking will not suffice. Universities and institutes have invested much time and resources into critical thinking frameworks (Condon & Kelly-Riley, 2004; Paul & Elder, 2006) and the reason is because many students enter university with limited skills in evidenced-based thinking. Our findings showed how some students began the course never having heard of evidence, beyond legal. Therefore, it may not be feasible to expect students to master in one semester, how to find credible evidence, analyse it, and synthesise it effectively with other types of evidence to defend an original argument. They will need ongoing reinforcement in several courses to become skilled in many aspects of critical thinking, which is foundational to scientific thinking.

At the same time, we learned that evidenced-based thinking can be facilitated through tools such as the typology of evidence. The knowledge of the different types of evidence opened doors for students to better understand claims, reasons, and ways to support their arguments. The typology benefited students by broadening their horizons and perspectives to "dig" into evidence and locate something outside of their preferences. For example, some were attracted to statistical evidence at the onset of the course, while others preferred anecdotal. The typology ensured that students were exposed to and encouraged to use different types of evidence outside those with which they were familiar. University professors must provide particular tools and time to allow students to explore different perspectives and consider what and how information can be used meaningfully.

This research supported the idea that "by promoting scientific thinking, educators can ensure that students are at least exposed to the basic tenets of what makes a good argument [and] how to create their own arguments…" (Schmaltz et al., 2017, p. 1). The use of the framework offered a first-step regarding those basic tenets; it offered students the exposure to, the vocabulary, and the differentiation between evidence types to make good arguments.

Through this research we also gained deep insights into students' patterns of thinking. According to Lucariello (n.d.), diagnosing student thinking around such areas as "student learning processes, those things that are either hard or easy for students to grasp, and the errors that students commonly make" (para. 5) benefits both the teacher and student. This is because when teachers become familiar with students' thinking patterns, they are more able to effectively plan instruction. The information we collected allowed us to better understand what and how students thought about evidence, thus allowing us to think more intentionally about our work in the classroom.

Through analysing students' descriptions of evidence, we gained new insights into how first-year university students think about supporting an argument through the use of different types of information. Moreover, by studying their use of evidence, which included supporting arguments and combining different types of evidence, we gained insights into how they grew to value supporting their arguments with credible information and creatively combined different types of evidence in order to strengthen the reasons behind their claims. They also grew in their ability to argue skilfully in research papers, where they synthesised evidence from several articles. This increased their abilities to think scientifically.

## Recommendations for Teaching

Though many frameworks exist for understanding the idea of critical thinking, university faculty would benefit from more pedagogical tools to promote students' critical thinking (Alwehaibi, 2012) and ultimately scientific thinking. We believe our framework provides an inroad to teaching critical thinking skills by isolating the discrete skill of evidenced-based thinking. Not only did this framework help our students, but it could also could assist those who wish to adapt it for teaching evidenced-based thinking in their own contexts. When students have the powers to define and differentiate between the types of evidence, they are better equipped to use them intentionally and thoughtfully.

This research contributes to the pedagogy of scientific thinking, particularly with regards to ways to begin teaching evidenced-based thinking. Ultimately, this research highlights the connection between scientific thinking, critical thinking, and evidenced-based thinking. By learning and using the typology of evidence, students developed their abilities to argue more skilfully and delved into scholarly material that they had never encountered before their university studies. They also had the opportunity to use both numerical and observational data as well as stories in order to convince others of their arguments.

Particularly, by learning and using the typology, students developed a new vocabulary with which to discuss, compare, and ultimately use a variety of evidence to support different aspects of their arguments. As students became comfortable with the typology, they used new vocabulary to show the process of argumentation. Students entered the course unfamiliar with terms such as argument, claim, credible, proof and peer-reviewed. Learning to use these terms increased students' sophistication around the discussion of an issue, and it supported more substantiated argumentative writing. They articulated different types of evidence in accordance with what they learned in the course and explained when they turned to each type of evidence.

In addition to contributing to the realm of scientific thinking, this work also contributes to pedagogical literature, in that it highlights how our teaching, and ultimately student learning, changed as a result of the data we gathered. For example, despite our efforts to clearly teach a typology of evidence, we learned through the focus groups that many students had *misunderstandings* of those categories. For example, confusion existed between anecdotal evidence and qualitative research; they thought that the two were synonymous because they both involve personal accounts from participants' perspectives. As a result of hearing these confusions in focus groups, we were able to go back to the full class and re-teach the differences between qualitative and anecdotal evidence.

Here are some concrete recommendations that instructors may implement in their college classrooms:

- Early in your course, even in the first lesson, teach the framework as a complete set of five types. Provide students with definitions for each of the types of evidence.

- Instructors may make modifications according to discipline. For example, forensic science instructors may add a type of evidence called "physical evidence" denoting tangible objects found at the scene of a crime.
- Assign readings to illustrate each type of evidence. For example, teach students to read statistical and qualitative studies in order to see the type of support brought for each type of research.
- Reinforce the typology throughout your course by creating a variety of activities. For example:
  - Give students prompts such as annotating text. Have students "colour code", highlighting the argument and evidence with different colours and annotating why each section is the argument and evidence.
- Have students create figures or graphic organisers to show the relationship between the different types of evidence.
- Provide students with opportunities to evaluate the credibility of sources (i.e. newspapers, websites) including their authorship, audience, relevance, claims, sources cited, date of publication, and type of venue published.
- Create a simulation where students use different types of evidence to solve a problem. Ours is called the *Bubba Murder Mystery* where students look at different types of evidence to determine the causes of a stuffed monkey's death in their classroom. Students completed a table where they categorised each type of evidence found, including each of the five types.
- Ask students to reflect on their learning throughout the semester in order to get feedback about both their understandings and misunderstandings of the types of evidence.

Provide students the chance to work with partners to debate different sides of an issue so that they could learn viewpoints (Shargel & Laster, 2016). This can lead up to a whole class debate.

## Conclusion

This research has implications for living in the digital world, training for research skills, and vocations. We live in a media-rich, information-saturated society and critical thinking "is an essential competency that can play a significant role in shaping the way students learn and think it today's information age" (Alwehaibi, 2012, p. 193). We hope that as a result of this work, students are better equipped to evaluate the credibility of evidence in their personal lives and translate this skill from their university training to their professions. Indeed, learning scientific thinking skills is particularly important and practical for training for the professions, as studies in the training of professions demonstrate the significance of evidenced-based problem-solving (Stevens & Witkow, 2014). For example, medical students in the United States must take standardised tests. One place where this need was made obvious was in the Medical College Admissions Test. In 2015, changes were made to a portion of the test; certain questions now assess "reasoning and evidence-based problem solving (e.g., using relevant theories to explain phenomena or make new predictions)" (Stevens & Witkow, 2014, p. 115). In this way, medical students are expected to think critically through their evidenced-based thinking. Such efforts can occur across disciplines and subjects so that university students will develop the skills to think more scientifically and transfer these skills to their careers.

We have illuminated how some first-year university students think about evidence and how their notions of evidence can change when exposed to a specific typology and lessons geared towards the skill of using evidence to support an argument. Ultimately, the goal of the course was to increase students' critical thinking skills; the data shows we made strides in this area. Here is one student who speaks to the ways in which the course supported her own development of scientific thinking skills as she expressed her new scepticism and desire to research information and not take her peers' words at face value.

> Before this course I was very easily persuaded. Now I realised that there's a lot of ways people can manipulate things to make it look their way. I'm a

lot more sceptical about what people tell me. I like having a well-informed opinion, and if I care about what I'm talking about, then I'll go into it for myself and see.

Like many of our students at the end of our courses, this student took charge of making decisions and achieved critical thinking with regards to questioning her sources and making it a point to explore information for herself. As our students move on to the next phases of their education, it is our hope and expectation that the evidenced-based thinking and argumentation skills they developed in our course will be further improved and transferred to other areas of their life.

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# Part II

## Challenges for the Development of Scientific Thinking in Higher Education

# 5

# Students' Difficulties During Research Methods Training Acting as Potential Barriers to Their Development of Scientific Thinking

Kieran Balloo

## Introduction

During higher education, students across all scientific disciplines are expected to develop an understanding of how knowledge is formed (Ryan, Saunders, Rainsford, & Thompson, 2014), so they can make effective use of this evidence in their decision-making. That is, students require an understanding of the systematic approaches used to undertake research as the basis of scientific thinking. This is usually achieved through participation in research methods training courses. However, the literature paints a negative picture of this type of training, in which students experience multiple difficulties that can then be expected to act as barriers to their development of scientific thinking skills. This chapter begins with a thematic review of common difficulties and highlights some of the pedagogical approaches that have been used in attempts to deal with these issues.

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A qualitative phenomenological investigation is then reported, which captures the undergraduate experience of research methods training. This chapter ends by discussing practical implications of the investigation's findings to aid instructors of research methods training courses.

## Thematic Review of Difficulties Experienced by Students During Research Methods Training

Research methods training courses are now a staple element of undergraduate and postgraduate social science degree programmes (Nind, Kilburn, & Luff, 2015). One of the aims of these courses is to prepare students for their own independent capstone research project within their own discipline (Hosein & Rao, 2017). Typically, course content is likely to develop students' abilities to: generate hypotheses and research questions; use multiple data collection approaches and instruments; analyse and interpret both quantitative and qualitative data; disseminate research findings; critically evaluate theory and research; and utilise evidence-based reasoning (British Psychological Society, 2019). Additionally, one of the major assessment methods in these courses is the research report (Hosein & Rao, 2014), which requires students to demonstrate scientific reasoning skills (Timmerman, Strickland, Johnson, & Payne, 2011). As noted by Murtonen and Salmento in Chapter 1 of this book, students need to understand the methods underpinning science to be able to understand what science is. Therefore, in addition to developing research and methodological skills, research methods training courses should enhance all other aspects of scientific thinking from Murtonen and Salmento's theory (i.e. critical thinking, epistemic understanding, evidence-based reasoning skills, and contextual understanding) as well.

Previous research has explored research methods education across a range of parent disciplines. The literature largely covers the same themes, regardless of the main discipline being studied, including: the attitudes and views of the students enrolled in research methods courses; the teaching approaches used to reduce any difficulties experienced by students on these courses; difficulties with, and/or preferences for, quantitative and qualitative methods; and the content and goals of these courses (Earley, 2014; Wagner, Garner, & Kawulich, 2011). Therefore, a dominant focus within the literature is the difficulties that students experience during research methods learning, which could cause barriers during scientific thinking skills development, so these difficulties will now be explored in more depth.

## Affective Issues with Research

Affective feelings, such as anxiety and apprehension from the lack of knowledge and uncertainty about doing research, are a natural reaction when commencing a project (Kuhlthau, Heinström, & Todd, 2008). For many students, the perceived importance of being capable of undertaking research, and the requirement to be able to apply research methods knowledge, is thought to overwhelm them, increasing their anxiety about research methods learning (Howard & Brady, 2015; Papanastasiou & Zembylas, 2008). Anxiety about this learning is largely seen to be related to statistics anxiety (Onwuegbuzie, Slate, Paterson, Watson, & Schwartz, 2000), since the use of statistical analyses represents a key characteristic of quantitative research (Goertzen, 2017). However, whilst it may not be unreasonable to anticipate that students will experience anxiety during research methods training, it is also potentially problematic. Anxiety may redirect students' cognitive resources away from the task at hand onto their intrusive thoughts, meaning they are less likely to use beneficial study skills, all of which could negatively impact on their achievement in research methods and statistics courses (González, Rodríguez, Faílde, & Carrera, 2016; Onwuegbuzie, Slate, & Schwartz, 2001).

Many students do not distinguish between research and statistics, so if they perceive they have weaknesses in their ability to use quantitative methods, they may believe they will perform poorly in research methods courses in general (Papanastasiou, 2014). Therefore, it is unsurprising that statistics anxiety is considered to be the most important predictor of achievement in these courses (Onwuegbuzie et al., 2000). Statistics anxiety involves feelings of anxiety experienced whilst exposed to any form of statistics (Onwuegbuzie, Da Ros, & Ryan, 1997). Statistics anxiety can be considered a form of state anxiety (Lavasani, Weisani, & Shariati, 2014), because it occurs as a direct emotional response to engaging in statistical activities, which are experienced as a perceived threat.

Since the use of statistical software has now become a dominant aspect of research methods courses, maths-based antecedents of statistics anxiety are thought to be less prominent than they used to be (Onwuegbuzie & Wilson, 2003). Statistics anxiety is a distinct construct from maths anxiety (Chew & Dillon, 2014), since maths and statistics involve different cognitive processes (Baloğlu, 2004). Townsend, Moore, Tuck, and Wilton (1998) did not find maths self-concept and maths anxiety to be significantly linked to statistics achievement. They concluded that this was most likely due to statistics assessments requiring explanation, justification and interpretation, in addition to the ability to use statistics appropriately. Furthermore, Bourne (2018) found that only one mathematical ability (being able to interpret graphs) was related to research methods achievement, and this was only the case for students during their first-year research methods course. However, the feeling of being non-mathematical may still pervade students' thinking (Murtonen & Lehtinen, 2003), and poorer earlier maths achievement can cause difficulties for students, even if this does not appear to have any actual effect on their subsequent research methods achievement (Murtonen & Titterton, 2004).

Statistics anxiety may not encapsulate all of the affective issues students experience during research methods training, since research activities also include non-numerical/non-statistical aspects. Research methods anxiety is a multidimensional construct focusing on the anxiety one experiences whilst engaging with either quantitative or qualitative methods (Papanastasiou & Zembylas, 2008). Onwuegbuzie (1997) examined the anxiety suffered by students whilst writing a research proposal and found that, independently of statistics anxiety, students may also experience research process anxiety, which includes: the fear of research terminology; the fear of not knowing how to apply their research knowledge; and reluctance to ask for help with research activities. The high amount of work involved in research methods courses, and perceived difficulty of this work, is also assumed to cause research anxiety (Wilson & Onwuegbuzie, 2001). Balloo, Pauli, and Worrell (2016) found that both research anxiety and statistics anxiety were negatively correlated with achievement on a research methods course.

Greater research and statistics self-efficacy has been linked to lower research and statistics anxiety (Perepiczka, Chandler, & Becerra, 2011; Trimarco, 1997), and students with greater research self-efficacy have been found to have a greater interest in research (Bishop & Bieschke, 1998). Self-efficacy represents an individual's belief in their own capability (Bandura, 2000). The effectiveness of self-efficacy as a motivational variable may lie in its ability to promote positive learning behaviours. Students with greater self-efficacy may set higher goals, be more persistent, and make use of efficient self-regulated learning strategies (Bandura, 2012; Sitzmann & Ely, 2011). Students with lower self-efficacy may use less effective study skills, because they perceive they would not be capable of using more sophisticated ones (Onwuegbuzie et al., 2001). Both performance self-efficacy and research self-efficacy have been shown to positively predict research methods knowledge (Balloo et al., 2016) and achievement in a research methods course (Payne & Israel, 2010). Self-efficacy, therefore, has the potential to reduce anxiety, promote useful learning strategies, and possibly improve achievement in research methods courses.

## Negative and Naïve Conceptions of Research

Conceptions of learning represent the beliefs that individuals hold towards a particular learning domain, including perspectives about themselves as learners and views about their learning environment (Vermunt & Vermetten, 2004). Correspondingly, conceptions of research represent the various ways that individuals experience research (Brew, 2001). Thus, 'a "conception" of some phenomenon reflects (variation in) individuals' experiences and development of an understanding of that same phenomenon in specific contexts' (Meyer, Shanahan, & Laugksch, 2005, p. 227). Negative or naïve conceptions of research may cause difficulties for students by affecting their perceptions of what research is and why they are studying the subject, as well as their motivation to learn the topic (Kawulich, Garner, & Wagner, 2009; Murtonen, 2005b; Murtonen & Lehtinen, 2003). Conflicting conceptions about research between teachers and students are likely to impact on the communication between these individuals (Pitcher & Åkerlind, 2009), acting as a barrier to learning during research methods training. This is likely to be compounded by the fact there is no universal conception of research across the academic community (Murtonen & Lehtinen, 2005), with variation in conceptions even being found amongst supervisors (Kiley & Mullins, 2005) and senior academics (Brew, 2001).

Many students appear to have little interest in carrying out research or undertaking research methods training (Ball & Pelco, 2006; Lei, 2010; Uttl, White, & Morin, 2013), and it is often felt to be a “dry” and “boring” subject to study (Briggs, Brown, Gardner, & Davidson, 2009; Burkley & Burkley, 2009; Murtonen, 2005a; Ryan et al., 2014). On degree programmes that have a significant research component, the majority of students seem to enrol without being aware this will be the case (Ruggeri, Dempster, Hanna, & Cleary, 2008). Research can also appear to be disconnected from students’ professional and non-professional lives, regardless of whether it involves statistics or qualitative methods (Dorfman & Lipscomb, 2005; Papanastasiou, 2005). Murtonen, Olkinuora, Tynjälä, and Lehtinen (2008) found that around half of the students in their sample did not feel they would need research skills in their future working lives. Furthermore, when students are particularly focused on their employment after university, they may not see the links between employability and research skills (Ryan et al., 2014). If students do not believe the research they are doing will have a meaningful impact on the real world, this is likely to affect their engagement (Rash, 2005). For example, in subjects such as social work, criminal justice, and psychology, students may have enrolled in these programmes in order to pursue a job in a “helping profession”, so research is not considered to be directly relevant to their career plans (Adam, Zosky, & Unrau, 2004; Briggs et al., 2009; Sizemore & Lewandowski, 2009; Vittengl et al., 2004). Thus, students may have difficulties seeing that research methods training can teach them broad scientific thinking skills that will benefit them when they graduate from university.

However, Secret, Rompf, and Ford (2003, p. 411) argued that it is a ‘stereotype’ to see all students as ‘research reluctant’, with many students in their study actually finding their methods course to be quite enticing, even if they were simultaneously fearful of taking the course. Similarly, Murtonen (2005b) found that negative views about quantitative methods were only linked to difficulties for some students. Furthermore, Balloo, Pauli, and Worrell (2018) found a distinct variation in students' conceptions of research methods learning, including views expressing: an understanding of the "bigger picture" of research methods learning in psychology and also the real world; the view that research methods detract from the real purpose of a psychology degree; a lack of appreciation for the role of research methods in psychology as a discipline; and the perspective that research methods are useful for developing valuable skills. Importantly, conceptions are likely to change over time through increased exposure to research, with more positive views about the value of research being expressed on completion of their research methods training (Kawulich et al., 2009).

## Cognitive Complexity of Research

Many of students' affective/motivational issues and negative/naïve conceptions of research are likely to be in response to the complexity of research and research methods: 'adequate learning of research methods requires complex and systemic thinking which integrates very different types of knowledge into a coherent but flexible mental model' (Lehtinen, 2007, p. 245). High intellectual and cognitive demands are placed on students as they attempt to develop procedural knowledge of the research process from abstract conceptual knowledge of methods (Howard & Brady, 2015; Leech, Onwuegbuzie, Murtonen, Mikkilä-Erdmann, & Tähtinen, 2007; Murtonen & Lehtinen, 2003). The topic of research methods is epistemologically complex, since it consists of various ontologically distinct subdomains (Lehtinen, 2007; Lehtinen & Rui, 1996) and it is likely to be far more mathematically-based and logic-driven that what many students on social science programmes are used to (Dilevko, 2000). Learning of statistics has even been equated to learning a second language (Lalonde & Gardner, 1993). This means that many students have basic gaps in their knowledge that can make the undertaking of empirical research an arduous task (Aguado, 2009). Even after undertaking a research methods course, many students appear to have problems in their understanding

(Murtonen, 2015). Some postgraduate students are still unaware of how basic research methods differ or how and why they should abide by ethical protocols (Diab, 2006). Methodological, analytical, and interpretational errors have been found to permeate through to master's theses (Rautopuro, Väisänen, & Malin, 2007) and even published research (Onwuegbuzie, 2002).

Balloo et al. (2016) focused on how undergraduates' understanding of research methods developed across the three years of their degree. Using a card sorting approach, students organised cards displaying different research methods terminology into categories based on their knowledge of how the concepts were related. Statistical analyses of the groupings indicated that even by the end of their degrees, understanding about some concepts (all of which had been covered during their research methods course) still eluded many students. Similarly, using a mind map technique, Murtonen (2015) found that some students still had a problematic understanding of research at the end of their methods course. For example, one of the misconceptions held by some students was that qualitative and quantitative methods could only be used in an empirical or theoretical context, rather than understanding that both approaches can be used depending on the situation.

Instructors also face challenges teaching the subject (Lewthwaite & Nind, 2016), which may contribute to students' difficulties. Murtonen and Lehtinen (2003) found that the majority of students experiencing difficulties with quantitative methods in their study felt the reason was due to poor teaching. It is felt that research methods are taught in an abstract way, which results in students having difficulties understanding its applicability to the other areas of their degree programmes (Benson & Blackman, 2003; Zablotsky, 2001). Quantitative methods instructors have been seen as lacking enthusiasm about teaching the subject by students (Williams, Payne, Hodgkinson, & Poade, 2008) and some instructors from a primarily qualitative background have admitted having a lack of confidence with teaching quantitative methods (Scott Jones & Goldring, 2015).

Whilst the accuracy of research skills instruction may differ based on the instructor's level of expertise (Feldon, 2009), issues may actually be more due to the structure of these courses rather than the quality of the teaching specifically. Research is often presented as an idealised process that only involves the fine-tuning of research questions and analysis of clean data, which only serves to make the whole endeavour even more abstract for students (Leech et al., 2007). Hughes and Berry (2000) suggest that 'the use of topic-related chapters in books on research methods leads to the fragmentation of the process' (p. 172). Similarly, Onwuegbuzie (2002) highlights how many courses teach research methods and statistics as a series of routine steps to be followed. A corollary of this is that students do not develop an understanding of research as a holistic process. This is significant, since a developmental trajectory of research skills has suggested that students acquire these skills asynchronously, beginning by learning how to situate their work within relevant literature and form hypotheses, to eventually learning how to analyse their data and draw conclusions based on their findings (Timmerman, Feldon, Maher, Strickland, & Gilmore, 2013). Thus, it is important to introduce students to the overall complexity of their research tasks from the outset, rather than simply teaching them isolated units of content (Lehti & Lehtinen, 2005).

## Pedagogical Approaches to Dealing with Students' Difficulties

With the exception of statistics anxiety, which has been causally, and negatively, linked to statistics achievement (Onwuegbuzie & Wilson, 2003), there appears to be little evidence to suggest the difficulties discussed actually impact on research methods course achievement, even though it has been claimed that they can 'hinder learning' (Earley, 2014, p. 246). This lack of evidence is not helped by the fact there is no pedagogical culture for teaching research methods in terms of a debate about best practices and approaches based on empirical research (Kilburn, Nind, & Wiles, 2014; Wagner et al., 2011). However, recent syntheses of the research methods education literature have attempted to draw together common approaches to teaching and learning of research methods that are often utilised in response to students' difficulties. Wagner et al. (2011) notes how instructors use various techniques (e.g. exercises, experiential learning, group learning, etc.) as ways to directly involve students in research.

Earley (2014) categorises these teaching approaches into: Active learning; problem-based learning; cooperative learning; service learning; experiential learning; and online learning modules. Furthermore, Kilburn et al. (2014) suggest that these teaching approaches appear to have the following pedagogical goals: an attempt at grounding students' understanding of research by making the research process more visible; an attempt at involving students in conducting real-world research or using real data; and an attempt at encouraging students to critically reflect on their involvement in research. Additionally, Onwuegbuzie, Leech, Murtonen, and Tähtinen (2010) proposed a useful framework for alleviating students' statistics anxiety by integrating mixed methods into the curriculum as a way to deemphasise the role of statistics. However, there is likely to be a substantial skills gap when attempting to establish a team of teaching staff with appropriate mixed methods expertise (Hesse-Biber, 2015).

Since self-efficacy appears to be a useful motivational variable in the context of research methods learning, two specific small-scale approaches to enhancing this are worthy of discussion. Elaborated feedback that allows students to make judgements about their work has been found to enhance their self-efficacy above a simple correct/incorrect response (Wang & Wu, 2008). Additionally, active learning tasks involving the practising of statistical analyses, as well as clear support from tutors, can reduce students' statistics anxiety and increase their self-efficacy (McGrath, Ferns, Greiner, Wanamaker, & Brown, 2015).

## An Investigation into the Undergraduate Experience of Research Methods Training

There is no cohesive framework for understanding how effective each pedagogical approach is for dealing with each of the difficulties discussed in this chapter. Furthermore, it is not clear whether students experience these difficulties as actual barriers to their development of scientific thinking skills and what actions they take to deal with issues themselves. For example, even if students have negative conceptions of research and/or experience anxiety, is this omnipresent throughout their overall experience of research methods training and is it actually debilitating for them?

A qualitative phenomenological investigation was undertaken for the current chapter to understand more about these experiences. The aim was to capture a general understanding of the elements that constitute the undergraduate experience of research methods training in order to observe how students deal with difficulties.

## Methodology

**Participants and procedure**. One-to-one semi-structured interviews were conducted with 12 first-year undergraduate psychology students who were undertaking a research methods course as part of their degree at a UK-based post-1992 university.[1] The course was assessed by two quantitative research reports, and at the time of the interviews, students had completed both reports, but only received their grade and feedback for the first report. Each week, the research methods course involved students attending a conceptual lecture and active learning workshop (lab class) in which they mainly practised statistical analyses. Participants were asked nine broad open-ended questions in interviews lasting approximately 30 minutes, covering: their feelings about undertaking research, their perceptions of their performance on the research methods course; their process of completing a research report; any strategies they use whilst completing research reports; helpful or unhelpful aspects of any approaches they use; and any changes they thought they could make to their approaches whilst completing future research reports.

**Analytical approach**. The purpose of the current investigation was to cast a spotlight on students' holistic experiences of research methods training. The aim was to understand any interactions between conceptions about their course, and affective and cognitive dimensions of their experience, as well as how these led (or did not lead) to perceived barriers to their development of scientific thinking skills. Thus, the current investigation drew on the descriptive phenomenological method (Giorgi, 1994) to explore students' lived experiences of research methods training. Giorgi (1997)

[1] Post-1992 universities are modern universities that were awarded university status under the UK Further and Higher Education Act 1992.

describes this method as involving three interlocking steps: phenomenological reduction, description, and the search for essences. The aim is for researchers to "bracket" their own preconceived notions of a phenomenon to describe the essence and structure of a particular personal experience (Finlay, 2009). Whilst most often used within psychology, Giorgi (2012) notes that the method is generic enough to be used to understand phenomena within other disciplines, including pedagogy.

For the current investigation, a modified approach to Giorgi's method, as set out by Worthen and McNeill (1996), was used. During an individual analysis phase, a seven-step process of phenomenological reduction was followed for each interview, which involved a gradual 'movement from concrete data to abstraction of meaning' (Worthen & McNeill, 1996, p. 27). Descriptions, or essences of meaning, derived from a particular situation (in this case research methods training) were produced for each participant called "situated meaning structures". A four-step group analysis process was then followed to identify common and collective themes within each situated meaning structure (Worthen & McNeill, 1996) in order to produce a general meaning structure representing an interpersonal and shared experience of research methods training for "the undergraduate". The general meaning structure is described in the next section followed by an explication of themes derived from this structure. Extracts from participants' transcripts aid the narrative for each theme to show how they are grounded in the data (the numbers in parentheses next to each quote denote the identification code given to each participant).

## Findings and Discussion

**The undergraduate experience of research methods training: General phenomenological meaning structure**. Research methods training is vital to the undergraduate's success during the other aspects of their degree and subsequently, when they enter employment. For those who perceive themselves to have prior weaknesses with maths, the thought of statistics elicits feelings of apprehension whilst they struggle to understand how to perform statistical analyses. However, a more prevalent concern relates to the "newness" of the research endeavour and the undergraduate's ensuing lack of experience with the research report format. Requirements for their initial research report were ill-defined, which made it an overwhelming and stressful experience to complete. There was a lot of dependence on detailed assessment guidance and resources. For their second report, there was a better idea of what to expect, and how to complete it. The experience of having done the first report, coupled with feedback, meant that the second report was perceived to be easier and less stressful. Workshop tutors and peers are a useful external resource for the undergraduate to seek help from. Peers or friends are perceived to be more able to appreciate the difficulties that students have, because they may also experience the same problems. Peer groups provide a safe space for trying and failing with statistics. There is some reluctance to ask for help from the tutor, because they might not be able to tell students the answers, but they do provide some reassurance by having more expertise than peers. Practising of statistical tests is crucial, and useful strategies for making research reports more manageable include careful time and report planning, and breaking reports down into their constituent parts. The undergraduate tends to form study environments away from the classroom whilst working on summative reports, with workshops being reserved for low-stakes formative exercises. The undergraduate articulates a multitude of skills they have developed as a direct result of their research methods course, including improvements in their writing, and better statistical and software skills. There is some desire to improve further, and some awareness of how this could be achieved, but the need to change the way they work causes a feeling of unease, which means that self-imposed barriers to development may still exist.

**Theme 1. Awareness that research methods training enhances broad scientific thinking skills**. Nearly all participants acknowledged that research was a core aspect of their discipline, so they understood that research methods training was necessary: 'I think [research methods] acts as like a foundation for everything else' (P10). There was a comprehension of how this training would be vital for developing the skills that would be crucial for fully understanding the other areas of their degree and would enable them to undertake their own final year capstone research project:

> I think [research methods training will be] quite beneficial for the next three years as it shows us how to analyse our data and everything like that for experiments we're going to do. (P1)

> In the third year we need to do some kind of research on our own … so you need to know what you're doing and know what your results actually show and … what tests to do and how to process [data] … just something you need to do if you want to do any kind of research … so it's kind of essential. (P5)

Some students also suggested that research skills can be useful for any type of career and they could see how research methods training had given them a range of non-research-specific skills:

> [Research skills are] something that even employers expect you to have been taught in university and [they] expect you to have that experience before you come into the job. (P7)

> Over the time my writing's been getting better. (P10)

> [Research methods training has] made me a lot more confident in my abilities to use computers and to use, you know [the statistical analysis program], and use Excel and stuff, and I think that's really helpful for the future. (P12)

Students were able to see how the training had multifaceted aims that went beyond research, suggesting an awareness that these courses do not just enhance research skills but also broad scientific thinking skills that will be useful to them when they graduate. This portrays a positive outcome compared to previous research that showed students had difficulties understanding the links between research skills and employability (Murtonen et al., 2008; Ryan et al., 2014). Furthermore, this supports findings by Secret et al. (2003) and Balloo et al. (2018) that students should not be seen as holding homogeneously negative attitudes towards research methods courses.

**Theme 2. Numbers and statistics cause apprehension, but not overwhelming anxiety**. Unsurprisingly, many students expressed negative affective reactions and/or difficulties with the numerical aspect of research methods: 'I'm not very great with numbers, or at least I believe I'm not that great with numbers. Just never have been, so I kind of dread it going into you know all the statistical analysis' (P12). As suggested by Papanastasiou (2014), some students seem to fixate on the statistical aspect of research, sometimes conflating statistics and research. However, students in the current investigation did not necessarily find statistics to be anxiety-provoking to the point of being debilitating. Instead of causing an overriding sense of anxiety, being presented with numbers seemed to only cause an initial experience of apprehension about having to carry out and interpret statistical analyses. Most students seemed able to move beyond this feeling through practice (this is discussed further in Theme 5):

> You know first of all you just see [quantitative data] as a long thing of numbers and you think, 'well that doesn't mean anything to me, that's just numbers', but then I try to understand it using the [text]book and [other resources] and so I understand what that data actually means [now]. (P1)

> They just give me data it kind of freaks me out but when I read you know, step-by-step what I'm doing and how I'm doing it, by the end of it I know what this data actually tells me and why it's useful. So I think it's the process of going through and actually doing it yourself that, you know, makes it a lot easier to understand and kind of like just comprehend what the numbers mean. (P5)

**Theme 3. There is a fear of the unknown when commencing research**. Whilst there were only minimal concerns about statistics, which were due to students' *knowledge* of their prior issues with numbers, their *lack of knowledge* about what research involves seemed to be a more salient concern for them. This is consistent with Kuhlthau's "Information Search Process" model, which proposes that individuals are initially apprehensive about research due to their lack of knowledge and uncertainty about the process (Kuhlthau et al., 2008). The first research report that students had to complete was generally seen as more stressful and challenging than subsequent assignments due to them not having a clear awareness of expectations: '[I] wasn't quite sure what I was doing and what to expect as I'd never written a research report before' (P1).

Participants with experience of studying research methods or statistics prior to university noted how much easier it was to for them to get their first report underway: 'I think because I did sort of [study] research methods, quite a lot of statistics and things like that [in secondary school], I found it quite easy [at university] in a way, and I quite enjoyed it but I know some people like struggle with it' (P8). Participants highlighted areas they 'struggled' with, such as structuring research reports according to expected conventions or using statistical tests, which again appeared to be more due to their lack of familiarity with research, rather than as a result of prior issues with maths. In line with previous research findings, students experienced the research report as a cognitively demanding task until they had more experience to fill in some of the gaps in their knowledge (Aguado, 2009; Leech et al., 2007; Lehtinen, 2007; Murtonen & Lehtinen, 2003).

With many of their initial concerns about undertaking research being due to students' lack of prior experience in this domain, affective responses to research appeared to reduce over time: '[The second report] was different because … you gain experience, you gain more confidence as well but … also you kind of realise from the first [report] to the last [report] what you did wrong the first time' (P7). With their initial report, there seemed to be a certain amount of dependence on step-by-step guidance: 'I wasn't really getting [the statistical analyses] very much [at the beginning] so the guide was kind of like my bible' (P5). McGrath et al. (2015) found that students felt "how-to guides" made expectations clear, which reduced their anxiety, and this appeared to be the same for the current sample; these resources mainly functioned to scaffold the unknown research process, helping to reduce students' anxiety and confirm they were covering what they needed to in their reports.

**Theme 4. Peers and tutors provide affective and cognitive support**. Many students talked about how useful it was to work with peers/friends, as they could share ideas and concerns, and reassure each other:

> Even if you're struggling in one of the sections like sitting together [with] friends or something, or even in your lab classes and going through stuff I think that would be really helpful. (P9)

> Working with friends on these assignments … they will just sit and just work and get it done, you know just work fast and I think that's made me work faster and also seeing [and] comparing their work to mine it's made me … raise the standard which my work goes to. (P12)

Students described how these help-seeking behaviours both reduced their doubts about whether they were doing everything correctly and provided a useful strategy for making research less difficult.

Some students also felt that tutors provided them with reassurance: 'In all the lab class[es] and things the minute you like need help, someone is there to help you and walk you through it … [my tutor] doesn't give you the answer she kind of makes you do it yourself which is really helpful' (P5). This help seemed to be sought from tutors because students knew they would have more expertise than peers, so asking them for help would be a way of ensuring no mistakes were made: 'If you ask another student [for help] then you could get it wrong as … they might not know themselves, so I'd ask a professional because he's the one that's teaching us the unit so he would know the answers anyway. But if he wasn't around, [I] guess I'd just trial and error or I'd just get it wrong and learn from it' (P6). McGrath et al. (2015) found that students felt tutors could increase their anxiety if they were not clear when explaining statistics, which may explain why some students preferred seeking help from peers over tutors. The current findings suggest that help-seeking may be effective for dealing with the cognitive complexity of research, as well as managing the affective issues it provokes.

**Theme 5. Feedback and practice enhance self-efficacy, reduce anxiety, and promote the use of self-regulated learning strategies**. After their first report, students worried less about what they needed to do for their second report. Whilst some of their reduction in anxiety may have been due to increased familiarity with research (see Theme 3), the key factor in alleviating their anxiety appeared to be the feedback comments they received for their prior report and their perceived ability to make use of this feedback: 'I could have the feedback [comments] up while I was doing my [second report] so you can work through when you've done it and be like, "don't forget that"' (P5). Students clearly articulated how they had made use of feedback to attempt to improve their work, suggesting that negative emotions tended to be elicited from doubts about whether they were doing what they should be doing, now clarified by feedback. Since feedback comments on reports aimed to allow students to make judgements about the standard of their work and how to improve it, it is anticipated that students' self-efficacy was increased as a result (Wang & Wu, 2008). Thus, feedback appeared to be key to facilitating more general forms of research self-efficacy. Greater self-efficacy could explain the reduction in students' anxiety (Perepiczka et al., 2011; Trimarco, 1997).

Continued practice with various examples of statistical analyses also helped students to feel more confident about how to report their research findings: 'During the beginning like when we were [first learning about statistics] I was like, "Oh there's too many numbers there's too much going on", but I think doing it, practising, practising going over lots of exercises then [learning about subsequent statistical tests], learning different things I think it's really improved [and] helped me with my statistical skills' (P9). Practice with statistical analyses appeared to enhance students' statistics self-efficacy, consistent with previous research suggesting that this type of active learning task would decrease anxiety and increase self-efficacy (McGrath et al., 2015).

As anticipated based on previous research (Bandura, 2012; Sitzmann & Ely, 2011), having increased self-efficacy meant that students seemed more able to set goals and make use of efficient self-regulated learning strategies, such as planning, time management, and study environment management:

> [For the second report] I think I did it more logically and planned it a lot better before I actually started typing it up. That's what I found really works is doing a plan. (P1)

> [I] timed myself a lot better this time. Time management was a lot better … I just said I'm not gonna [sic] do more than one section a day … so it broke it up and then it didn't seem like too big of a task. (P12)

> I totally did [my reports] at home just because I find it easier to work alone and in silence, whereas in like a lab class, although it can be quite silent it's just too many things going on, like too many people around and obviously

> that's talking and stuff and in my room I prefer that I can just have my notes all around me and just have my own space, rather than doing it in a big area. (P8)

**Theme 6. Ongoing barriers to the development of scientific thinking skills**. Most students were aware of areas in which they could improve and how they might go about this: 'Maybe if I spent more time a day [working on my report] I could have more time at the end of the report to go back and check it myself rather than expect someone to help me out, and it'd probably help me realise my own mistakes rather than having someone else point that out for me' (P7). However, many students had difficulties putting these new ways of working into plans of action:

> Even if … there is a way of doing it better I will try it, but if I don't feel like I like it then I won't continue doing it like that, whether … it's gonna [sic] benefit me or not. (P6)

> I think just [more] practise [would benefit me] … because a lot of the time when I produce my results … I'm unsure. I'm like, 'is this the right result? Has everyone else got it?'…. [What stops me is] time I guess again, especially now with a lot of revision and stuff so I don't really have time to sit there and practise because I know I do have a test tomorrow. (P11)

It appeared that even if some students knew they were working inefficiently, they would continue working this way just because they were comfortable, meaning this could act as a barrier to their continued scientific thinking skills development. Students noted how other responsibilities outside of their research methods course made it hard for them to find time to put in extra work.

## Practical Implications for Research Methods Courses

Pedagogical approaches highlighted in the syntheses by Wagner et al. (2011), Earley (2014), and Kilburn et al. (2014) provide useful aims for instructional designers of research methods courses in the long-term. However, there may also be some smaller-scale pedagogical solutions that could be implemented more immediately. Based on the findings from the current investigation, combined with experience from practice, research methods instructors may want to consider the following pedagogic suggestions:

- Try to make explicit links between research methods and scientific thinking skills to show students how they are developing useful abilities to use evidence that will benefit them in their working life.
- Students would benefit from understanding how research acts as a foundation for all other learning within their discipline. Therefore, an overview of the "bigger picture" of research in terms of the whole process, and also how it fits into the overall discipline, could be part of an early teaching session. This should encourage students to form less negative and naïve conceptions of research.
- Look for opportunities for synergy between research methods courses and the other elements of students' programmes, such as basing examples on experiments/studies they are learning about in their other modules/units to show how research underpins theory and how research methods is not simply an "add-on" to their degree.
- Since research anxiety may be linked to the uncertainty and complexity of the research process, clarity around research assignments is essential. Some students in the current investigation highlighted how they look at journal articles to model their reports on these, so exemplars of similar work to their research reports will help students to become more aware of how to structure reports according to appropriate conventions (see also Carless & Chan, 2017, for a discussion about the importance of student and teacher dialogue around exemplars). If students are clearer about what they are trying to achieve and feel capable of doing this, this may increase their research self-efficacy.
- Students in the current sample highlighted how feedback was beneficial for enhancing their research self-efficacy. Students also need to be aware of how to take action on this feedback in order for it to be useful (see Winstone & Carless, 2019, for examples of good feedback practices).

This should avoid students feeling like they have to take a "trial-and-error" approach with initial summative research assignments.

- Since "low-stakes" assessments may have a positive impact on students' motivation (Nicol & MacFarlane-Dick, 2006), consider having an early assignment with a lower grade-weighting to take some of the "stakes" out of this initial submission when students still lack knowledge of what research involves.
- Students should be given time to develop their statistics self-efficacy through practising statistical analyses in exercises that are directly relevant to their summative research assignments. These should be contextualised within the "bigger picture" of the research process to avoid students conflating statistics and research. Furthermore, where possible, avoid "analysis/results sections" being too "high-stakes" (e.g. one mistake equals failure), as it encourages students to put more emphasis on statistics than the rest of the research process, which reinforces the aforementioned misconception that statistics and research are the same (Papanastasiou, 2014).
- Peer and tutor support can help reassure students. Collaborative learning is an approach often used in research methods training (Earley, 2014), so try to allow students to work in peer groups on formative activities supported by workshop tutors. This should be managed, so that students do not become dependent on each other and are still able to undertake summative assessments independently.
- Students should be encouraged to develop useful study skills and self-regulated learning strategies that work for them. For example, if students find it difficult to work in a noisy environment, like a research methods workshop, they should not be expected to work on summative assessments during class time.
- If students are using inefficient strategies, they need to be presented with alternative approaches that they can believe will lead to better outcomes, otherwise they are unlikely to change their approaches.
- Build opportunities into class time for students to revise and practise aspects learnt earlier in the term and provide enough time for them to manage potential affective and cognitive issues before they commence research assignments.

## Conclusion

As shown by the thematic review in the first part of this chapter, a large portion of the literature depicts an undesirable picture of research methods education in which students struggle with affective and cognitive issues and have negative and naïve conceptions of research. Yet, the findings from the current phenomenological investigation suggest that many of these concerns do not actually debilitate students or act as permanent barriers to their development of scientific thinking skills. Since the current investigation only explored perceived barriers experienced by students whilst studying research methods, future research may benefit from examining the cognitive processes involved in scientific thinking development.

Research methods training courses are fundamental to the development of students' scientific thinking skills, so it is crucial that they are well-designed. In the long-term, it may be advantageous to attempt more bold new approaches to teaching research methods that deal with students' difficulties. However, in order to build more of a pedagogical culture for teaching research methods, educators are encouraged to use more empirically-informed approaches to ascertain the actual issues their students are experiencing. They should attempt to understand whether these issues are causing barriers to their students' development, and whether the pedagogic approaches they are using are likely to actually remove these barriers.

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# 6

# Threshold Concepts of Research in Teaching Scientific Thinking

Margaret Kiley

## Introduction

As many Masters and Doctoral supervisors/advisers comment, helping candidates to develop scientific thinking can be challenging. This chapter proposes that using a threshold concepts framework can be one way of assisting those working with research candidates to develop some of the knowledge and skills required for successful scientific thinking. In doing so, it includes the idea of liminality, that is, supporting learners as they move from 'not knowing that they don't know, to knowing that they don't know'; a painful and challenging experience for some. It is often while in this liminal state that learners can feel 'stuck' and not know how to progress no matter how hard they try and so often they want to withdraw from study. In this chapter, following an outline of the research and practice on threshold concepts and related learning experiences, some strategies for teaching are then provided as possible ways of helping learners come to an understanding of these critical concepts as they become effective scientific

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thinkers (see, for example, Kiley, 2009; Mantai, 2017; McKenna, 2017; Wisker & Kiley, 2017).

## What Are Threshold Concepts?

Research on threshold concepts was first reported in the early 2000s with Meyer and Land's ground-breaking work (Meyer & Land, 2003, 2005, 2006). They proposed that each discipline contained a number of critical concepts which were essential for learners to fully understand if they were to progress their learning in that discipline (Davies & Mangan, 2007; Land, Meyer, & Smith, 2008; Meyer & Land, 2006). The authors argued that when a learner fully understands such a concept they then cross a learning threshold often resulting in an ontological and epistemological change. Kiley and Wisker (2009, p. 413) describe this as a conceptual threshold crossing, that is where 'a number of indicators…signal when learners have crossed conceptual thresholds to gain, articulate and put into practice one or more of these threshold concepts in their research learning'.

Critical to the understanding of threshold concepts are the criteria which the authors suggested were required for a concept to be designated a threshold concept. The initial criteria that were proposed were that the effect of understanding the concept was: 'transformative, irreversible, integrative (possibly) bounded in any conceptual space, and (potentially) troublesome' (Meyer & Land, 2006, pp. 7–8). Land (2010) then proposed the addition of discursive, and reconstitutive.

The *transformative* nature of a threshold concept suggests that the understanding of the concept transforms the way in which the learner views the related disciplinary knowledge and themselves as a learner in that discipline. The *irreversible* feature of a threshold concept proposes that once a learner has fully understood the concept they cannot 'not understand' it. The *integrated* criterion suggests that understanding a particular concept allows a learner to integrate other learning, which they previously thought to be unrelated, into an integrated whole. On the other hand, the *bounded* nature of a threshold concept means that the concept assists in learning certain aspects of the discipline. Finally, with regard to the initial set of criteria, drawing on the work of Perkins (2006), Meyer and Land suggest that a threshold concept is potentially *troublesome* and difficult to understand. Often learners will describe the learning experience as more difficult than 'it should be' and certainly more challenging than they expected. The criterion of *discursive* suggests that grasping a concept changes the way in which a learner might talk about this concept; an issue discussed later when describing mimicry. The final criterion, *reconstitutive* refers to the ontological shift that occurs when a learner has been able to integrate learning (Land, 2010). Disciplinary examples of threshold concepts include *learning about others* (Cousin, 2006) and *opportunity cost* (Shanahan & Meyer, 2006). As many Economics lecturers will attest, most undergraduate Economics students can provide a correct definition of opportunity cost, but far fewer can actually provide evidence of having fully understood the concept.

However, returning to the troublesome nature of understanding a threshold concept leads to another aspect of the literature and that is that as learners struggle to come to terms with a particular concept they experience being in a liminal space.

## Liminality

Based on Turner's (1979) work, it is argued that being in a liminal, often uncomfortable, state is when a learner leaves the *comfortable* state of 'not knowing that they don't know' and moves to 'knowing that they don't know'. When learners are in this liminal state they are often described as being 'stuck' (Meyer & Land, 2006). While in this state students can feel frustrated and as if they are 'going around in circles' or 'knocking their head against a brick wall' (Kiley, 2014) until they finally do understand what it is they 'know they need to know' and cross the particular threshold of learning. As Meyer and Land (2006) suggest, it is as if the learner has passed through a portal and by crossing the limen they can then suddenly see the result of understanding the particular concept.

Noted in this learning is the idea of mimicry where learners are often observed as mimicking the behaviour of those who they think 'know' until they actually do understand (Meyer & Land, 2006, p. 24). In research, this phenomenon can be seen as a novice's way of following the readymade rules or models that are assumed to produce the desired result. Murtonen, Sahlström, and Tynjälä (2009) called these 'scaffolding rules', which were taught to students and used by them at the beginning of their learning, but were not really used in authentic work situations after the student had attained a certain level of expertise.

Another experience reported by learners when in a liminal state is oscillation where they report that they think they understand, and then realise that they don't, but then again feel they are close and then again realising that they are still some way from fully understanding the concept. As some would suggest, it feels as if they are taking one step forward and two steps backward (Kiley, 2014).

## Examples of Threshold Concepts in Learning to Think Like a Researcher

Using the threshold concepts framework, Kiley (2009) undertook research to explore whether there were possible threshold concepts in learning to be a researcher. The research involved 19 interviews and 26 surveys with experienced doctoral supervisors across a range of disciplines and countries. While a number of questions were asked, it is possible to summarise the overall question as: *When you say a research candidate 'doesn't get it' what is the 'it' that they don't get?*

From the data six concepts were identified: argument/thesis; theory; framework; knowledge creation; analysis; and research paradigm (Kiley, 2009). For example, many respondents reported that they had worked with research candidates who struggled with understanding the concept of *argument* or having a *thesis*. For these students it was common to describe or list various ideas and/or findings without proposing an argument. It seems that for these candidates, understanding the need for an overall thesis was a considerable challenge. Part of this challenge might be explained by the use of the term 'thesis' in some countries where it is taken to mean the dissertation or monograph as well as an argument.

A second concept posing difficulty reported by supervisors of research candidates was that of *theory* (Kiley, 2015). The difficulty might be demonstrated in the use of a theory to frame one's work, or the use of a theoretical approach to the data collection and analysis, or developing a theory or theorising one's research findings.

'A third major challenge for some candidates reported by respondents was the concept of *framework* as a means of locating or bounding the research' (Kiley, 2009, p. 299). Respondents suggested that some students struggled with the idea of framing or limiting their research question and approach, particularly early in candidature where the project can straddle many topics and sub-topics.

The concept of *knowledge creation* was one where learners had difficulty with their role in producing original research, even if quite modest, rather than simply reporting the research of others. For most universities one of the key criteria for a successful doctoral thesis is that it makes an original contribution to knowledge. Understanding and appreciating the concept of knowledge creation and original contribution can challenge some candidates, particularly if their previous studies have encouraged certain approaches to learning (Marton & Saljo, 1984).

A fifth threshold concept identified in learning to be a researcher was the concept of *analysis*. This difficulty was often highlighted when candidates were preparing their research methods chapter with considerable detail about the data collections strategies yet with little about the analysis strategies. Another example that was given was where qualitative approaches were being used and candidates demonstrated a descriptive, rather than analytical approach to their work.

The final concept that arose from the data was that of *research paradigm* or as described in some areas Epistemology. This issue arose when candidates were approaching their work, whether it be the literature or the analysis, without appreciating that their epistemological view was influencing the way they approached that work. As Crotty (1998, p. 3) argues: Epistemology is 'the theory of knowledge embedded in the theoretical perspective and thereby in the methodology'.

Additionally, as Crotty (1998, p. 2) suggests, epistemology/paradigm is a strong influence throughout one's research as demonstrated in the following:

> What kind of knowledge do we believe will be attained by our research? What characteristics do we believe that knowledge to have?… How should observers of our research—for example readers of our thesis or research report—regard the outcomes we lay out before them? And why should our readers take these outcomes seriously? These are epistemological questions.

An anecdote might help to explain this issue. A colleague from the Law Faculty had been engaging in a discussion about epistemology and suggesting that it *just didn't make sense.* But as he left the building he walked down a timber ramp (instead of stairs) that was wet due to recent rain and he almost slipped. As he did he reported thinking *Wow, there is a law case in making, you could certainly sue the University for that.* As he thought this he suddenly realised that he was thinking like a lawyer and so started to ask himself how would an architect look at the issue of a slippery ramp, or someone with a disability consider it? While not quite an epistemological breakthrough, for the first time he realised how one's paradigm influences the questions, and no doubt approaches to research, that one would be using in addressing a research question.

Other research has now added to our understanding of threshold concepts in learning to be a researcher. See, for example, Humphrey and Simpson (2012) where they suggest that understanding the concept of writing as a central aspect of meaning-making in research is a threshold concept. Furthermore, Trafford and Leshem (2009) propose that 'doctorateness', that is, a range of components coming together to become a researcher is, in itself, a threshold concept. This concept relates well to even earlier work by Meyer and colleagues on students' conceptions of research (Meyer, Shanahan, & Laugksch, 2005, 2007). In this research the authors identified a number of conceptions that candidates held about research. The conceptions included research as: re-searching; an insightful process; finding the truth; and problem-solving as well as a number of conceptions that the authors described as misconceptions (Meyer et al., 2005, pp. 233–234). Some of the misconceptions included:

- 'Research becomes true after it is published'
- 'When qualified people do research the results are always unbiased'

- 'If followed correctly research procedures will always yield positive results'.

In the domain of bachelor's and master's students learning, clear difficulties with understanding basic methodological conceptions have also been found. In a study by Murtonen (2015), 75% of education master's students expressed problematic conceptions of methodology at the beginning of a research methodology course, and 50% still did at the end, despite the fact that they had had many research courses in their prior education. Students showed misconceptions and false links among the concepts of *empirical, theoretical, qualitative, quantitative, testing of hypothesis*, and *analysing of data*. Misconceptions included ideas, such as, that in empirical research a researcher is in close contact with the subjects of the study, and for this same reason, qualitative research would be empirical, because in it researchers are in personal contact with the subjects of the study. Some students thought that quantitative research is conducted mainly in an office on a computer, i.e. testing the theory, and thus it would be theoretical, and not empirical. Some students thought that qualitative methods are theoretical (and not empirical) since they can be used to create theory. On the contrary, some students thought of quantitative methods as empirical (and not theoretical) because they involve manipulating empirical observations to get statistics. Similar findings were obtained by Balloo, Pauli, and Worrell (2016); using a card sorting procedure to longitudinally model Bachelor's students' knowledge of methodological terminology, they found that it took multiple methods courses to see significant improvements in the majority of students' understanding of research concepts. These examples show that the very basic concepts used by methodology teachers are difficult threshold concepts for many students and are not easy to learn. Thus, the teachers' intended outcomes on research courses may stay remote, despite the concepts being taught.

Appreciating these conceptions and misconceptions helps us to understand why is it that some students have difficulty with understanding some of the concepts involved in learning to think scientifically or like a researcher. How can threshold concepts assist scientific thinking?

As outlined above, there are a number of identified threshold concepts involved in learning to be a researcher and to develop the knowledge and skills of scientific thinking. Helping candidates to recognise these different concepts and the difficulty experienced by many of them fully understanding these concepts, and thereby progressing in their learning, can help in structuring relevant learning experiences (Kiley, in press). These experiences can be through formal courses and workshops, or between supervisors and candidates, or candidates and their peers as outlined below.

## Learning Through Programmes, Courses, and Workshops

Formal programmes that are designed around the various threshold concepts related to learning to be a researcher can be an effective way of helping with scientific thinking. The two examples provided here briefly outline how addressing the various threshold concepts can assist in framing a curriculum for research learning and teaching, and thus the development of scientific thinking skills. If one were to identify the learning outcomes for a formal programme, such as a Graduate Certificate in Research Methods which has been designed to help Masters and Doctoral research candidates, one stated learning outcome might be: *learners would demonstrate an understanding of the concept of analysis.* This learning outcome would not only require students to demonstrate skills in analysis, but an understanding of the actual concept of analysis. Achievement of such a learning outcome would contribute to the development of the habits of mind of a researcher as proposed by Walker (2012) when he suggested what questions one should ask when developing a curriculum for doctoral education:

> First, what habits of mind do you want the people to have to help them be lifelong learners? Most of what they learn (in many fields) will be out dated, irrelevant or wrong in five years. So, clearly, they're going to have to be able to learn new things. What habits of mind do you want them to have in order for them to be able to do that? What content knowledge? What skills and what experiences do you want them to have? (Walker, 2012, p. 14)

One of these habits of mind is the concept and skill of analysis with all its complexity and significance. However, the difficulty with a programme that precedes the actual research is that often the student needs to demonstrate various knowledge and skills in a hypothetical way through critiquing the literature or through the use of a 'manufactured' activity. Therefore, to demonstrate this understanding candidates would need to not only be able to critique analysis in various journal papers, but also suggest analytic methods appropriate to their potential research question and methodology. That is, to explain the concept of analysis in addition to demonstrating the relevant analytic skills.

Another learning outcome might be something along the lines of: *learners would be able to discuss and demonstrate the use of theory.* Again, this activity might be occurring before the learner actually undertakes her/his own research. Given this, it is likely that much of the demonstration of understanding will come from critiquing the work of others.

However, in addition to the use of threshold concepts, as the basis for courses and workshops, the introduction of the idea of liminality and being 'stuck' can also assist learners in fully understanding the key concepts and progressing with their research. Being in the liminal space generally implies that the learner is actually undertaking research and this provides opportunities for supervisors to highlight particular concepts and understanding.

## How Might an Understanding of Liminality Assist a Learner's Scientific Thinking?

While one might not think of the term 'being stuck' as a particularly educative one, research suggests that the emotional aspect of feeling stuck can be a critical aspect of learning. McKenna (2017), in her paper on crossing conceptual thresholds, comments: 'All 28 participants [in her study] acknowledged the sense of being stuck during their doctoral studies and this question [about being stuck] elicited heartfelt description' (p. 462). For example, one respondent reported: 'I was stuck pretty much consistently—together with a feeling of complete inadequacy' (p. 462).

From the research and reported experiences, one of the most effective ways to assist candidates to cope while being stuck in a liminal state is to help them recognise the state, and the emotions that accompany it. This is the idea that it is not uncommon, perhaps even to be expected, that most candidates have been, and are still, going through the liminal stage of learning and that feeling completely inadequate is not just novel to the individual candidate.

The role of feedback and the type of feedback provided when a candidate is in a liminal state can be critical in assisting learning. For example, helping the candidate appreciate that while their recent work is certainly a development/improvement of earlier work, it is still not 'quite there'. This can be a difficult situation for both teacher and learner in how to give sufficient encouragement to help keep the candidate going, and yet at the same time, enough critique and feedback to help in expanding and developing the work (Stracke & Kumar, 2016).

A suggested way of assisting learners is to invite candidates who are more advanced in candidature to reflect on their experiences with less experienced peers (Boud & Lee, 2005). This can be through group meetings, journal clubs, writing partners and writing groups, and candidate associations. Not only can peers provide feedback on work, but often they are able to share experiences in a way that highlights that having difficulty is not at all unusual. In fact, Kiley (2014) found that candidates reported that peers were often more helpful in making sense of their difficulties than were their doctoral supervisors.

Perhaps of particular value for inviting candidates to work together, for example in writing groups or with partners, comes from the work of Aitchison (2009) who found that giving feedback to peers helps the provider of the feedback to learn how to accept and utilise feedback from others, generally their supervisors.

Another strategy that is often reported in the literature is to highlight the idea of mimicry or as McKenna (2017, p. 462) suggests 'A key notion in the threshold concepts literature is that students sometimes "fake it 'til they make it"'. By mimicking the ways of behaving, speaking, and presenting that they see their more experienced peers and supervisors doing allows learners to develop their own sense of ownership and feeling of authority. The alert supervisor is the one who is able to identify the mimicry and then the moment of authenticity following the crossing of the conceptual threshold (Kiley, in press).

Additional to having candidates understand the liminal state and the idea of being stuck, and possibly mimicking, there are other, perhaps more 'academic' strategies that are often used. One common example is journal clubs where candidates analyse and discuss discipline-related journal articles and identify key issues in the scholarly presentation of the research. While some journal clubs focus specifically on the content of the article, working through issues such as structure and language can be particularly helpful to the candidate in a liminal state. While it is generally reported that such clubs and groups are common in the natural science disciplines, this is perhaps based on the idea that the candidate will be reading articles for their content. However, in the social sciences and humanities such groups can also be useful when the criteria for selecting the articles are more attuned to structure, critique, theory, discussion of methodology and analysis, and so on. In fact, reading something from outside one's topic area may well make it easier to see the underpinning arguments and presentation rather than being distracted by the content: being able to see the wood for the trees.

Relating to the concept of thesis or argument, using metaphors and examples to explain these concepts is often seen as an effective way of helping candidates with this concept. For example, the idea of being in a court of law where one lawyer, perhaps for the defendant, will outline her case by stating the positive aspects of her client's position. However, in addition, she will explain that it is not just enough to put one side of the argument, but to suggest what the opposition are likely to argue and outline, from the evidence, why this is not appropriate. In this way, supervisors can help candidates with presenting both sides of the argument and then suggesting why the data supports one in particular.

Another strategy recommended by Metcalfe (1996) regarding argument is the use of written examples that are deconstructed and critiqued. His book has numerous examples of how this might work in the business discipline. Using examples from previous theses in the discipline can be helpful with this as they are likely to be close to the candidate's own topic of research.

A third strategy that has been observed is the frequent use of the opening line: *In this talk/presentation/paper/discussion/thesis I will argue that … and I will present the data that supports this argument.* While initially it is highly likely that there will be considerable mimicry, over time, and with support, the mimicry is likely to decrease.

Interviewees in the Kiley (2009) and Kiley and Wisker (2009) studies suggested that taking on the role of Devil's Advocate was also a very successful way of encouraging candidates to develop an argument. Such a role needs to be carefully considered, particularly if doing this between two supervisors during a supervisory meeting with the candidate. As Gunnarsson, Jonasson, and Bilihult (2013) suggest, often supervisors can 'role play' opposing views in order to help the candidate appreciate differing perspectives. However, as they warn, before the end of the meeting it is critical that the supervisors assist the candidate in coming to their own conclusion, rather than leaving them 'up in the air' with conflicting advice.

As noted above, for some candidates grasping the threshold concept of theory can be a real challenge, particularly those who come from some of the professional disciplines. As Salmento, Kiley, and Murtonen (2017) found in their study of teacher education students, there were at least four concepts of theory reported. The first and most basic was a conception that related theory to everyday thinking, whereas the second conception was that theory explained practice. The findings identified a third conception which was that theory models phenomena and the fourth that theory is being created through research. The authors suggest that one way of explaining this wide variation is that the term 'theory' is used in many different ways including the every-day through to sophisticated research and so it is confusing for those learning to think like researchers, that is, to think scientifically.

Strategies reported in the literature again relate closely to teaching. For example, discussing journal articles that have been specifically chosen for their use of theory whether it be to frame the study, provide a methodological approach or propose a theory from the research. For some candidates, particularly those who have more basic conceptions of theory, this activity needs to be undertaken a number of times, whereas for some others, their world view is theoretical from the early stages of candidature.

## Conclusion

It might already be abundantly clear that the strategies above involve teaching in some form or other. For some doctoral supervisors this would come as a surprise as they see supervision being related to their role as a researcher, certainly not their teaching role. And yet, through one-to-one interaction, as in the supervisor/candidate or through teaching/learning relationships or in groups of peers where the interactions are structured to encourage peer teaching, are strategies for assisting candidates in learning scientific thinking.

Therefore, this chapter will end with some comments on the supervisor rather than the candidate. As many of the handbooks on supervision suggest (see, for example, Boud & Lee, 2009; Lee, 2012; Taylor, Kiley, & Humphrey, 2018; Wisker, 2012), there are distinct pedagogical roles for doctoral supervisors. These roles link closely to the perceived purpose of the doctorate.

As Akerlind & McAlpine (2017, pp. 1690–1693) suggest, the doctorate has a role in:

> enabling students to become self-sufficient as researchers, through training in research skills and requirements … enabling students to become innovative as researchers, through developing their ability to create new ideas…[and] enabling students to develop as individuals, by ensuring their enjoyment of and commitment to the doctoral experience.

For each of these three purposes, the authors suggest various pedagogies. For example: ‘When asked what they did as supervisors to help their students think innovatively, the participants described questioning and challenging students in various ways, and encouraging them to consider alternatives’ (Akerlind & McAlpine, p. 1691).

Therefore, research supervisors have a critical role in assisting the candidate with understanding key issues and concepts related to research (Kiley, in press). Using research-related threshold concepts and the idea of being in a liminal space are two ways of framing this teaching either through courses, workshops, one to one meetings, or feedback on written work.

Being alert to the candidate who is 'stuck', 'going around in circles', mimicking, and feeling inadequate are important roles for the supervisor as a teacher. Additionally, this chapter has argued that appreciating the specific threshold concept that the candidate needs to fully understand in order to cross the threshold of 'doctorateness' and assisting in that crossing is a critical role for the supervisor in the development of scientific thinking.

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# 7

# The Acculturation and Engagement of Undergraduate Students in Scientific Thinking Through Research Methods

Anesa Hosein and Namrata Rao

## Introduction

In undergraduate social science degrees across the world, students are often expected to complete research projects, dissertations or theses (Hosein & Rao, 2014). In order to undertake any research study, students will normally engage in scientific thinking skills that would enable them to critically assess, analyse and evaluate the data and associated literature to formulate research questions and find answers. How students are expected to develop these scientific thinking skills may be either through a structured programme of learning, such as a research course within a university, or through developing their critical thinking skills that is embedded within their degree programme as they move through each level. There is sometimes an underlying assumption that scientific thinking skills are generic

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and consistent across disciplines (Phillips & Bond, 2004). However, the research paradigms that encourage particular scientific thinking skills may depend on the context in which the students are undertaking the study, such as their discipline, university and country (Kivunja & Kuyini, 2017). Becher and Trowler (2001) explain that the way we approach and think about knowledge is through the lens of our discipline and thus the development of scientific thinking skills within disciplines is about becoming part of an academic tribe, demarking the disciplinary territory and in some ways internalising the disciplinary thinking and practices.

Within the social sciences disciplines, and more commonly within the UK, most of the scientific thinking skills related to the research dissertation are expected to be developed within research methods modules (Hosein & Rao, 2017b). Research methods modules are modules that are often run the year prior to undertaking the research dissertation, with the research methods and research dissertation making up the research phase of the degree. In recent years, there has been a move to embed research methods and scientific thinking within the teaching of the core modules rather than as stand-alone modules (see for example Buckley, Brown, Thomson, Olsen, & Carter, 2015; Greene & Yu, 2016). However, traditionally they have run as several stand-alone modules covering quantitative and qualitative analyses either together or separately with the separate option being the tradition within sociology and psychology disciplines. In these modules, the assessments often lead to group work or examinations (Hosein & Rao, 2014, 2017b). More commonly, a single module, referred to as 'research methods' may cover both positivist and interpretivist research paradigms and students develop a research proposal as the assessment (Hosein & Rao, 2017b).

This chapter explores how these one-off stand-alone modules focussing on the teaching of research methods can enable the development of scientific thinking skills. In particular, it looks at how these modules can indoctrinate or socialise these students into the scientific thinking skills of their disciplines. We use the lens of acculturation theory to examine the socialisation. Unlike Becher and Trowler (2001) who examined socialisation on academics who were already firmly rooted in their discipline, our focus is on undergraduate students who are still on their journey of being socialised within their discipline's knowledge and practices and are still taking early decisions on whether they would proactively be socialised into their discipline (Howkins & Ewens, 1999). Acculturation theory, therefore, affords a way of looking at the socialisation as being a tensile force, where students are pushed towards engaging and learning the scientific thinking skills advocated by their discipline and may, therefore, demonstrate different degrees of socialisation and associated disciplinary skills.

## What Are Scientific Thinking Skills?

In universities, academics want students to gain higher order thinking skills. These higher order thinking skills are normally the scientific thinking skills that students should further develop during their university education. We expect that students will gain competence in the higher order thinking skills by the time they graduate, such as using the methods of scientific inquiry to evaluate and critically analyse knowledge as well as using skills to test and revise theories for solving problems (Zimmerman, 2007). These are essentially the higher order thinking skills that curriculum designers try to imbue in the research methods modules. Curriculum designers assume that students entering universities will not have accrued these higher order thinking skills that are 'distinctive' within their discipline before starting their undergraduate studies (Entwistle, 2005).

Achieving higher order thinking skills may not in itself create the 'distinctive' discipline-specific higher order thinking skills. For example, achieving higher order thinking skills in physics does not necessarily make a student have the higher order thinking skills for English literature. We contend that students can achieve some generic set of higher order thinking skills which are transferrable across all disciplines, but there are some discipline-specific thinking skills. Students who achieve these discipline-specific thinking skills are then embedded in the disciplinary higher order thinking skills which may be often unique to the discipline and more sophisticated. This approach suggests that students become imbued with a particular epistemological and ontological lens for viewing and thinking about the world and start thinking like a physicist or a sociologist, for example. We, therefore, suggest what Entwistle (2005) alluded to, that these distinctive discipline-specific ways of thinking, are the scientific thinking skills. It is to be emphasised that these epistemological and ontological beliefs are often honed and enhanced by understanding the research processes and also through undertaking research in the discipline to gain experiential learning. This distinctive way of thinking is the epistemic thinking of the discipline. Epistemic thinking includes both the epistemic cognition and metacognition of the discipline (Barzilai & Zohar, 2016).

Typically, first-year students should have achieved lower order disciplinary thinking skills of where the reality of their discipline is represented as facts and the reality is known and certain. This is typical of the learning outcomes in high school education (see for example the European Qualifications Framework [European Commission, 2019]). Kuhn, Cheney, and Weinstock (2000) refer to this as absolutist epistemological understanding; in this epistemological understanding, the students consider disciplinary knowledge as mainly factual but recognise the need to compare assertions to determine any falsehoods. Through the university process, students are expected to achieve the epistemic or distinctive way of thinking within their discipline by the end of their undergraduate degree (Entwistle, 2005). It is during the research phase of most degree programmes that the disparate higher order thinking skills are brought together to allow students to demonstrate their epistemic thinking within their discipline. Thus, the undergraduate dissertation, a capstone assessment, allows students to bring together and demonstrate their higher order thinking skills (Garde-Hansen & Calvert, 2007).

Typically for a three-year degree in most countries, the scientific thinking skills that students are engaging in during the second year of their degree via the research methods module, are aimed at developing the student's skills in formulating a research problem, solving unstructured disciplinary problems, applying creative thinking skills and using analytical skills within the disciplinary context. During the final year, students in their dissertation module hone these analytical and evaluation skills when undertaking a piece of disciplinary research and in writing the research report/dissertation. Thus, there may be disciplinary differences in how these skills manifest themselves (Greene & Yu, 2016).

Further, building on Entwistle's (2005) work, we argue that these epistemic thinking skills are both threshold epistemes (Perkins, 2006) and threshold concepts (Meyer & Land, 2003). Threshold episteme is the thinking that shaped the students' sense of the entire discipline and this includes transitioning and learning the language of the discipline (Perkins, 2006). Threshold concepts, like threshold episteme, are considered as troublesome knowledge. A threshold concept is the knowledge that is needed to understand a discipline, and once learned, it is difficult to unlearn it. However, getting over the threshold of learning an important concept takes time and students are often left in a liminal space, where they are at the brink of understanding the concept but are still not quite there. In the threshold concept domain, Meyer and Land (2003) demonstrated that the critical thinking or the type of knowledge that is needed within each discipline is distinctive. In other words, to become socialised into the discipline and its ways of thinking, students need to understand the troublesome knowledge within their discipline, the 'threshold concepts'. Once students know and understand these threshold concepts and have the epistemic language of the discipline, this paves the way for them to acquire the discipline-specific higher order scientific thinking skills. What makes students understand these threshold concepts to acquire the discipline-specific higher order thinking skills remains unanswered. However, one could assume applying and evaluating the discipline-specific knowledge during the research phase to problem solve and create new knowledge may be helpful in securing the discipline-specific threshold concepts as students are learning how to use their disciplinary language and concepts in context. We use the acculturation theory in the following section to address the question of how students become socialised into the disciplinary higher order thinking.

## Acculturation Theory as a Framework for Understanding Students' Engagement with Scientific Thinking

Acculturation theory, proposed by Berry (1997), is a conceptual framework from cross-cultural psychology that looks at the strategies that migrants use to adapt or settle into their new cultural contexts. However, this is not a uni-directional adaption, and this mirrors the complexity of the society that the migrants adapt into, which explains the multiplicity of Berry's acculturation strategies. Berry argues that there are three factors that influence the creation of plural societies (i.e. societies with different cultures)—voluntariness, mobility and permanence. Voluntariness indicates the level that people volunteer to move from one context to the next, for example, expatriates versus refugees. Mobility refers to how individuals come in contact with a new culture, that is, whether they move into a new culture, or whether they experience a new group moving into their environment. Finally, permanence refers to the extent that the group intends to stay within the new/changed context, that is, whether they become permanent or temporary migrants.

Whilst these are the main factors that influence the exposure to a new culture within a plural society, Berry (1997) goes onto explain that acculturation groups, may adopt different strategies that affect their acculturation, and it is contingent on two values and beliefs:

1. Cultural maintenance—this is the extent of the maintenance of their own cultural identity.
2. Contact and participation—this is the extent of the involvement in their own and other group's culture.

Depending on the level or extent the migrating group subscribes to these values and beliefs, they may adopt four different acculturation strategies (Table 7.1) called integration, assimilation, separation/segregation and marginalisation. Both the marginalisation and separation acculturation strategies create a sense of isolation within the plural society, with those who are marginalised often left with little support from their cultural background or sense of cultural identity. Those individuals who adopt an assimilation or integration acculturation strategy may well be supported within their plural society, however, those with an assimilation strategy will lose the support from their original cultural background and lose a sense of cultural identity.

This conceptual framework does have its critics. In particular, Berry (1997) presented these acculturation strategies as being independent and at the same time, not uni-linear (Berry, 2003) when there might well

**Table 7.1** Acculturation strategies

| Contact and participation | Cultural maintenance | |
|---|---|---|
| | Low | High |
| Low | Marginalisation | Separation/segregation |
| High | Assimilation | Integration |

be a case where individuals may occupy the liminal/in-between spaces. We take Berry's categories to be a continuum rather than occupying one category, that is, we expect individuals to have a gradation in the amount of cultural maintenance, rather than an all or none approach and often they may move from one space to another rather than just occupy one space for all their life.

There is evidence to suggest that the three strategies of assimilation, integration and separation are not completely independent of each other (Schwartz & Zamboanga, 2008). Further, there is unlikely to be a marginalisation acculturation theory as individuals are unlikely to have a cultural identity that does not borrow from their current or historical cultural identities and instead they may well be facing a cultural identity confusion (Schwartz & Zamboanga, 2008).

## Transitioning from High School to University

We have used acculturation theory as a framework to explain students' progressive engagement with scientific thinking skills as they transition through their university education and engage in disciplinary research methods. First, we consider the motivations for entering a particular degree programme at a university. Unlike in high school where students are required to study a range of subjects, at university, students often select one main subject in which they major. The selection of this subject is dependent on the number of spaces on the programme and the past performance of the students. Therefore, there are many cases where students may transition into university programmes they did not intend to originally study, but one which was available to them due to various limiting factors such as not securing the entry tariff coupled with limitations posed by limited places, lack of availability of the desired subject, etc. (Hosein & Rao, 2017a; Lastusaari & Murtonen, 2013). Further, there may be some students who enter into university because it is a rite of passage and therefore they do not always know which subject they would like to study and may choose subjects that closely align to their friends or to parental expectations (Briggs, 2006). Therefore, students entering university can be viewed as educational migrants. There are some who enter by choice (voluntariness), what in literature is referred to as self-initiated migrants rather than being forced onto a particular educational path, referred to here as educational refugees. Further, extrapolating from Kuhn et al. (2000), we suggest that high school students may have a primarily absolutist approach to thinking about their discipline (not necessarily in their own personal thinking skill) as this is the level of thinking, as we noted before, that is promoted through the national educational frameworks.

In moving into university, it is likely students may maintain their cultural thinking from high school or adopt the cultural thinking from university, where some may make this transition in thinking skills more easily than others. Therefore, to update Table 7.1, for the context of educational migrants, we will have an acculturation strategy as seen in Table 7.2. When we consider disciplinary acculturation of the educational migrants in university education, the assimilation strategy is perhaps seen as the most conducive to the development of the disciplinary higher order scientific thinking skills. Assimilation strategy in this context resembles that of the socialisation into the discipline, that is, students are expected to leave their high school thinking skills behind and to embrace the discipline's scientific thinking skills. Students are also expected to embrace the contact and participation in disciplinary discussions and practices and discard high school thinking skills when participating in written and verbal discussions and in the analysis of arguments and data. Bragg (1976) explains that it is through such a disciplinary socialisation process that higher education can support students to achieve the subject-specific threshold concepts to allow the development of higher order scientific thinking skills amongst their graduates and that university undergraduate programmes are designed to achieve this socialisation or assimilation process. This can perhaps emulate the evaluativist approach suggested by Kuhn et al. (2000), where the

**Table 7.2** Acculturation thinking skills—strategies adopted by students moving from high school to university education

| Contact and participation within the disciplines' scientific thinking skills | Cultural maintenance of high school thinking skills of the discipline | |
|---|---|---|
| | Low | High |
| Low | Marginalisation | Separation/segregation |
| High | Assimilation | Integration |

student can use the lens of their discipline to make judgements on assertions in their discipline by using appropriate disciplinary arguments, theories, principles and evidence. It is here through the assimilation acculturation strategy that students move from becoming disciplinary migrants to disciplinary citizens. Therefore, it is when the undergraduate programmes cannot achieve this assimilation process into the discipline's scientific thinking skills that it creates situations where students adopt other acculturation strategies, which may be less conducive to the development of higher order scientific thinking skills.

In the integration strategy, students tend to use a combination of the thinking skills which they would have developed at high school in combination with some of the higher order scientific thinking skills of their discipline. The integration approach can map onto a student transitioning from an absolutist approach with some elements of the evaluativist and multiplist understanding where the multiplist understanding is when the student recognises that there are multiple realities coming from different disciplinary traditions hence knowledge is uncertain, however, the student is unable to make judgement on them (Kuhn et al., 2000). Students adopting a separation strategy in university education may use a greater proportion of absolutist understanding during their degree and have limited critical thinking skills to even consider different perspectives or standpoints. Students adopting a marginalisation strategy within their university education would be those who in general are marginalised from the studies as such not having predominantly gained high school level thinking (that is absolutist) and hence may find it difficult to transition into higher education. They are likely to have a lower level of developmental understanding such as a realist understanding of their discipline, that is, for them reality is known and certain (Kuhn et al., 2000). However, these students are perhaps unlikely to make it to university or complete university education as their realist position will encourage the remembering and reproduction of facts that would not be awarded positively through the assessment procedures of both the university and the high school (Asikainen, Parpala, Virtanen, & Lindblom-Ylänne, 2013).

We contend that the research methods and dissertation modules in a degree are the vehicles via which students are able to explore or cement their stance of ontological and epistemological perspectives in their epistemic thinking and hence can play a significant role in transition to an integration or assimilation strategy to university education as these courses are key to developing and demonstrating these skills. However, the question that remains unanswered is—what determines the acculturation strategy students choose to adopt/demonstrate when making the transition to higher education?

## Self-Determination Theory

We noted previously, the acculturation strategy that students demonstrate may be dependent on their motivations to study a discipline. Ryan and Deci (2000), in their self-determination theory (SDT), explain that there are two main types of motivation. The motivations of students into their different disciplines may differ depending on whether they have an intrinsic or extrinsic motivation towards their disciplines. These motivations may affect their proactive acculturation into their disciplinary way of thinking, that is, the threshold concept and episteme that is inherent in their discipline. SDT suggests that students self-determine their growth or achievements in their life in order to achieve self-growth. These achievements are driven by their intrinsic motivation. However, their intrinsic motivation may be thwarted by feelings of competence, supportive-autonomy and relatedness. Competence is the feeling of considering oneself capable of achieving the requirements of the degree programme, whilst supportive-autonomy is where students feel supported in having control of different aspects of their learning, whilst relatedness is the feeling of being part of a community.

In intrinsic motivation, students are motivated to pursue their discipline or subject because of genuine interest and passion for the subject, that is, they want to be part of the disciplinary culture and its way of thinking. Hence, students would seek opportunities to learn about their discipline thinking and to engage in the research of that discipline. However, if at any point they do not feel like part of their disciplinary culture (relatedness), or come against something difficult that they do not feel they can achieve (competence) or feel as if their learning is being imposed on them rather than them being in control of their learning experiences (supportive-autonomy), they may then adopt an extrinsic motivation. In the extrinsic motivation orientation, students aim to study a particular discipline as a means of achieving a goal that is not related to a genuine interest in the discipline. However, students who may not want to be part of the discipline may eventually become invested and interested in their discipline/degree.

Therefore, when we have students who are education migrants who have come into a discipline to be with their friends or because the degree may be important for their future job prospect rather than a genuine interest in the subject, then we are faced with an issue of extrinsic motivation. In the current marketisation era of higher education particularly prevalent in Western education, some students are looking for returns on their investment (Tomlinson, 2013, 2016). Therefore, there is likely to be more extrinsic motivation coming into play, and fewer individuals coming into the subject for genuine interest in the discipline. This means that extrinsically motivated students are possibly less likely to proactively engage in the discipline's way of thinking (Howkins & Ewens, 1999) and are hence in danger of not being integrated or assimilated into their discipline. This is perhaps particularly so for the social sciences where students' careers are often not linked to the degree that they are studying (Hosein & Rao, 2017a) and hence for students, there is limited need or requirement to think, behave or use the language of the discipline except for passing the assessments.

## Pedagogical Interventions Within Research Methods

Getting the extrinsically motivated students to engage in scientific thinking skills of their discipline may present a challenge. There is likely to be a twofold problem here, first, that of the engagement with scientific thinking skills and second, being able to overcome the disciplinary threshold concepts and episteme to enable a genuine engagement. Intrinsically motivated students who have had an interest in the discipline since high school may have the willingness to acquire these or already have acquired some of these scientific thinking skills and hence, are more likely to face the second issue. This makes the transition for such intrinsically motivated students from the lower order thinking skills acquired in high school to the higher order scientific thinking skills of the discipline less fraught with challenges. However, for the extrinsically motivated, the higher education curriculum has to create opportunities to engage them in the discipline-specific higher order thinking skills.

Those students who have used an integration or separation acculturation strategy are more likely to inhabit the liminal space of absolutist and multiplist epistemological understanding. To reach the evaluativist epistemological understanding, then, it puts the onus on teachers to help students transform their lower order thinking skills into the discipline's epistemic thinking. How do teachers get them over this liminal space within research methods modules? Research methods modules because of their design emphasise the analysing and evaluating of arguments and data. However, teaching students these processes alone, unless the students are proactive, may not create the change to epistemic thinking.

To allow students to start acting and thinking in the way of the discipline, teachers need to create opportunities that tap into students' intrinsic motivation that would allow them to proactively want to engage in the epistemic thinking of the discipline. Pedagogical activities designed by the teacher need to ensure that students' competence, autonomy and feelings of relatedness are not compromised.

Therefore, firstly, within research methods modules, teachers need to create more open-ended assessments that can allow students to investigate problems within the discipline that is of interest to them which can tap into students' intrinsic motivations (Enis, 1993). These open-ended assessments, for example, can take the form of supportive project-based learning (including problem-based and enquiry-based learning) within research methods modules. Through these pedagogical methods, students can realise the unstructured nature of problem-solving within the discipline (Milne & McConnell, 1999). Thus, through support and dialogic feedback from teachers (hence, allowing feelings of relatedness), students can consolidate the epistemic language for describing the problem, such as, through the use of appropriate theories (Ajjawi & Boud, 2017; Nicol, 2010). Therefore, students can begin to look at problems through the discipline's lens and use the tools, methods, principles and theories to analyse the problem. However, any supportive structure from teachers should open up autonomy rather than be restrictive such as the need for compulsory attendance as this can affect intrinsic motivation (Wijnia, Loyens, & Derous, 2011). The extent that this described approach can develop the evaluatistic thinking may not be sufficient. Therefore, teachers should also be able to, through their dialogic feedback and support, help provide counter-stories to students' investigations or to ask students to triangulate their data. This approach can help students gain the support from teachers to examine issues from different perspectives (allowing for increased competence), using different theories and different methods which allows students to build their judgement of the different perspectives. In this way, students' epistemic thinking is being built to recognise that in the social sciences there is not one story but different counter-stories seen through different epistemological and ontological lenses. Allowing students to experience these different approaches can help them to recognise the limitations of different methodological and analytical approaches in their discipline and moves them to understand that there is no definite answer. Through this approach, it can help students to recognise how and where they position their ontological and epistemological selves. However, to get students to recognise their positions, these concrete experiences need to be reflected upon in order to create the conceptualisations of epistemic thinking (Kolb, 1984). Through reflecting in the written form, students can create their self-authorship of their epistemic thinking (Magolda, 2008).

Hosein and Rao (2017b) have used this type of pedagogical intervention to support the development of students' epistemic thinking in educational studies. In their intervention, students were required to pilot a research method looking at an educational issue that was important to them (hence, ensuring the autonomy of the students). Students were then required to write a reflective essay of the experience to consolidate their epistemic thinking. Hosein and Rao (2017b) noted that this process helped students' epistemic metacognition of educational research through allowing them to form their academic identities as educational researchers, that is, they were becoming to think and act like an educationist. Therefore, students need a space for reflective thinking to allow them to move from the liminal space that they exist it.

Thus, research methods modules present a place where the more extrinsically motivated students can be supported by their teachers to develop the higher order research skills within a discipline by helping them to explore issues that the students are interested in. The modules offer the students an opportunity to choose a research problem of interest to them and they are, then, encouraged to develop and demonstrate the higher order thinking skills in finding an answer to their research problem. One challenge the teacher may face is in making students see the purpose of these modules for developing scientific thinking skills that will be useful in their prospective careers rather than thinking of the disciplinary scientific thinking skills as something discrete and detached from their future career prospects or something that is of relevance for their discipline/university education only (Hosein & Rao, 2012; Murtonen, Olkinuora, Tynjälä, & Lehtinen, 2008). For example, Hosein and Rao (2012) noted in their study of widening participation students, that the majority of these students who were starting their research methods course felt that the research methods would provide them with information literacy skills for searching for a job, with very few recognising the relevance of scientific thinking skills to their future jobs.

## Conclusion

This chapter used the lens of acculturation theory and positions students moving from high school into university education as educational migrants who have to adapt to a different culture of thinking that of scientific skills, which is what makes university education distinctive. We posit scientific thinking skills are higher order thinking skills that are epistemic in nature. The SDT provides a possible basis for identifying the groups of students who would need the most support in achieving scientific thinking skills.

The discussion uses the idea of threshold concepts, that is, that disciplinary scientific thinking skills are a threshold concept, such that there may be students who may never secure the scientific thinking that is expected for their discipline, even within research methods and dissertation modules which are often designed to encourage such skills. These are the students we termed as the marginalised and separated. Students who have intrinsic motivation may be proactive in becoming socialised into their disciplinary community and may have less resistance to their epistemic thinking approach. Students with extrinsic motivation in a degree may feel more inclined to their discipline's epistemic thinking skills, by helping them to have more autonomy to investigate issues that are important to them, and create support structures that allow them to feel part of the disciplinary community, feel competent to achieve these thinking skills as well as supported by teachers in achieving these thinking skills. Therefore, in order to support the students to acquire scientific thinking skills, the teacher needs to design the curriculum, particularly the research methods courses, that scaffold students to the three aspects of SDT in students' learning, that of supportive-autonomy, relatedness and competence. If these three aspects are not engendered, there is a danger that students may inhabit non-optimal acculturation approaches.

Further, it is still unclear how students overcome a threshold concept, as there is no clear research on how students make this jump and when their thinking shifts. Research suggests this may take years to occur or it might be a momentary thing, that is, the students just 'get it' (Meyer & Land, 2005). The process of 'getting it' is difficult as it requires a completely different way of thinking. However, what we as educators can do is to create a learning situation to support this 'getting in'. That is, allowing students opportunities via curriculum and assessments to develop and demonstrate higher order thinking skills when the shift in thinking occurs that students either successfully integrate or assimilate in the higher order thinking skills of their discipline. This requires the analysis, evaluation, problem-solving and creative thinking that engages students in the aspects of their curriculum and assessments which are particularly attuned to fostering such skills.

Students who have a marginalisation acculturation approach may not even make their way into university, and therefore such a strategy may not even be seen in higher education, as these students are unlikely to engage in higher order thinking skills and even the lower order thinking skills of high schools, which may mean that they are unlikely to have the opportunity of progressing on to university education. However, those students in higher education who have a separated acculturation approach may still cling on to the lower order thinking skills from high school rather than engaging in the higher order thinking skills which is more commonplace in university education. As educators, we need to consider how we can engage such students who may be averse to engaging with higher order thinking skills. The challenge may also be to be able to recognise such students and create strategies to develop a learning environment which is conducive to promoting intrinsic motivation.

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# Part III

## Fostering the Development of Scientific Thinking in Higher Education

# 8

# Expertise Development and Scientific Thinking

Erno Lehtinen, Jake McMullen and Hans Gruber

## Introduction

Studies aimed at enhancing scientific thinking and research skills are important in all fields of university studies. However, only a small number of university graduates will continue as researchers, whereas a majority will begin work in professions that are not predominantly scientific. This raises the question of the relevance of students learning scientific research skills (Murtonen, Olkinuora, Tynjälä, & Lehtinen, 2008). Do they gain

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access to the competences which professional researchers need? What is the role of the knowledge of research methods and scientific thinking skills in other professions where highly educated people work?

Advanced knowledge is a crucial driver for the functioning and the development of contemporary economies and societies. Because of that, the role of scientific research findings is becoming more and more important in all professional fields. Professionals in various fields should develop the expertise needed in using scientific evidence in their daily work. Additionally, it is increasingly important that researchers develop the high-level expertise that makes scientific breakthroughs possible. In this chapter, our aim is to deal with the nature and development of scientific thinking in the field of research and other high-level expert professions and discuss what could be the contribution of expertise research in understanding the development of these scientific reasoning competences.

## What Is Expertise?

Exceptional performers in many fields, including craftsmanship, science, sports, music, and medicine, have long interested researchers and the public. Investigations have helped in understanding why some individuals reliably outperform others, explaining underlying reasons and mechanisms, predicting individuals' development of expertise, studying their influence on the societal communities they are part of, and supporting people in developing successful professional performance. Accordingly, some scientific explanations of human excellence have emerged while others have disappeared (Ericsson, Hoffman, Kozbelt, & Williams, 2018).

The Dutch psychologist De Groot (1946) initiated a novel line of scientific endeavour, as the first to inspire a completely new perspective on the nature of outstanding performance. In particular, he was the first to focus on domain-specific aspects of performance and in contrast to domain-independent aspects. De Groot focused on the differences between the best chess players' cognitive processes, in particular their problem-solving, and those of lesser performers. This problem-solving was captured using think-aloud protocols to gain verbal reports (Ericsson & Simon, 1993). De Groot found that (a) the best players had qualitatively different representations of chess positions than weaker players, (b) they had more and better information about problem situations, (c) crucial patterns and critical situations were more easily recognised, and (d) their analyses and action proposals of given chess positions were closely related. These qualities appeared crucial for finding the best chess moves in a short time.

Later, the role of knowledge in information-processing theories has been emphasised. This was initiated in the early 1970s spurred on by the inadequacy of using search processes to model complex human behaviour and the clearer evidence of prior knowledge's role in solving problems. It was at this stage that De Groot's work was finally acknowledged, once increasing evidence confirmed his notion that even basic information-processing is affected by prior experience (Chase & Simon, 1973a, 1973b).

Since then, empirical evidence had confirmed that the advantages held by exceptional performers are not based on a general supremacy but are instead limited to the domain. A new theoretical view around the concepts of "expert" and "expertise" was thus designated. These theories about the acquisition of expertise explained performance as domain-specific, "hand-made", and based on the growth of routines, skills, and abilities gained through extended, carefully designed practice ("deliberate practice"; Ericsson, Krampe, & Tesch-Römer, 1993). Additionally, theories about the restructuring of expert knowledge based on experience emerged (Boshuizen & Schmidt, 1992; Kolodner, 1983), and support for the acquisition of expertise was considered important in instruction (Brown, Collins, & Duguid, 1989). These studies confirmed the immense plasticity of human cognitive performance. Expertise was demonstrated to be the most appropriate adaptation to the requirements and constraints within a domain (Ericsson & Lehmann, 1996; Gruber, Jansen, Marienhagen, & Altenmüller, 2010), leading to changes in neural, physiological, cognitive, and perceptual-motor parameters.

## Deliberate Practice

The process of knowledge restructuring describes how experience leads to changes in domain-specific cognitive representations of individuals. Not just any experience leads to knowledge restructuring as such. Instead, relevant cases are needed for preparing to act appropriately in the domain and meet professional requirements. The core idea of deliberate practice is that such processes must be fostered and guided in practice activities. Performance levels of professional musicians were not related to the amount of domain-related activities in total, according to Ericsson et al. (1993). Instead, the total amount of solitary practice was most closely associated with performance levels. This solitary practice involved training specific aspects of performance, as recommended by teachers: "Part of the practice is to gradually embed the trained task in its natural context with regular time constraints and less predictable occurrences" (Ericsson, 2009, p. 417). This focus on improving performance differentiates deliberate practice from playful engagements and routine, mindless performance. These latter forms of activity are less impactful on performers' current levels.

Years of practice often do not lead to development beyond local levels of competition in sports, as can be easily recognised in many athletes. Instead, deliberate practice—sustained, conscious, and goal-oriented training—is required for outstanding high-level expert performance. Such active learning requires continuous effort to overcome barriers to performance and improve levels of performance, as noted by many others (Bloom, 1985; Cleveland, 1907; Dreyfus & Dreyfus, 1986).

Already early in their careers, experts' learning processes differed from their peers, as noted in the retrospective interviews of Ericsson et al. (1993). Future experts had more dedicated coaches and teachers were more efficient in their practise, and demanded higher achievement. Experts' training activities were, for a long time period, solely aimed at improving their performance. Even if they know it may improve their performance, individuals rarely spontaneously engage in deliberate practice. Instead, they engage in typical activities based on external rewards or inherent enjoyment (Lehmann, 2002). It is crucial for those who engage in deliberate practice to have teachers or mentors who offer targeted feedback and explicit teaching goals, which provides the possibilities for improvement through error correction and repetition.

Deliberate practice and teacher-guided instruction are closely connected. A teacher's ability drives the performance improvements that come from the gradual development gained from deliberate practice (Lehmann

& Ericsson, 2003). This ability is driven by the accumulation of artefacts and knowledge that has occurred in complex domains. Teachers share this accumulated knowledge with learners with an understanding of future skill requirements and can thus support learners' enculturation into expert communities of practice.

## The Theory of Knowledge Encapsulation

The theory of knowledge encapsulation stems from medical expertise development research (Hobus, Schmidt, Boshuizen, & Patel, 1987; Lesgold et al., 1988; Patel & Groen, 1986). The theory denotes three processes that characterise expertise development: knowledge accretion and validation, knowledge encapsulation, and illness script formation (Boshuizen & Schmidt, 2008). The theory has roots in De Groot's (1965) paradigmatic case processing research. It is a theory on knowledge restructuring, which is useful in explaining the positive relation between expertise and recall-precision in chess. However, in medical case processing research the relation between expertise level and recall is inconsistent, sometimes positive (Norman, Feightner, Jacoby, & Campbell, 1979) and sometimes negative (Patel & Medley-Mark, 1986). These inconsistencies suggest that the relation between the level of expertise and case recall in medicine is curvilinear. An inverted U-shape curve appears that is described as an "intermediate effect" (Schmidt & Boshuizen, 1992). Practitioners experience recall performance improvements during early training (up to six years) followed by falling performance with additional experience. This decrease in performance is associated with (1) increasing use of macro-concepts, (2) increasing reorganisation in recall in comparison with the initial case structure, and (3) a decreasing dependence of item recall on perceived importance of the item (Claessen & Boshuizen, 1985; Schmidt & Boshuizen, 1993a). Additionally, written case explanations and diagnostic think-aloud protocols of the underlying mechanisms follow an inverted U-shaped relation between the use of biomedical knowledge and expertise (Boshuizen & Schmidt, 1992; Schmidt & Boshuizen, 1993a; Van de Wiel, Boshuizen, & Schmidt, 2000; see also Patel & Groen, 1986).

In this context, the concept of "knowledge encapsulation" was first introduced (Boshuizen & Schmidt, 1992; Schmidt & Boshuizen, 1992). It referred to experts' use of macro-concepts in case recall (Schmidt & Boshuizen, 1993b). Although intermediates used a great deal of detailed biomedical knowledge, both experts and novices used very little. Despite this, experts used a great deal more macro-concepts that integrated biomedical and clinical knowledge than novices.

Given this integration, the drawn-out process of knowledge encapsulation appears to both shorten lines of reasoning and use umbrella terms to integrate new knowledge parts (Boshuizen, Schmidt, Custers, & van de Wiel, 1995). The complexity of the encapsulations used by experts and novices appeared to differ. Novices had incomplete concepts that affected their diagnostic performance. They treated certain crucial symptoms as unrelated and inexplicable, which contributed to incomplete case representations (Boshuizen & van de Wiel, 1998).

Repeated processing of domain-relevant cases appears crucial for learning and gaining experience (Prince et al., 2003; Schmidt et al., 1996). The typical task (e.g. diagnosis), which structures the process as well as the outcome, is inherent in this case processing. However, extant research relies on cross-sectional designs, limiting the surety of this assumption. A recent longitudinal study improves on these previous studies, but still has too short a time frame to move beyond previous cases (Boshuizen, van de Wiel, & Schmidt, 2012). Students compared their knowledge with cases and compared consequences and enabling conditions with different expressions of a disease. Relevant resources were needed to debug faulty knowledge.

## On the Role of Scientific Thinking When Experts Use Evidence in Their Work

In many professions, high-level experts are not researchers themselves. Yet, they need to understand the nature of scientific research to make crucial decisions. Most professional expert practices are based explicitly or implicitly on research evidence. In some fields, particularly in medicine, the use of research evidence is well-organised by consensus bodies, which help individual professionals make use of research findings in their practical work (West, 2000). However, in most other professional fields, there is no organised system for the use of research findings in practical work. Instead, it is the responsibility of individual professionals to find and interpret existing evidence. The use of evidence is, however, not a trivial issue (Reed et al., 2005; Susin, Nogueira Haas, & Kuchenbecker Rösing, 2010). During the last decades evidence-based practices have been enhanced in many professions and the ideas originally developed in medicine are spreading to other professional fields, such as education (Slavin, 2002). In spite of the popularity of the evidence-based approaches, only a few studies have critically focused on the skills and knowledge needed when professionals evaluate scientific evidence and make use of it in developing, conforming, or changing professional practices.

The first question is what kind of evidence professionals are looking for. Critical scientific thinking requires a deeper understanding that scientific research does not give direct answers to practical or societal questions. Seeking out evidence and afterwards combining and evaluating evidence dealing with different aspects of a question requires advanced professional skills. For instance, in the medical field there is a distinction between two types of sources of research providing evidence for practice: (a) comparative effectiveness research, which considers both costs and benefits, and (b) evidence-based research, where the aim is to find the best evidence to maximise best outcomes independently of cost. Expert practitioners must be able to take into account the differing goals of these approaches when weighing up the evidence. However, these alternative sources of scientific evidence are not so explicitly available in all fields.

The second demanding expert practice in using research evidence is to evaluate the usefulness and trustworthiness of the findings coming from different forms of research (Bowen & Zwi, 2005). To evaluate and make use of this variety of possible scientific sources in a sophisticated way requires well-developed knowledge and skills to reason about affordances and constraints of different research methods and designs. Informative findings can be found from case studies, small-scale experiments, surveys, large-scale (randomised) experiments, reviews, and meta-analyses (Nutley, Walter, & Davies, 2007, 2009). However, the methods of data collection, sample sizes, sample qualities, quality of experimental design, type of statistical analyses, etc., vary across studies, which must be taken into account in evaluating the suitability and relevance of research findings in informing practice. For instance, in medicine, evidence-based recommendations are normally based on meta-analyses. However, individual large randomised experiments are also often used as the basis for recommendations for policy and practice. Small-scale experiments and qualitative studies can provide insight into new phenomena in a way that is not possible to find from aggregated evidence (Flather, Farkouh, Pogue, & Yusuf, 1997).

However, recent trends in meta-science have clarified the difficulties facing even researchers in interpreting scientific findings (Ioannidis, 2005). For instance, meta-analyses are widely seen as most reliable sources of experimental evidence, although they are easily misleading without adequate methodological knowledge. The very idea of aggregating a large amount of experimental results from several studies is to overcome the biases of individual studies. They help to deal with inconsistencies in research and make it possible to analyse moderating and mediating variables (Stone & Rosopa, 2017). However, meta-analyses can also have weaknesses that limit the reliability and validity of the results, which must be taken into account when the findings are used in political decisions or developing professional practices. For example, publication bias results from authors being more willing and able to publish statistically significant results. This means that even though meta-analyses cover findings from a large number of studies, the results can be positively biased because of this distorting tendency in publication. Furthermore, only some meta-analyses include original studies that have replicated the same treatment. More often meta-analyses summarise findings from varying study designs and treatments and it may be difficult to say what the results exactly mean (Flather et al., 1997). All these features of meta-analyses mean that interpretation of them can be challenging for practitioners.

While these specific challenges require explicit expertise in methodological areas, perhaps the biggest challenge in the use of scientific evidence in professional practice and political decision making is related to the need to combine very different types of knowledge or epistemic cultures (Knorr Cetina, 1999). Studies have shown big differences between epistemic cultures of various research fields and professional practices making use of findings of these fields. There are differences for example in terms of contextualisation or dealing with complexity and uncertainty (Kastenhofer, 2007). This means that evidence coming from the scientific literature should be combined with other forms of knowledge used in practical work situations (Bowen & Zwi, 2005). For understanding the challenges of evidence-based policy and practice, the relationship between scientific and other types of knowledge is a crucial, but inadequately addressed, question in studies of evidence-based practice and policy. However, in studies of expertise development, the relationship between theoretical and practical knowledge has been extensively studied. The situation is similar to the processes dealt with in studies on knowledge encapsulation describing how formal knowledge is integrated with practical and situational scripts (Boshuizen & Schmidt, 1992). Formal knowledge of scientific evidence and even deeper knowledge of methodological constraints of the available evidence is not necessarily beneficial for the expert performance, if the person is not able to create macro-concepts integrating various forms of scientific knowledge and situated knowledge developed in practice.

## Experts in Science—Do They Think Differently?

There is a rich research tradition focusing on the development of scientific thinking in children and adolescents. These studies have mainly focused on how students of different levels of schooling learn to understand the scientific control-of-variables strategies or how students' epistemic beliefs about the nature of scientific knowledge are developed. Some studies, however, have analysed students' scientific thinking more broadly. These studies highlight that scientific thinking is a more complex phenomenon, which requires varying skills and knowledge. Kuhn, Iordanou, Pease, and Wirkala (2008) distinguished three aspects of scientific thinking that are more advanced than just controlling variables. The first is related to variable control but refers to the strategic ability to coordinate effects of multiple causal influences on an outcome. The second aspect is a mature understanding of the epistemological foundations of science, in particular understanding scientific knowledge as human constructs. The third aspect is the skilled argumentation typical to scientific domains, including the ability to coordinate theory and evidence.

These skills can be considered as the standards of scientific thinking, which university graduates should have learned during their studies. However, they are demanding. People typically consider only one hypothesis at a time, pay attention to the superficial similarity when using analogies, and often ignore information that would be important in reasoning about possible causal effects (Dunbar, 2001a). Many middle school students failed in tasks requiring this type of advanced scientific thinking (Kuhn et al., 2008), although some of the students managed to gradually learn to deal with these aspects of scientific thinking.

What about expert scientists? Does their work rely on the same skills? Are these skills more automatised and fluid? Or is there something more in their cognitive processes that makes professional scientists' thinking qualitatively different from the general scientific thinking required from university graduates (Murtonen, 2015)? There are only a few studies that have directly compared novices' and experts' abilities to apply general scientific thinking skills needed in research. The results of Schunn and Anderson (2001) show that university students have learned relatively advanced knowledge and skills related to scientific thinking in methodology courses, but they have difficulties in applying this formal methodological knowledge and general scientific thinking in concrete research tasks. Experts, using this knowledge in their daily work, are much better than students in applying general methodological knowledge when they have to design experiments for studying complex effects and relationships. These findings can be interpreted as evidence that university graduates and expert scientists basically share the same methodological knowledge and skills, but expert scientists are more fluent and skilful in applying this knowledge base.

However, in the Schunn and Anderson (2001) study there were also some findings showing differences between experts. The expert participants were selected so that one group were specialists in the particular scientific content (memory research) used in the experiment and the other group were researchers of other psychological contents. When planning experimental designs in the study, the experts of other domains applied a general rule to keep experimental designs as simple as possible, whereas the content experts applied more complex designs. These findings indicate that expert performance on demanding scientific tasks can only partly be explained by domain-general formal principles of scientific reasoning. Actual scientific practice is also based on expert scientists' rich domain knowledge which can mediate and facilitate the way how general scientific thinking can be applied in particular tasks.

Schunn and Anderson (2001) conducted their study in a computer-based environment, the Simulated Psychology Lab, where participants had to plan experimental designs according to the instructions given by the researchers. As such, this was a representative scientific task of the field (see the role of the representative tasks in evaluating expertise by Ericsson, 2006). However, completing the tasks took place outside the real research contexts in which experts were doing their normal work. This raises the question of the role of context in expert performance. Previous studies have highlighted the role of abstractions and generalisations in experts' thinking but, at the same time, the crucial role of particular cases and conditions in concrete activity contexts (Feltovich, Ford, & Hoffman, 1997).

## Scientific Expert Communities: Situated Practice and Epistemic Cultures

Along these lines are also influential sociological and anthropological studies on the functioning of scientific communities. Knorr Cetina (1999) has studied the knowledge creation processes in high-level scientific groups. These studies have highlighted the big differences between disciplines and groups in terms of criteria of empirical evidence, ways to deal with object relations, and relationship between theory and empirical research. These domain-specific features of scientific disciplines, called epistemic cultures by Knorr Cetina, challenge the notion of a unified scientific method. The differences between epistemic cultures can be seen in many aspects of scientific reasoning. For instance, molecular biology and ecology differ in terms of temporal/spatial scale, de-contextualisation and re-contextualisation of research objects, and dealing with complexity and uncertainty (Böschen et al., 2006; Kastenhofer, 2007). From this point of view expertise in science cannot be explained merely as a proficiency of a general scientific method or knowledge about the concepts and methods typical for a domain (Mieg & Evetts, 2018). Instead, these must be considered as necessary but not sufficient skills needed in real research work. In addition to the advanced proficiency of general scientific thinking, experts in science are a part of the epistemic culture of their field.

A more radical view highlighting the non-formal aspects of professional scientific practices was presented by Latour and Woolgar (1979), who carried out anthropological studies in science laboratories and argued that a typical experimental study results in mixed and inconclusive findings. In the real research processes, there is a continuous attempt to find out possible failures in the designs or measurement methods and a selection of useful and non-useful data. From this point of view, expertise in science would mean the ability to combine general and domain-specific scientific knowledge and thinking, and to cope with the messy and unexpected situations in research practices.

These sociological and anthropological studies indicate that explanations about the nature of scientists' expertise have to go beyond knowledge of general scientific methods and scientific thinking. However, neither the studies of Knorr Cetina nor the investigations of Latour offer a basis for more detailed analyses of the nature of scientific expertise and cognitive processes used by experts in these contexts. More detailed analyses of the cognitive demands, which researchers face in real research contexts can be found in the few cognitive science studies focusing on science experts' work in real research situations. In a series of studies, Dunbar (2001b, 2002; Dunbar & Fugelsang, 2004) used an approach that combines the detailed analysis of researchers' and research groups' scientific reasoning in real situations in science laboratories and in-depth analysis of the same reasoning processes in de-contextualised testing settings: "Rather than using only experiments, or observing only naturalistic situations, it is possible to use both approaches to understanding the same phenomena" (Dunbar, 2001b, p. 117).

Findings of these studies are in line with the sociological and anthropological findings: "Much of the time the scientists have unexpected findings, ambiguous results, and uninterpretable data" (Dunbar 2001b, p. 121). One crucial cognitive activity is the reasoning about these ambiguous results, which sometimes leads to novel scientific discoveries. Skills to reason about these situations in a way which is creative and scientifically solid at the same time, and to be able to use various cognitive and scientific reasoning strategies, characterise the scientific expertise in action. The protocols of high-level research groups, presented in Dunbar's (2001b, 2002) studies, highlight the advanced cognitive strategies to use analogies and to reason about causalities within real research work contexts. Importantly, these strategies are not affected by the typical biases people have in de-contextualised experiments on analogical and causal reasoning.

On the other hand, ambiguous findings in real research situations are often a starting point for methodological innovations aimed at controlling possible sources of error. The term "scientific uncertainty" has been used to describe typical situations in a real research context. No measure can be 100% correct and there is practically always a lack of information (Alagumalai, 2015). Deep knowledge about this uncertainty and rich well-developed strategies to deal with errors and missing information are central to science expertise.

According to Dunbar (2001a), researchers have conventional procedures, distinct from the formal models of scientific methods. These procedures resemble the practical scripts described in studies on professional practices in medicine (Boshuizen & Schmidt, 2008). For example, dealing with unexpected results seem to follow a kind of practical script of phases, which are consistently repeated in similar situations (Dunbar, 2001a). These procedures cannot be found in formal methodological texts, but they are effective ways to recognise errors and to find genuinely novel theoretical explanations in cases when errors are not sufficient explanations for the unexpected results. It is likely that these procedures are also dependent on the epistemic cultures of different fields.

Short term studies of research groups and science laboratories can give insight into the epistemic cultures and situated practices but do not necessarily show how successful scientists create the outstanding methodological and theoretical capacity for themselves and for their research groups. Retrospective studies unravelling the different phases of careers of high-level scientists indicate that strategic networking is a key activity, which makes it possible to get access to emerging theoretical ideas and novel methodologies (Gruber, Lehtinen, Palonen, & Degner, 2008).

On the basis of this analysis, it is possible to present a model of high-level professional skills of scientists in which expertise consists of several layers. The first layer refers to domain-general scientific thinking and skills including advanced epistemological cognitions and abilities to control multiple variables and draw causal conclusions. This knowledge is basically learned by most university students in the methodology courses, but professional scientists who need these skills frequently can apply these general skills and scientific thinking on a more advanced level than university students.

The second layer is a rich and well-organised domain-specific knowledge base, which researchers have acquired during basic studies and researcher training, and further developed as a part of their research practices. Because of the integration of general scientific thinking and domain-specific knowledge base, scientific experts can comprehend more complex designs, better interpret unexpected results and draw more adequate causal conclusions in their own field than in other fields they do not know so well.

The third layer refers to disciplinary epistemic cultures and situated practices. These challenge the notion of unified scientific thinking and clearly go beyond the formal models, principles, and rules of "standard" scientific thinking and methods. These are the aspects of scientific expertise that are learned through participation in daily work and discourses of scientific communities of practice.

These multiple levels of scientific expertise already explain why it typically takes a long time to become a highly recognised researcher. The model describes the different aspects, which can constitute expertise in science. However, as in other forms of expertise, the level of the scientific expertise of an individual depend on the amount and quality of deliberate practice focusing on these different aspects.

## How Do Expert Researchers Get Their Superior Skills?

There is no single model of expert level scientific thinking. Instead, expert scientists' exceptional performance is based on a large variety of competences developed during formal studies and work experiences. Some of these competences are domain-general and often learned in formal education; some are domain-specific, partly mediated by formal curricula; and some are situationally developed in research practice within research groups and laboratories. General competences are partly the same higher order cognitive processes that people also use outside of science, such as induction, deduction, analogical reasoning, and problem-solving. Some of these general scientific reasoning processes are closer to the research context, such as thinking about experimental designs. However, most of the scientific thinking and reasoning is domain-specific, focusing on particular concepts and theories or domain-specific methods (Dunbar & Klahr, 2012). In addition, several researchers have shown, that domain- and situation-specific informal practices of research groups and laboratories and scientific reasoning related to them are a crucial part of the competences of expert scientists (Dunbar, 1995; Knorr Cetina, 1999; Latour & Woolgar, 1979).

Scientists' ability to create new knowledge and discover novel phenomena have raised questions about the functioning of scientists' minds (Dunbar & Klahr, 2012). Most earlier research has tried to explain the exceptional achievement of top scientists through general innate or early developed personal traits such as intelligence, conscientiousness, autonomy, openness, flexibility, and cognitive complexity (Barrett, Vessey, Griffith, Mracek, & Mumford, 2014). Later empirical research has recognised some personality features typical of successful researchers, but the predictive value of these background variables is low. For example, openness was the only personality component of the Big Five Inventory which somewhat correlated with scientific creativity (Grosul & Feist, 2014).

Instead, the experiences researchers have had during their academic career and the contexts in which they have worked seem to be stronger predictors for their successful research careers than any personal traits (Barrett et al., 2014). This is in line with the general findings of expertise research. Abilities and other background variables may play a role at the beginning of the expertise development, and certain threshold levels may be needed, but their effect is weaker or disappears among the higher levels of expertise development (Ericsson, 2014). On the other hand, extended practice as a researcher does not mean that all experienced researchers would gradually become superior scientific thinkers. This is also in line with the findings of expertise research in varying professional fields, which has shown the difference between routine experience and deliberate practice (Ericsson, 2018).

There are a few studies that have analysed the nature of experience and practice in the development of expertise in science. Barrett et al. (2014) used bibliographic data of 93 historically eminent scientists and Mumford et al. (2005) used obituaries of 499 more recently deceased highly respected researchers in studies aimed at analysing the impact of different aspects of their careers on the quality of scientific achievement. Both studies highlighted some features of the careers leading to exceptional achievement that are similar to findings of expertise research in sports, music, and other professional fields. As well, they found some other aspects that might be more specific for the development of scientific excellence. Scientists seldom start to systematically prepare for their career at early ages, in contrast to top athletes and musicians. However, early engagement in the research field and early contact with an important mentor was also found to predict exceptional performance during their later career (Mumford et al., 2005). In both of these studies, scientific activities during earlier phases of the career, which were strong predictors of later success, parallels with deliberate practice (Ericsson, 2018). For example, deliberate early practice was one of the strongest predictors of later creative scientific achievement (Mumford et al., 2005).

Additionally, focused collaboration within their own research group and with researchers from outside has been strongly highlighted in studies about the career development of successful researchers (Barrett et al., 2014; Dunbar, 1995; Dunbar & Klahr, 2012; Gruber et al., 2008; Mumford et al., 2005).

One of the common findings in expertise research during the last few decades has been that nobody is an expert in many different fields, but rather, in relatively specific domains. The findings of scientific excellence are somewhat different. Studies of older eminent researchers have shown that transitions between research topics within broader research areas predict exceptional scientific creativity (Barrett et al., 2014). However, it is an open question as to whether this is still the case among contemporary research.

## Discussion

It is a well-documented finding that increasing experience in work does not always lead to increasing expertise. On the contrary, studies show that it is typical even for highly educated professionals such as medical doctors that expertise development is arrested after a few years in practice (Ericsson, 2018). Active seeking and using novel scientific evidence in developing one's own work practices can be seen as an attempt to avoid the arrested expertise development. Because of the different epistemic cultures dominating the professions where scientific knowledge is produced and the practical work conditions where it is used as evidence, the evidence-based development of practices is far from trivial. It requires a form of professional deliberate practice, which helps to increase the awareness of these epistemic differences and to develop applied scientific thinking needed in evaluating the suitability of the evidence in concrete situations. In the expertise literature, there are many definitions of the superior skills of experts. Based on the analysis presented in this chapter we suggest that, concerning expertise in professional contexts, the advanced skills needed to use scientific evidence should be added to the differentiation of experts from novices and experienced non-experts.

It is natural to think that successful scientists are experts and particularly experts in scientific thinking. However, it is not straightforward to use the established definitions of expertise when scientists are considered. Herbert Simon, a Nobel laureate himself, described this tension by the ironic claim that "normal" science fits in the typical description of expert problem-solving, whereas scientific thinking needed in "revolutionary" scientific discoveries fits better with the way novices' problem-solving is defined. Scientific activity leading to revolutionary novel findings happen by trial-and-error searches, which characterises novice problem-solving. "The search may be highly selective—but it reaches its goal only after many halts, turnings, and back-trackings" (Simon, Langley, & Bradshaw, 1981, p. 5).

If expertise is defined as domain-specific, and based on the growth of routines, skills, and abilities gained through extended, carefully designed practice ("deliberate practice"; Ericsson et al., 1993), it fits well with some aspects of high-level scientific thinking. Well-developed mental models of general standard scientific concepts of theory, control, causality, and validity are clearly aspects of competent scientific thinking where deliberate practice is needed. In the same way, acquiring the established conventions and practices belonging to domain-specific epistemic cultures and practical working of research groups and laboratories are good examples of deliberate practice.

Research on expertise has successfully unravelled important features of high achievement in the arts, sports, and many professional fields. However, expert performance and development in scientific thinking has not been extensively studied. A better understanding of the processes of producing new scientific knowledge and making use of scientific evidence in practical work would be beneficial for developing research studies in university programmes and in looking for work conditions and processes which could support continuous expertise development.

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# 9

# Developing Scientific Thinking and Research Skills Through the Research Thesis or Dissertation

Gina Wisker

## Introduction

For doctoral students, master's students, and final year undergraduates (referred to throughout as research students), the final assessment is usually a dissertation or thesis. The product is an end in itself with assessable merits; however, it also stands as a proxy to indicate a range of higher order thinking, changes related to how the candidate sees themselves in the world, practical skills and actualisation, which all are part of scientific thinking. At the outset of a research journey, the range of challenges, developments, changes, and achievements are rarely discussed, nor is there always explicit support for tackling them successfully. I suggest a model of four quadrants (see Fig. 9.1) of interlinked higher order research-related skills, explored and discussed here.

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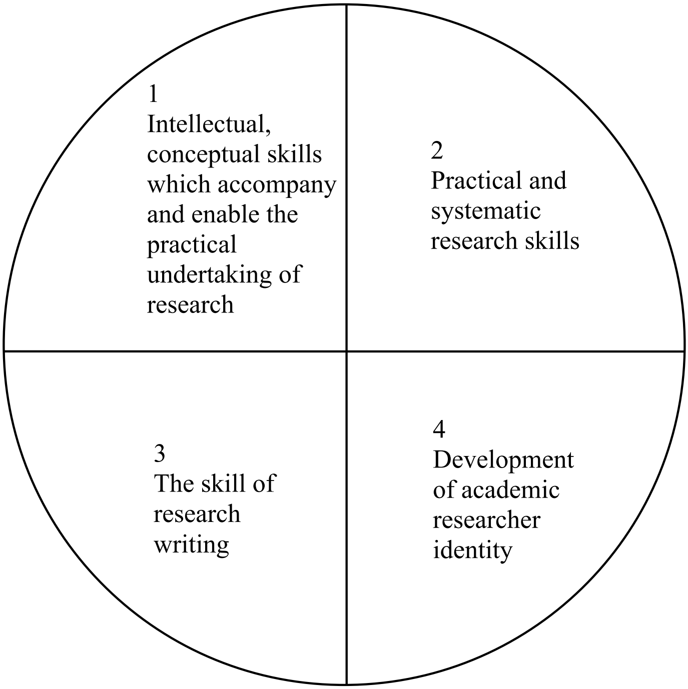


**Fig. 9.1** The four quadrants of higher level research skills for scientific thinking

The first involves *intellectual, conceptual skills which accompany and enable the practical undertaking of research*. These are conceptualising, theorising, visualising, and embodying skills, beginning with identifying significant enough problems, gaps, researchable questions and issues, and brainstorming ideas. They involve dealing with and enabling 'learning leaps' or 'conceptual threshold crossings' (Kiley & Wisker, 2009; Wisker & Kiley, 2017). These emerge from working with the complex conceptual, critical and creative ideas of the research in process, ensuring both that this particular research offers a real contribution to knowledge, and that effective higher order thinking, approaches, and practice habits are established for future research.

The second is the variety of *practical and systematic research skills*, including: Finding ways to ask and address the questions; planning and conducting research effectively; literature searching and management; situating the work in a dialogue with other work in the field, ensuring it is possible to see the contribution the work makes; determination and application of methodology and methods; and data analysis and the determination of findings from this theorised data, which are of significance and relevant to the aims of the project and the research question(s).

The third is *the skill of research writing*. Some of this is practice work integrated with the development of more complex thinking and theorising. Developing various appropriate modes of writing and fluency (Aitchison & Guerin, 2014) starts with practical processes of note taking, engaging with literature in a maturing argument, annotating, analysing, and expressing findings from theorised data. It moves on to the expression of new knowledge and understanding within a coherent format with a story and an argument spine. Crucially, it also involves fluency in the genre of a research dissertation or thesis, in the discipline.

With the first three quadrants we can see a trajectory from early dependence on supervisors, systems and the work of others through to more independent thinking, conceptualising, decision-making, construction of new ideas and outputs, articulation, and responsibility. These scientific research and writing skills show confidence and ownership of the processes and contribution. They also relate to the *development of academic researcher identity*, the fourth quadrant, which includes issues of health, managing stress, resilience, managing relationships with supervisors, belonging as a researcher in communities and with others, as well as dealing with a 'risk' career (Castello et al., 2017).

All four quadrants are interactive throughout the research. The development journey through each quadrant is ongoing, through conceptual, practical, writing and identity, although not necessarily at the same pace (success in articulation in the writing quadrant can aid confidence in academic identity, for example). The three skills-related quadrants feed into the fourth, developing a researcher identity (Aitchison & Guerin, 2014; McAlpine, 2012). The trajectory of the fourth area, developing a researcher identity, is one of induction, enculturation, realising a sense of belonging as an academic researcher and of the enacted right to the confident edginess, the voice of contestation, and of well-grounded contributions.

The quadrants can also be seen in relation to Willison and O'Regan's (2006) Research Skills Development (RSD) framework, which maps a development from early dependence and thinking to more complex work and enhanced autonomy for undergraduate researchers in particular. The RSD is expressed in a complex diagram wherein the research student moves from supervisor-directed to more autonomous work and elsewhere I have shown how this can be used to ensure a mixture of scaffolding and freedom for undergraduate research and its supervision (Wisker, 2018).

In this chapter, I theorise and explore characteristics of and ways of developing higher order scientific thinking and researcher skills in these four quadrants. They are not developed in a simple linear fashion with one preceding the other, but rather influence each other and interact throughout the research learning journey. I also consider effective, practical, sensitive support, from a research and experience base, located in the behaviours of research students, in university infrastructure, supervisory practices, research, and other communities.

## Methodology and Methods

### Sources, Resources, Background: Developing the Four Quadrants Model

Several main sources from my own work and that of others lie behind the identification of the four quadrants and their development of higher order skills in each. A significant inspiration emerged from the research undertaken on the 'doctoral learning journeys' (DLJ) project (2007–2011), where the doctoral learning journey was initially explored (survey of 350 doctoral students, 30 kept a log and were interviewed, 20 supervisors and 2 examiners were interviewed) to discover if, how, and when learning leaps or conceptual threshold crossings (Wisker et al., 2010) took place in doctoral students' journeys. Important findings from the project concerned the understanding of the learning leaps, conceptual threshold crossings and changed perceptions accompanying both journey and contribution to knowledge. The research learning journey is fundamentally linked to dimensions concerning the research student in the world, being in the world, ontology, and of emotional and personal experiences. The other two dimensions we found relate to professional practice—its influence on and through doctoral study, and institutional contexts which scaffold and enable or sometimes hold up doctoral work.

This early work DLJ concerned doctoral research students. The dimensions were then taken forward into work on wellbeing with education master's and doctoral students using a series of semi-structured interviews over two years and producing a supportive toolkit (Morris & Wisker, 2011). Much research by myself and others after that of the DLJ has focused on emotional and personal elements of doctoral students, emphasising wellbeing and supervisor relationships (Strandler, Johansson, Wisker, & Claesson, 2014; Wisker & Robinson, 2013), while academic identities work focuses more on the ontological sense of being a researcher in the world and employment. The DLJ dimensions could also be seen as relevant to undergraduate research projects over a shorter span of time. The main focus of the dimensions relates to context, epistemology and ontology. Latterly when working with Willison and O'Regan's (2006) RSD, I have focused on undergraduate research students (Wisker, 2018).

My work based on Willison and O'Regan's (2006) RSD research skill development framework (Wisker, 2018) concerns supervision of undergraduate student work, moving from highly supervisor-directed through to independence. The RSD framework is targeted at both the understanding of the process of research and the support developed for undergraduates undertaking projects, dissertation research and writing, and therefore engaging with scientific thinking, although that term is not used in the RSD framework. My work (Wisker, 2018) considers attitudes and approaches to research, developing confidence and autonomy of the choices of research processes, for example, and improving skills by practice and confidence. I constructed two case studies of undergraduate student research, one in a final year Gothic literature module, and one focusing on a single dissertation student. It was not empirical exploration or testing, rather the narratives of the case studies told the story of teaching a module and supervising a single student, helping to move their research work from dependent and information-based through to more independent and conceptual work, developing scientific thinking.

With both systems (DLJ and the four quadrants) seen as diagrammatic, it is possible to consider the whole person in context moving forward intellectually and cognitively with their research processes and practices, and their writing, and developing as a confident researcher, scientific thinker and communicator, able to practise the skills and approaches learned at undergraduate level on further postgraduate projects or projects in professional practice. The consideration of further professional practice work is not the subject of this chapter. Rather, I suggest bringing the dimensions into view, perceiving and supporting the whole research journey, practical and cognitive skills, writing skills, and the development of researcher identity.

Critical to the process of working with students to help develop the four quadrants are: The supervisor/student engagement; communities with whom they share ideas, problems, and emotional and intellectual support; and the institutional infrastructure, from rules and regulations guiding expectations and the work, to the provision of varieties of learning opportunities and support, such as online examples and constructive materials. The institutional learning and personal support which these represent can help engage, direct, clarify, scaffold, disentangle, and recognise the work of the research student as they move forward in their successful development.

## Doctoral Learning Journeys

Figure 9.2 was developed from the DLJ data analysis (Wisker et al., 2010) to gain a picture of doctoral learner processes and the perceptions of this from students, supervisors, and examiners.

The diagram centralises the doctoral learning journey as the development affected by all the other dimensions. It indicates experiences of, and interactions between, intellectual and cognitive developments, being-in-the-world (seeing yourself as a researcher), personal and emotional experiences (domestic responsibilities, health, relationships with others), and professional relationships to the project, in context, and present or future jobs. Students, of course, must meet the course requirements which the institutional dimension represents. It can support and scaffold and in some instances limit their work.

The whole journey is a linked experience. Research students might not be working with or for professional experience, but could be

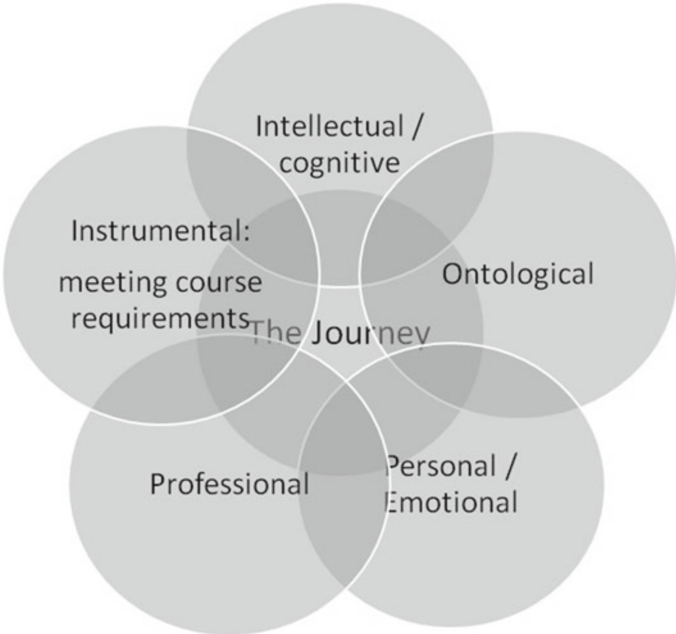


**Fig. 9.2** Doctoral learning journeys—dimensions

working towards achieving qualifications which will make them employable, so professional dimensions are nearly always part of the picture when considering development of student research skills, scientific thinking, behaviours, beliefs, attitudes, and processes (Boud & Walker, 1998; Leibowitz, Wisker, & Lamberti, 2018).

The dimensions of personal, emotional, ontological, and cognitive are what we concentrate on here. It is important that research students and supervisors see these dimensions as linked, interacting, and influential on breakthroughs in learning. These dimensions map onto the four quadrants of research learning for scientific thinking.

## The Quadrants Explored in Detail in Development

### Intellectual, Conceptual Skills, Scientific Thinking Which Accompany and Enable the Practical Undertaking of Research

Conceptual skills of theorising, conceptualising, visualising, and embodying, essential in scientific thinking, underpin and enable the practical undertaking of research. The first few research journey steps are crucial. The construction and development of research projects on conceptual levels begin at the start of the project even with limited time, or if the work is part of a larger project, since the student must carve out their own understanding and their own place in a larger project.

Theorising the development of conceptual, critical, and creative work is enabled by conceptual threshold crossings (Trafford & Leshem, 2009; Wisker, Kiley, & Aiston, 2006; Wisker, Robinson, & Kiley, 2008). We identified the notion of conceptual threshold crossings to identify moments when postgraduate students make learning leaps and begin to work at a more conceptual, critical, and creative level. It builds on threshold concepts in the disciplines (Flanagan, 2018; Land, Meyer, & Smith, 2008; Meyer & Land, 2003) which open up understanding of ways in which disciplines see knowledge and its construction in the world. Research students make (or don't make) learning leaps at various stages in the learning journey, becoming more in control of their own research, realising what they are creating, understanding, and shaping, and what their conceptual findings and contribution to knowledge are. Researchers pass through confusions, blankness, stuck places in thinking, and then liminality and perceiving and constructing new understandings, and new knowledge.

The conceptual work begins with identifying significant enough problems, gaps, researchable questions and issues, brainstorming ideas, and conceptual threshold crossings or learning leaps follow. The discipline-related threshold concepts are:

- Transformative
- Irreversible
- Integrative
- Troublesome knowledge

While conceptual threshold crossings result in:

- Ontological change
- Epistemological contribution

In the research journey there are likely to be opportunities for conceptual threshold crossings which are game-shifting moments when the research student realises what new understanding they have from their research, what the contradictions are at the core of something taken for granted, in which the links between ideas and processes are made clear, and start to perceive what contribution their work makes to established knowledge and understanding. Crossings take place at stages in the research project and writing, and once they are realised, researchers should be able to work not only on this project but others, in more conceptual, critical, and creative ways.

Conceptual threshold crossings can take place in all disciplines, and are mainly a way of defining and understanding the breakthrough in learning, the learning leaps made at stages in research learning when moving through confusion and into new understanding, through a liminal space of anxiety into some clarity and gradual or immediate confirmation of new ideas, perspectives, and understandings. For example, one breakthrough in learning is to realise that the way in which you ask a research question, the methodology and methods you use, will affect the kinds of answers produced, and so the kind and quality of the findings. Determining appropriate methodology and specific methods and knowing for a particular project is a common conceptual threshold crossing and essential for scientific thinking, since for research, methodological skills are essential (see Chapter 1 of this book). There are also likely to be sudden insights about the project and findings. Breakthroughs and conceptual threshold crossings are signalled by revelations in the middle of experiments, reading, interviewing, writing, sitting thinking alone, discussing in a conference; these are all moments of engagement of ideas with oneself and the world. This leads to clarification then expressions of new levels of creative, conceptual, critical understanding, and work.

Working conceptually contributes vitally to scientific thinking and to the more solid sense of being a researcher, and often expression in writing triggers understanding. Enabled by these conceptual threshold crossings and realisations, researchers can make a contribution to knowledge, related to being and becoming in the world as a researcher, linking to underpinning academic identities.

The DLJ project report (Wisker et al., 2010) focused on postgraduates' experiences with threshold concepts and conceptual threshold crossing, and supervisors' experiences of identifying conceptual threshold crossing and 'nudging' them across. One research student in our DLJ project commented on being stuck in her work, feeling that it was fragmented. She was damaged and silenced by harsh supervisor feedback and felt demoralised. However, having a constructive supervision followed by presenting her work at a symposium enabled her to identify the main themes and argument, and the important elements of the findings to make her case. The shape and structure, as well as the conceptual levels of her work and the contribution to knowledge, became clearer.

In another report from the same project (Morris & Wisker, 2011), participants reported ways in which they moved on from stuck places in their research project and their understanding. What emerged was the usefulness of working with supervisors in a dialogue, being reflective and keeping a reflective log to learn from developments, working with others in supportive communities, and using institutional staged moments including seminars or presentations at external conferences to help direct their sense of structure, argument, contribution to knowledge, and the achievement of their work so far.

Supervisor dialogues, constructive feedback, presentation opportunities, and community support, followed by reflection, can all nudge and accompany necessary learning leaps or conceptual threshold crossings which enhance the conceptual levels of the research work, and the achievement and self-aware confidence of the researcher.

## Systematic and Practical Research Skills

Some of the processes and the trajectory of the research journey can also be visualised and understood by considering the stages and cells of Willison and O'Regan's (2006) RSD, which indicates a movement from bounded, supervisor-directed research through to more self-directed work. Seeing research and project development along these lines both helps demystify the development and a researcher's position within it. It helps identify challenges and practices needed to move on, however difficult they might feel at each stage. It can therefore be a structured guide for both supervisor and students. The development of skill, confidence, and autonomy are essential. Brew (2001) discusses autonomy in varied research, while the focus on developing students as researchers (Healey, Bovill, & Jenkins, 2015; Healey, Flint, & Harrington, 2014, 2016; Jenkins, 2001), emphasises embedding research enthusiasm and skills in curricula throughout the degree.

In an earlier piece (Wisker, 2018), I considered the freedoms and frameworks offered by using a structuring device such as Willison and O'Regan's (2006) RSD to plot, support, and chart the development of a range of practices, systemic research skills, behaviours, and cognitive intellectual skills. I asked:

> How far can we help manage a balance between frameworks of development and support, and the kind of independence undergraduate student researchers need to develop? If we use the Research Skill Development (RSD) (Willison, 2009, 2012; Willison, Sabir, & Thomas, 2017) and other frameworks at every step of the undergraduate research journey, will this be a straitjacket? Or an essential, supportive scaffold? (Wisker, 2018, p. 1)

The question about such scaffolds underpins this chapter, with research students moving through practical skills and conceptual levels of work, asking questions and planning, actioning theorised ways of addressing these questions with appropriate methodologies and methods, and developing their practical skills and gaining autonomy and confidence. Willison and O'Regan's (2006) RSD offers a structuring framework to support the ongoing skills and autonomy recognised as important by practitioners and researchers (Boud, 1988; Bruce, 1995; Butler, 1999; Fazey & Fazey, 2001). The RSD framework builds on earlier work (Willison & O'Regan, 2005) linking research development stages with autonomy in practice. It has rows corresponding 'to the six major student research facets' and 'the movement through these facets is not linear, but recursive' (Willison, 2009, p. 5), which recognises, I would argue, that there are new challenges at different stages in research and in different research projects. While it focuses on undergraduate research, the issues and development from closed inquiry to self-directed research are familiar in researchers' journeys more generally. The RSD helps visualise and map movement on a continuum ranging from closed inquiries towards predetermined outcomes, involving high levels of structure and guidance, using prescribed methods and processes, to open inquiries with high levels of autonomy and self-determination. Development of independence in research in the RSD framework (Willison & O'Regan, 2006) is on the far right hand side of his diagram as 'Unbounded researching', where research parameters and processes are student developed and directed.

According to Murtonen (2005, 2015) and Murtonen, Olkinuora, Tynjälä, and Lehtinen (2008), undergraduate research students often perceive research methodology and methods as highly theorised, difficult, and irrelevant. This could happen even though the research work is theorised, and theory deriving from the literature review and theoretical perspective work is also used throughout to help develop a perspective. Theories are practical because they are put into operation to help focus the thinking, research process, and analysis.

Asking questions, developing a research project and actioning it involves many more straightforwardly practical skills such as time and project management, perhaps using Gantt charts, critical path analyses, project management systems, and interviewing skills. In my workshops with supervisors supporting undergraduate and postgraduate research, I engage participants in auditing skills (i.e. the practical development and tracking of skills). These include sampling, ways of gathering data, modes of questioning, and then practical applications of data analysis activities (among many others). I refer students and supervisors to the practical guides including my own *Undergraduate Research Handbook* (Wisker, 2009/2018), *Postgraduate Research Handbook* (Wisker, 2001), and others including

Walliman (2011), Phillips and Pugh (2010), and Bell (2010). Seeing the question through to the methods which can be used to address it, the data analysis and potential findings help identify the sticking points and the stages, the gaps between aims, question, and methods, and vehicles or tools used. Realisation of a good fit between the research question, data gathering or creation methods, and analysis methods helps bridge that gap, and make those links. In the workshops and books, I explore this form of tracking by asking for help with a range of fictitious students who present with topics for research. Turning a fascination into a research project includes understanding how it can be made real, doable.

Intellectual engagement as well as practical skill awareness can be developed with dialogues. My own work with students is largely dialogue-based (Wisker, 2012; Wisker, Robinson, Trafford, Warnes, & Creighton, 2003; see also Grant, 2008; Kobayashi, Grout, & Rump, 2013, 2015; Li & Seale, 2007; Schulze, 2012). I foreground supervisory dialogues as 'the heart of the research student's learning' (Wisker, 2012, p. 187), and early research work with supervisors revealed a range of dialogues used to variously inform, critically challenge, support, reinforce, and engage in theorised discussion with students. Activities from the books can initiate skills of questioning, and lead to practice and understanding of the ways the practical skills of each step of the research project and its writing up supports the achievement of the project. Visualising and engaging in a dialogue help the translation of a research topic into a reasonable doable project (Fig. 9.3).

Supervisor dialogues with research students can elicit and enable them to construct the performance, the understanding, and clarity in their own work, helping them establish and maintain confidence and student voice. It is important that students increasingly lead on questions and sharing of ideas and findings rather than being led by supervisors, so the power dynamic can shift until confidence and autonomy are evident. Many of the student interactions in the dialogues which we analysed (above, Wisker et al., 2003), however, show only supervisors leading, giving information, and encouraging challenge, while students seek recognition, support, and confirmation. More balanced dialogues would be an aim, and the final student category shows secure confidence which surely should be the outcome of the dialogues. Dialogues are essential for the development of

| Supervisor's interventions | Student's responses |
|---|---|
| • **Supervisor's interventions**<br>• didactic<br>• prescriptive<br>• informative<br>• confronting<br>• tension relieving/social<br>• encouraging critical, problematising & problem solving attitude<br>• eliciting<br>• supporting<br>• summarising<br>• clarifying<br>• collegial exchange. | • **Student's responses**<br>• seeking direction and information<br>• seeking feedback<br>• information giving<br>• information seeking<br>• working out through talk/developing ideas and plans through dialogue<br>• student defining ideas<br>• student developing ideas<br>• student judgment re: needs<br>• student pleasing supervisor<br>• student relating previous work to own work, theory to practice, experience to research culture<br>• student taking control<br>• tentative-provisional thinking<br>• uncertainty (of reaching PhD)<br>• unclear end result<br>• clear idea of the project as PhD. |

**Fig. 9.3** Teaching and learning behaviour in supervisory dialogues focusing on supervisors and research students (Adapted from Wisker et al. [2003, pp. 391–392] and Wisker [2012, pp. 196–198])

understanding and so too are systematic stages of scaffolding for developing independence, which Willison and O'Regan's (2006) RSD exemplifies.

## The Skill of Research Writing

Some of the essentials and some of the pitfalls of research writing are rarely made clear. There are, however, many self-help books and research-based articles and books, as well as websites, which can accompany and support the developing research writer so that they feel less isolated, and find ways of managing the structuring, expression, and completion of writing which does their work justice, and aids the establishing of good writing habits.

Research informing this section was conducted for several publications and involved both (i) individual interviews and (ii) responses collected (each with ethical clearance and consent) from participants in workshops with doctoral students, supervisors, and academics who write for publication (Wisker, 2014, 2015; Wisker & Savin Baden, 2009). It reveals several stages to the writing process, and tactics to deal with blockages and breakthroughs in writing, particularly for those undertaking a large scale piece such as a doctorate.

*Stages and shapes of the writing.* I take a logical approach, demystifying the research writing process. Some parts of the writing are descriptive and informational and can be written clearly and straightforwardly, while others are more complex and conceptual and it could be difficult to express them clearly. The research writer starts to understand what is emerging from their work through a careful use of different forms of writing in the sections of the work, and a managed use of the continuum of writing from the free flowing outpourings of clever ideas (Elbow, 1973; Wisker, 2015), to highly focused, highly accurate, well expressed even elegant writing, in the context of the field and of that particular piece. Writing is both practical (relying on space, time, mood, dedication) and also conceptual (it needs theories, concepts, imagination, narrative, argument). Some of our best understandings come through having to struggle to explore what we are beginning to understand, in dialogue with others (reading, discussion, etc.) and framing and expressing it in writing.

A first step is brainstorming of ideas and moving on from a brainstorm to collate and organise those ideas, developing a plan, and summary statements to clarify one's own understanding. The writing itself is in several forms which take place in different parts of the research paper/article/essay/thesis/dissertation so that the development of the argument can flow, driven by and situated in clearly understood and well-presented ways through earlier essential work (i.e. literature review); clear well argued, theorised and intentionally detailed methodology and methods with that mix of understanding exactly why this methodology and these methods will ask and address a question these ways. Next, the information and detail about the sample: what, where, when, why, how, how many, and limitations.

There is a mix of logical progression and sound, accurate, well-organised expression, and some more creative expression in research writing. Identifying sources and taking sound notes which are accurate in detail, appropriately referenced but also contain the engagement, discussion, and response which drives the argument as a spine throughout the whole piece, realised through the appropriately selected data which has been discovered, selected, analysed, thematically sorted, and put together logically to underpin and drive the argument, which itself has developed throughout.

I have written elsewhere (Wisker, 2015, 2018) about some of these stages based on research and experience with workshopping and with my own doctoral students and academic colleagues undertaking research writing. These could be useful for postgraduate students and supervisors to consider when writing, demystifying the intentions of parts of the writing, and the shapes of articles and longer theses. These stages of writing and of the article or thesis comprise:

- Brainstorm ideas, frame questions, and explore appropriate theories for theoretical perspectives to help focus research and address questions;
- Organise, plan the research and its writing;
- Structure writing time; both 'snacks' for small writing tasks and 'binges' for longer writing periods to develop momentum to finish (Murray, 2016);
- Consider the logical shape of an academic piece and write a skeleton structure to support both the research and the steps forward in the writing;
- Write differently in the different sections so they play their part (abstract, introduction, literature review and theoretical perspectives, methodology and methods, data and discussion, conclusions—slightly different for

different disciplines—check with journal article and thesis structure and shapes as models) (Wisker, 2015);

- Use select work from others' writing in your writing (properly referenced) to situate it in previous work and engage with your own in a dialogue—and not just as a prop;
- Have an argument spine throughout to which all the selection and discussion of data, and all the arguments through it, are linked;
- Make sure the piece also tells a story, i.e. why, which, what was done, what was found or constructed, and why it matters;
- Write iteratively—for example, start an abstract early then return to it and finally ensure it captures what contribution the work makes; write and rewrite (return iteratively to all sections) to ensure the whole is cohesive;
- Ensure there is sound argument structure throughout; and
- Ensure the rigour of the research—sound theory used as perspectives, focused literature review, clear ethics, appropriate methodology and methods, awareness of limitations, appropriate data analysis, selective, theorised and focused use of data, discussion and findings focusing on what is being found and understood and why it matters.

**Finally.**

- Ensure the conclusions pull together factual findings and conceptual findings—what is now known (factual information), and what meaning is developed further, what is differently understood (conceptual), and emphasise what the contribution to knowledge is and why it matters;
- Rigorously check bibliography/references/notes;
- Return to the writing often and iteratively to tidy clarify, neaten links, ensure it does express what you have found and understood; find the right clear clever expression and remove the repetition; and
- Know when to stop.

Some overall good habits which have emerged from research carried out by Wisker and Savin Baden (2009) and later (Wisker, 2014) produced sound ideas about good practice both in writing skills and in the breaking of writing blocks. In these studies, narrative interviews were used with research students and academics who write for academic outputs (and some also creatively) to explore their breaking of writing blocks, and moments of breakthroughs in their writing which we recognised as conceptual threshold crossings after which their work was more concentrated, self-aware, conceptually, creatively, and critically focused. The result was that they knew what they were writing about, how to write it, and why it mattered.

Respondents in the 2009 study by Wisker and Savin Baden noted a range of good writing habits to enable the quality of writing outputs and also acknowledge being 'stuck' and finding ways through that stuckness through: reading new literature which opened up new thinking; writing in a free flow and structuring and finessing later, or doing almost anything else to unblock that horrible paralysis of sitting in front of a blank screen or a piece of work which was a jumble. In this study, 'Julie', an experienced, published academic member spoke about managing being stuck, developing confidence, and good writing habits. When respondents were asked about being stuck in their writing they acknowledged that it happened regularly, was stressful, and that managing what they wanted to say was important. Some talked of engaging in other activities to break the paralysing focus and inactivity. These activities were both academic (focusing on another section of the research) or relaxing, such as going for a walk. Both freed the mind up to escape the stuck place and to think more clearly. Through this, the work came back into view more clearly and they could then return to the writing. Perseverance and planning are also seen as essential (Wisker & Savin Baden, 2009).

Moving on beyond that stuck place as the words start to shape themselves and the ideas to flow can also be challenging, and another successful academic writer in our research acknowledged that it was important to write herself out of being stuck, sometimes with reflective writing, or simple writing until the ideas became clearer and she could explain herself better (Wisker & Savin Baden, 2009).

Writing, and writing even if it is not yet elegant or flowing, helps reduce the feeling of being stuck and starts to form responses which can later be reshaped. Redrafting is important too; writers might not share that they redraft over and over and some might spend a morning on a single short paragraph to get it right, but they do. Writers are never alone with useful blogs and websites such as DoctoralWritingSIG (doctoralwriting.wordpress.com) and The Thesis Whisperer (thesiswhisperer.com) and I always share these with research writers who can find solidarity in others' experiences and a wealth of practical and psychological tips.

The work for the piece 'Toil and Trouble' (Wisker, 2016) also used interviews with doctoral students and academic researchers who write and dealt more specifically with issues of the relationships of doctoral writing to the development of a researcher and a researcher identity. Issues raised included 'impostor syndrome', the balancing of time, and the involvement of the personal as well as the professional in writing. Some noted tensions between expectations that they write, and the very personal sense of self (expression, worth, and actualisation) also involved in writing.

Research writing is a professional activity producing outputs which can be shared with the academic world and have effects on professional practice, social justice, affecting human and animal life and processes. It is important to share through writing, and it is also much tied up with the sense of achievement, takes personal time, and is fundamentally linked to ontology; one's being in the world, one's sense of direction, solidity, usefulness in the world.

## Developing a Researcher Identity

During research projects, writing, and engaging with research communities, researchers develop their academic identities. Although at the start the research could seem just like an extension of undergraduate study, or doing a job, this is a long journey with a project outcome and possibly an academic or research-related job or other outcome. As a career, research is as we now know volatile and insecure, often mundane rather than challenging. The focus of academic identity work also includes employment, which varies from self-funded engagements personally or professionally driven to paid employment directed at the research project or conducted alongside it.

It is a 'risk career' (Castello et al., 2017) because of the dearth of academic jobs, and a strange process because research and writing are utterly bound up for many in their sense of identity, challenge, development, and achievement. Other elements of researcher identity beyond the job (or insecurity related to dearth of jobs) (McAlpine, 2012) include issues related to being in the world, and health, achievement, and self-actualisation. The doctoral learning journey indicates an ontological 'being in the world', academic identity dimension to undertaking a doctorate and there have been many recent studies on doctoral students developing academic identities (Aitchison & Guerin, 2014). Current work considers mental health and wellbeing (Johansson, Wisker, Claesson, Strandler, & Saalman, 2013; Strandler et al., 2014), and indicates difficulties which can arise during the doctoral journey including stress and exhaustion, lack of direction, and coupling development of the project and its writing, with agency and self-worth.

When considering academic identities, the fourth quadrant of being in the world, becoming, and wellbeing are uppermost, focussing on developing healthy and sustainable (if changing) researcher identities. Phenomenology and existentialism each deal differently with notions of a core of self, relationships with the shared world and change over time, and in academic identity contexts (McAlpine, Amundsen, & Turner, 2013). Identity, including academic identity of research students changes in relation to external change (Ivanic, 1998), and development (Baker & Lattuca, 2010), so introducing notions of 'becoming' and 'unbecoming', related to researcher identities over time and place. Some of these identity changes are enforced, some result from personal choice (Archer, 2008; Pyhältö, Nummenmaa, Soini, Stubb, & Lonka, 2012).

Davies and Danaher (2014) consider empowerment in the context of prioritising some research activities over others for early career researchers, while others (Castello et al., 2017) look at developing professional identities of early career researchers in response to changing 'signals' in research careers. This latter example was a multi-site study repurposing large data including the DLJ (Wisker et al., 2010). Work considering the personal wellbeing and resilience of research students (Vekkaila, Pyhältö, & Lonka, 2013) while appearing in academic identity development feeds into all the quadrants since intellectual and cognitive levels of work, skills in research and writing are all affected by academic identities, mental and physical health and wellbeing, and relationships with supervisors.

The affective elements of doctoral students' learning journeys (Holbrook et al., 2014) deal with the academic researcher role and pressures. Some research focusing on postgraduate students (Haksever & Manisali, 2000; Poyatos Matas, 2008, 2009) indicates that lack of clearly defined goals and milestones can cause anxiety during research and thesis writing. Muurlink and Poyatos Matas (2010) considered ways to alleviate stress, enabling wellbeing and emotional resilience. Other theorists (Lombardo, 2006, 2007) add in optimism (Carver & Scheier, 2005) rather than pessimism, planning ahead (Lombardo, 2006; Lombardo & Richter, 2004) and constructing positive narratives about success which fuels positive, resilient academic identities.

This work all fed into our 'Troublesome Encounters' research of two years of interviews and resultant toolkit (Morris & Wisker, 2011) identifying difficulties and supporting postgraduate students' wellbeing and resilience. This has been augmented by interview-based research with doctoral students including those in medical science in Sweden (Johansson et al., 2013; Strandler et al., 2014) and on doctoral orphans (Wisker & Robinson, 2013) all of which highlight stresses, supervisory breakups, and suggest ways forward ranging from emotional resilience to community building and university infrastructural support.

Conducting research at any stage might initially look like a straightforward next job as a student but it is both fundamental to all learning, and intricately intertwined with one's own sense of identity, belonging, worth, and achievement. An important part of developing a researcher identity is the realisation of the necessary characteristics for successful research, recognising their grounds and evidence in one's own practice and identifying what needs to be developed. Some of these are practical systematic skills such as asking realistic questions and so moving to constructing doable projects including highly theorised or creative projects with no final answers. A part of this research journey is demystifying the essential stages of research and being a researcher, knowing that a research student is or will need to become an 'ideas person', a hard systematic worker with breakthroughs in learning, and a completer finisher who ties up ends and details, knows what they have found and constructed and can communicate it. These skills contribute to identity, a feeling that one has the right to research, and that what you are working with and on and producing is worthwhile.

Researchers need to develop a (suitably well-founded) inner sense of confidence from the quality and worth of their own work, and dynamic links with an outer community local and international—which reduce the isolation and lack of clear direction, demystify the processes, share information, build current and future networks, and help confirm identity and achievement. Research is very hard systematic work, keeping sound notes, retrying processes and re-asking questions, working through expression until it is clear and the writing does make a contribution, underpinned by sound practice and intellectual processes evidenced in the data and through clear argument in the written work, the outer projections of the research journey. This should be shared with others for review, confirmation, contestation, helping clarify the work and position as a researcher. In a study by Wisker and Savin Baden (2009), a strong link was found between writing and academic identity. And many of our respondents spoke of a writer's identity, formed by recognising and being recognised as a writer. This was seen as another form of ontological change and, ultimately, perhaps of security (p. 241). Some of the stages of writing also focus a sense of changing as a person, shaping one's being in the world (Wisker et al., 2010) perhaps initially, or recurrently, or in a single stuck moment or moments of confusing feedback or rejection. This is destabilising in terms of an academic and research writer identity.

Researchers are always renewing, reviewing, and moving on. This is exciting, challenging and possibly a little destabilising, but some of the edginess of destabilising and challenge fuels the excitement and the movement into new work. Once an ever becoming researcher realises that in a discipline or interdisciplinary area they have found or created something of worth, and expressed it well, they have crossed a conceptual threshold in researcher identity. Self-realisation, self-actualisation, always contested and moving on, begins to produce affirmation and worth, seeing the world and self differently (ontological change and epistemological contribution) (Wisker et al., 2010) and need to know the worth of this as well as its challenges. Without the ideas, hard work, and completer finishing of research—which the last element ensures something is done with the research—there would be no movement forward in ways through issues, how we can conceptualise and comment on the world and our place in it, involving everything from curing cancer and homelessness to having a fuller more meaningful understanding of the ways a writer or artist help us see the world and our position within it.

It is useful for students to find out about internal and external institutional systems which might be both supportive, including Vitae and the Concordat for researchers, which also focus on dimensions and stages of being a researcher, and jobs. Students should seek out or develop internal support networks. This helps with demystifying the process and experiences of undertaking research learning from planning to completion and offers solidarity. Communities and sharing reduce isolation and help individuals to see their own development needs, strengths, and progress. One of the respondents (Morris & Wisker, 2011, troublesome encounters) saw the Ph.D. as an individual experience so that belonging and the development of relationships was very important.

Conditions for academic wellbeing for both students and supervisor include: a pro-research student culture—guidance, mentoring; training opportunities; personal/professional, technical and academic skills; access to funding; academic community with formal and informal opportunities to contribute; a pro-wellbeing culture—proactive, built into academic life; supportive infrastructure—access to services, facilities, pastoral care, and mentoring.

All of this supports development in the academic identity quadrant. Developing and maintaining positive and successful academic identities involves engagement with people and places, as well as skills and confidence in the throughput of researcher work from ideas to structure and problem-solving, hard focused work to completer finishing, the well-honed writing of well-received theses, dissertations and articles, shared through presentations and publications and for which there is (appropriate to the discipline) impact.

For supervisors there is a crucial role clarifying the research journey, maintaining appropriate support, challenge, and confirmation of achievement engaging research students in the various internal and external communities, making the practices and processes clear. They can help confirm researcher identity, while also opening windows on the research world beyond, clarifying the complexities of researcher roles and jobs, helping with introductions, joint equally recognised publications and references.

## Conclusion

Becoming and being an academic researcher is a complex, whole person experience. The four quadrants of skills identification and development have emerged from a range of research projects and experience with supervision, research writing, and workshopping. They concern conceptual, scientific thinking skills, practical skills, research writing, and academic identity development. Each need attention in any development process.

For researchers, there is an international, ever-changing community to join. Research is both a challenge and a lifeline. This is not just about practical skills, it is also about the development of scientific thinking skills, a form of cognitive intellectual development, and about changing ways of seeing yourself in the world.

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# 10

# Developing Scientific Thinking Towards Inclusive Knowledge-Building Communities

Angela Brew, Lilia Mantai and Aprill Miles

## Introduction

This chapter sees the development of scientific thinking through engaging undergraduate students in various forms of research and inquiry as related to wider transformations of higher education needed to prepare students for professional life in the twenty-first century. Ideally, a whole-of-university approach provides the best kind of environment to enable and foster development of scientific thinking via pedagogy, curriculum and scholarly communities. Towards this objective, this chapter examines a seven-year educational development programme aimed to promote

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undergraduate research opportunities and research-based learning as ways to develop scientific thinking. The programme is framed within a model of universities as inclusive scholarly knowledge-building communities (Brew, 2006). Throughout the chapter this model provides ways to think about the future of universities and their role in the development of scientific thinking based on fundamental values of inclusivity, knowledge building, research, scholarship and the development of university communities.

## Background

Widespread growth in initiatives to engage undergraduates in various forms of research and inquiry is evident worldwide and in the preceding chapters of this book. Such initiatives have, for many years, taken the form of co-curricular programmes as common in the USA. However, since the Boyer Commission (1999) report on undergraduate research engagement in research universities, increased efforts have been made to integrate research into the curriculum (see, e.g. Hu, Kuh, & Gayle, 2007; Katkin, 2003). Research on the benefits of undergraduate research (e.g. Lopatto, 2010); students' responses to it (Visser-Wijnveen, van der Rijst, & van Driel, 2016); and how it can be integrated into the curriculum (e.g. Brew & Mantai, 2017; Zimbardi & Myatt, 2014), has grown.

On the one hand, research-based learning can be viewed as a new pedagogy to develop scientific thinking defined more broadly by Murtonen and Salmento in Chapter 1 of this book. Scientific thinking as defined by Murtonen and Salmento goes beyond learning of natural sciences, while Salmento and Murtonen (Chapter 2), as well as Hyytinen, Toom, and Shavelson (Chapter 3), highlight components of scientific thinking as being: understanding of concepts and procedures, epistemic understanding of knowledge, and critical thinking. More specifically, it is a pedagogy that develops evidence-based decision-making and critical thinking skills as discussed by our colleagues earlier. A number of pedagogical models have been used to aid the view of research-based learning as a pedagogy. For example, Healey and Jenkins (2009) map different ways that teaching and research are brought together. Levy and Petrulis (2012) map student activity according to who frames their inquiry. On the other hand, research-based learning can be viewed as requiring a whole-of-curriculum approach, for example, the connected curriculum model of University College London which maps the ways students can connect with the university (Fung, 2016). Balloo in Chapter 5 of this book has outlined students' approaches to research activities which involve external help-seeking strategies and self-regulated learning strategies. A whole-of-curriculum approach arguably has the potential to address such students' needs.

However, the development of research-based learning across undergraduate, postgraduate and doctoral levels to develop scientific thinking goes beyond questions of pedagogy and curriculum. Engaging undergraduates in research-based learning needs to be viewed in the context of the university as a whole (Smith & Rust, 2011). This is clearly recognised in the US Council on Undergraduate Research whose characteristics of excellence in undergraduate research (Hensel, 2012) encompass all aspects of university functioning. However, this challenges educational development because engaging undergraduates in research renders many common university practices problematic. The changes required involve all levels and parts of the university, challenging both teaching and research, and changing institutional strategies and objectives. Fundamental assumptions about the role of undergraduate students in the university, the nature of knowledge and who is to be involved in generating it, as well as the relationships of students to university research, all require attention. Such challenges are embedded in ideas about students as producers (Neary, 2010), students as partners (Healey, Flint, & Harrington, 2016), and students as change agents (Kay, Dunne, & Hutchinson, 2010). Hierarchies are questioned and this changes students' relationships with academics. A more inclusive higher education; one in which students take a role as actively participating in the academic project of the university is indicated. It is therefore clear that a broader model is required; one that goes beyond questions of curriculum and pedagogy to integrate students and their learning within the overall academic enterprise of the university.

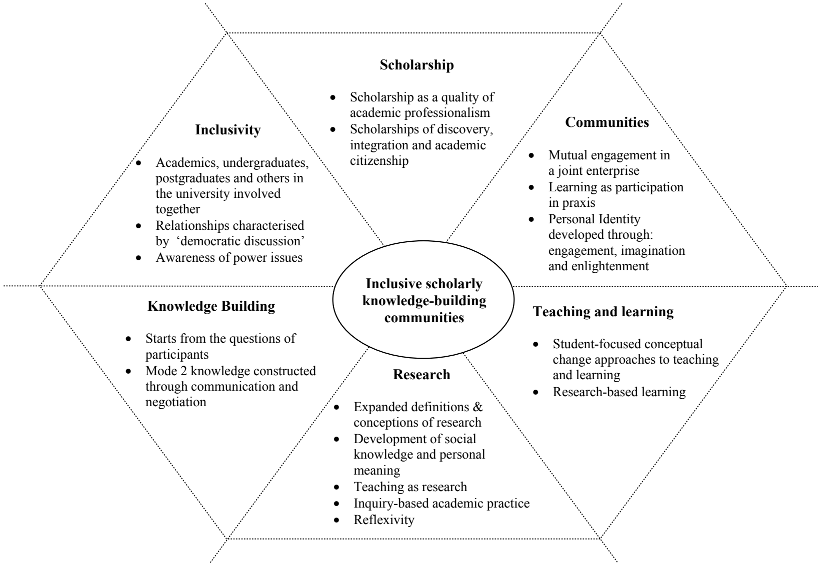


**Fig. 10.1** Model of universities as inclusive scholarly knowledge-building communities (Brew, 2006, p. 32)

## Universities as Inclusive Scholarly Knowledge-Building Communities: A Model

Following investigations of research-teaching integration and practices of undergraduate research engagement in different countries, Brew (2006) developed a model based on the idea that universities should become inclusive scholarly knowledge-building communities. This model creates a context in which students as partners, as producers and/or as change agents can happen. The hexagonal model has six interlinked facets.

In Fig. 10.1 the dotted lines suggest that the boundaries of the facets are not distinct, but merge into each other. The lines extend beyond the hexagon to suggest that institutions are interlinked into society and accountable to, e.g. industry, professions, family, and media (Brew, 2006).

Smith and Rust (2011) suggest that probably all institutions of higher education aspire to the idea of inclusive scholarly knowledge-building communities, but that much needs to be done to realise such an objective.

So what do universities need to do? How can such changes be leveraged? How can developers facilitate the climate needed so that students can fully participate in the academic project of the university? Brew (2006, p. 31) suggests that universities might use the model as a guide for implementing institutional policies and strategies designed to bring teaching and research together. This suggests it can be useful in guiding educational development programmes. Brew argues that the model is dynamic as its focus is on the processes of meaning-making by students and academics building knowledge collaboratively. It therefore goes beyond models focused on curriculum and pedagogy to take account of the whole university, providing a framework for developing universities as inclusive scholarly knowledge-building communities where it is desired to build on institutional policies and strategies in a multifaceted academic development initiative.

In this chapter we demonstrate the usefulness of this model through the example of a seven-year programme of educational development and enhancement designed to develop undergraduate research and research-based learning in a large Australian research-intensive university (approximately 39,000 students) and in Australasian universities more generally. The programme aimed to increase opportunities for students to engage in research within the undergraduate curriculum and in co-curricular programmes, and to enhance performance and showcase best practices where curriculum is informed by research. It aimed to enhance practice in equipping students with research skills and critical thinking through exposure to research problems and authentic research environments.

The university aims to: "Equip students with research skills and critical thinking, through exposure to research problems and realistic environments", and to: "Increase opportunities for students to engage in research within and across the curriculum" (Operational Plan, 2010) provided the starting point. The programme was designed to dovetail with other academic development initiatives carried out in the academic development centre, e.g. curriculum internationalisation, graduate attributes, community engagement, and graduate studies in university learning and teaching.

Each facet of the model is discussed here using examples of educational development initiatives from our programme. In the discussion, we explore the extent to which the programme has contributed to building scholarly knowledge-building communities and examine the appropriateness of this model as a framework for educational development activity in other contexts. We argue that providing opportunities for students, academics, and others to work together in scholarly ways to research, teach, learn, and build knowledge together, is important in contemporary universities.

## The Model in Practice

### Model Facet 1: Research

Brew (2006) argues that conceptions of research need to go beyond notions of funded research that is evaluated through national research assessments, to include knowledge about the university and the work context, and personally relevant inquiries. Teaching through reflexive approaches to research and inquiry is encouraged.

This broad view of research was integral to the undergraduate research development programme. Various research projects were included exploring existing practice. Undergraduate and postgraduate students worked with academics to conduct research. Much of this work has been published, so some examples are presented here with brief summaries and links to relevant literature.

**Students' awareness of research**. To provide some baseline data, 200 students across faculties were interviewed by an undergraduate about their awareness of research. An adapted version of the questionnaire used by Turner, Wuetherick, and Healey (2008) and Spronken-Smith, Mirosa, and Darrou (2013) was used. The findings replicated these studies demonstrating considerable lack of student awareness about research in the university. Students views of what they gained from their teachers engaging in research demonstrated that students liked hearing about their teachers' research but wanted to hear more (Hajdarpasic, Brew, & Popenici, 2015).

**Learning outcomes that mention "research"**. Using a university-wide database of course outlines, learning outcomes were searched to find the extent to which they focused on research, inquiry and related activities. It was concluded that while the university aimed to have a research-rich environment for students, at the time, this was not reflected in the learning outcomes specified, only 15% of which mentioned research.

**Visibility of research**. The visibility of research across campus was examined through analysing photographs of noticeboards, corridors, and the campus more generally. It was found that opportunities to promote research were missed, possibly contributing to our finding that students lacked awareness of research. Encouraging greater visibility of research resulted in some improvements, e.g. corridors showcasing research posters, space made available to advertise undergraduate research opportunities and activities (Popenici & Brew, 2013).

**Challenges and barriers to implementing research-based experiences for students**. Perceived constraints to implementing research-based learning were investigated through twenty interviews with academics engaged in developing it. We found that their definitions of undergraduate research differed and that these differences led to different forms of student engagement ranging from atomistic and uncoordinated to holistic and integrated practices (Brew & Mantai, 2017).

**Undergraduate research programme coordinators**. A survey of undergraduate research programme coordinators across Australia examined the outcomes of such programmes. The coordinators reported a significant gap between student demand and availability of research experiences (Brew & Jewell, 2012).

These investigations constituted examples of inclusive scholarly communities since students were involved in all of the research. This was in itself an important academic development strategy. Dissemination of findings in staff development programmes, university committees, conferences, and journal articles expanded staff conceptions of undergraduate research and contributed to discussions of future needs.

## Model Facet 2: Teaching and Learning

The model of inclusive, scholarly, knowledge-building communities requires a shift to student-focused conceptual change approaches to teaching and learning and the development of research-based learning within the undergraduate curriculum. A staff development programme was designed to disseminate and discuss research findings, enhance academics' appreciation of undergraduate research potential, and contribute to curriculum change initiatives. It consisted of:

1. A university-wide working group (with staff and student representatives nominated by the 30 or so heads of department), that met over a three-year period to promote and communicate departmental activities. Issues discussed included, e.g.: research skills development, decision-making, ethical issues, standards and best practice in research-based learning.
2. Central workshops and showcases, e.g. using research in capstone courses, supervising undergraduate research, and designing research-based undergraduate courses. Presenters were academics across disciplines or external visitors.
3. A website (http://www.undergraduateresearchaustralia.com), was established including resources, examples of good practice, upcoming events, and conference proceedings.
4. A unit of study on implementing undergraduate research offered through the university's learning management system was made available to staff.
5. Informal discussions, were facilitated face to face and online, e.g. via a wiki.

This programme was evaluated through records of working group meetings reported in university committees; workshops, events, and resources formally evaluated through exit and follow-up surveys; critical reflections of the working group, and scholar/ambassadors (see below); and the project leaders reported through regular meetings.

## Model Facet 3: Knowledge Building

While the educational development programme through its workshops and committee presentations contributed to the university's knowledge about undergraduate research engagement, discussions during an earlier Australian Learning and Teaching Council (ALTC) Fellowship, identified a need to spread knowledge of undergraduate research across the broader Australasian community. The Brew model stresses the importance of Mode 2 knowledge (Nowotny, Scott, & Gibbons, 2001) which is negotiated within society. Consequently, in 2014 we organised a "Posters in Parliament" event in Parliament House Canberra (based on the UK and the US experience) to showcase high quality undergraduate research to key figures and representatives from research funding bodies as well as members of the House of Representatives and Senators. This was a way of educating policymakers about the quality of research that undergraduates can achieve and highlighting the need for funding.

Events like this publicise undergraduate research. Judging by written comments made by attendees, and the large number of letters of support received from Vice-Chancellors, other senior university officials and politicians, this one-off event certainly had an impact in raising the profile of undergraduate research. It also had a significant impact on the student participants themselves. Students told us of their newly gained confidence and motivation and their follow-up email correspondence with various key figures as a result of the event. An undergraduate presenter now doing a PhD wrote:

> Both [federal politicians] showed great interest in my project, as both had a personal connection with [topic] and were aware of how greatly it affects the wider community. … [One] was incredibly encouraging, and adamant that I send him a copy of my published paper as soon as I can. In all, I hope the event will continue in the future, as it will help draw further connections, interactions, and initiatives between students, universities, politicians, and the government.

A one-off event is clearly insufficient to build knowledge of undergraduate research across Australia but this event established a precedent. The high cost of the event and the lack of further funding precluded Posters in Parliament becoming an annual event such as are now held in the USA and UK. Other ways to promote and support undergraduate research are needed.

## Model Facet 4: Inclusivity

The development programme challenged university authority structures by involving students as full participants at all times: investigating practice, implementing the staff development programme, and in presenting research in their universities and in parliament. Students have an important role to play in educational development related to learning and teaching more broadly but are often left out of developments. Inclusivity is central to this model.

Our programme included undergraduate pedagogical research internships. By encouraging undergraduates to devise projects of relevance to their particular departments, we intended to grow a community of undergraduate scholar/ambassadors. Projects were supervised by departmental academics and students worked in partnership with a project member. The students were actively encouraged to take a lead in becoming scholar/ambassadors for undergraduate research and to become initiators and drivers of change in learning and teaching.

This was one of a growing number of undergraduate research schemes being implemented in different departments across the university. Working with undergraduate students on projects of this nature challenges academics to treat students as equal partners. In collaboratively implementing projects with their lecturers, students reflected on how they were treated differently in comparison to their classes, thus highlighting the challenges of creating inclusive scholarly communities. Engaging students in research provides a framework for different kinds of relationships. The Brew (2006) model suggests that relationships should be characterised by what Brookfield and Preskill (1999, p. 7) call "democratic discussion" where there is an awareness of the issues of power and how it is exercised. One of our challenges as academic developers on this project was to ensure that we engaged in democratic discussion with the students working with us (including, e.g. mutual receptiveness, listening, appreciating the contributions of all, and humility). We drew attention to issues of power and authority in our discussions with academics, thus breaking down what Brew (2006, p. 117) describes as an "academic apartheid", to lay the foundations for students becoming partners in the academic project of the university.

## Model Facet 5: Scholarship

The scholarships of discovery, integration, engagement, and academic citizenship (e.g. Boyer, 1990) are integral to the Brew model, as is the idea of scholarship as a quality of academic professionalism (Brew, 2006). All of these ideas involve students as scholars. An example of how undergraduates can create and drive a scholarly culture of research is the establishment of an entirely student-led undergraduate research internship scheme (MURI). This was established by some of the scholars/ambassadors and others to provide disadvantaged students with the opportunity and support to participate in research with academics, and/or to design their own, or work on other, research.

The peer-led structure of MURI furthers the concept of students as partners in learning. Peer-led group sessions facilitate deeper engagement with research skills and build research interns' confidence to communicate research to each other and the wider community. Students within the MURI programme are encouraged to communicate their research to a wider audience. One student commented:

> The most beautiful thing about MURI team is the team itself. They provide a learning environment that you feel inclusive, supported and that makes you feel enjoyable to join in and learn. (2014 MURI student)

Another student-led initiative is the Undergraduate Research Student Society (MUURSS). Initiated by past volunteers from the first Australasian Conference for Undergraduate Research in 2012 (see below), MUURSS attracts students who have participated in undergraduate research experience programmes, and other students with a keen research interest. The Society hosts various events including workshops, stalls during induction weeks, social events, and a joint conference with MURI. As ambassadors for undergraduate research across the university, MURI and MUURSS provide a pressure group to lobby for changes to curricula, and encourage undergraduate research within departments.

These initiatives demonstrate the capacity of students to work not just as academics' partners but as initiators and drivers of change. As such they present a hitherto largely untapped resource in the work of academic developers. These examples in one institution are mirrored by a growing number of student-led scholarly initiatives worldwide.

## Model Facet 6: Communities

The model encourages the development of scholarly communities where students, academics, and other staff jointly engage in developing university communities through inquiry groups. This was promoted through a number of aspects of this programme. However, there remained negative attitudes of many senior staff to undergraduates engaging in research not just in our university but across the sector. The US experience encouraged us to seek widespread appreciation of undergraduate research and to grow a community of committed staff and students in Australasia.

Therefore, to initiate nationwide communities of undergraduate research scholars in our region, in 2012 we organised the first Australasian Conference of Undergraduate Research (ACUR). The event was overwhelmingly successful with 130 presentations given by undergraduates on topics ranging across all disciplines; a pattern that was repeated when we organised the second conference the following year. These conferences attracted numerous student volunteers, sponsorship, academic reviewers, and comments on social media. The best papers were subsequently published in an undergraduate research journal.

Following these two conferences, a grant from the Australian Government's Office for Learning and Teaching was obtained to make the conferences sustainable in the longer term. A Steering Group consisting of representatives from Australian and New Zealand universities was established, linked to a community of individuals developing undergraduate research worldwide. This provided a base for disseminating information and a forum for establishing documentation ensuring the quality of future conferences. Through this process the Australasian Council for Undergraduate Research was born.

Five further conferences have now been held in different Australian universities and the eighth is planned. Steering Group members work within their institutions in a variety of ways to develop undergraduate research communities and to prepare students for conference attendance. Approximately 800 students have presented their research at ACUR conferences to date with a combined audience total of 1000 individuals. These conferences have grown successive communities of undergraduate researchers as well as brought together within institutions across Australasia individuals committed to the encouragement of undergraduates' engagement in research.

## Discussion

This chapter has examined the use in educational development of the six facets of a model of universities as inclusive scholarly knowledge-building communities. A seven-year programme of undergraduate research development was designed to shift how universities and the wider Australasian society perceive undergraduate research. The model establishes a set of values and aspirations to guide the educational development process so it is pertinent to explore how it could be used in other contexts.

It is impossible to fully estimate the overall impact of such a complex development programme even in one institution let alone across the whole sector. From the evaluations conducted at every stage there is evidence to suggest that the programme was important in stimulating a cascade of continuing developments in engaging undergraduate students in research. This is demonstrated in: the ongoing work of former Working Group members developing research-based learning; their continued support for students to attend ACUR conferences; continued student engagement in organisations such as MURI; and, importantly, new strategic institutional research-based learning initiatives. Undergraduate research is more strongly embedded in our university's learning and teaching plan:

> We'll bring teaching and research together within the curriculum through program-based education that combines research-enhanced teaching with research-based learning. Informed by research, research-enhanced teaching integrates disciplinary research into our courses. Research-based learning provides opportunities for students to participate in and conduct research, learn about research, develop skills of research and enquiry, and contribute to

> the University's research effort. (Learning and Teaching Strategic Framework 2015–2020,[1] p. 22)

These aspirations are echoed in the university's research strategy which now sees as key strategic priorities, e.g., exposing undergraduates to researchers, establishing research internships, and encouraging "undergraduate participation in activities that actively promote participation in research (e.g., the Australasian Conference of Undergraduate Research)" (Strategic Research Framework, p. 27).

However, the model of universities as inclusive scholarly knowledge-building communities presents a bold vision requiring nothing less than a change in institutional culture and as such our programme merely scratched the surface. Developers value reflexivity and critical evaluation of their own practice (Wilcox, 2009) and this means that development programmes always inevitably fall short. More can always be done. The question we address here is how useful the model is in guiding academic development practice in the development of scientific thinking.

*Research* is fundamental to academic development whatever topics are the focus (Brew, 2006). It is clear that research carried out by the undergraduate scholars/ambassadors benefitted the participating departments through the involvement of academics in critically reflecting on aspects of teaching and learning. The scholars themselves developed scientific thinking through the research they conducted. By engaging in research in our programme, e.g. on students' awareness of research, and on the barriers to implementing research-based learning, we were able to make the case for change in a number of areas. Research can be fed into committee and other discussions and provide facts to inform future policy and practice at all levels.

*Teaching and learning* is the focus of many if not most academic development programmes. Focusing on student engagement, student partnerships and inquiry-based approaches to teaching and learning is relevant no matter what the focus of the development initiative. One of the key lessons for us in this programme is the importance of engaging students

[1] https://www.mq.edu.au/__data/assets/pdf_file/0015/209400/MQ-LT-Strategic-Framework-White-Paper-Sep16_Spreads.pdf.

in discussions of curriculum, in pedagogical research, and in encouraging students to demand changes in their education. As Hutchings (2002) suggests, students should be engaged in the scholarship of teaching and learning. This provides students with necessary scientific skills they can use in other contexts and an additional stimulus to change that is useful to developers.

*Knowledge building* now takes place within "transaction spaces" in Mode 2 knowledge generation (Nowotny et al., 2001, p. 103). This involves academics, students, and others within the academy working with other professionals and interested people and groups in society to generate new ideas and new ways to explore and substantiate them. Developers need to establish opportunities for new ideas to emerge through research and discussion with interested parties wherever they happen to be; inside the university or outside of it. Academics interviewed in this project demonstrated considerable use of and interest in undergraduate research across departments both within the curriculum and in special scholarship or internship programmes. They pointed to the need for opportunities to develop new knowledge about how to grow students' scientific thinking skills through implementing research-based learning within the curriculum. Sector-wide appreciation of the value of undergraduate research began to be developed through the ACUR conferences and the Posters in Parliament event which raised the national profile of undergraduate research by drawing the attention of, and putting students directly in touch with, senior higher education officials and some members of the Australian parliament where students were able to demonstrate their scientific thinking. We recognise this is just the start of a process and much more needs to be done. The ACUR was established to sustain programme developments beyond project funding. The vision for ACUR sees it becoming a peek body possibly funding undergraduate research scholarships, organising events for supervisors and institutional leaders to disseminate information and ideas, exchanging information about research scholarships available to undergraduates. This broader vision is only possible with considerable funding support and/or sponsorship. However, the important point here is that developers need to establish sustainable knowledge-building structures that continue beyond their project.

*Inclusivity*. Many university educational development initiatives focus on aspects of inclusivity, e.g. internationalisation, widening participation, indigenisation, and entrepreneurship. It is important that such initiatives not only encourage inclusivity to be developed but that they also embody inclusive practices. Students who participate are the academics of the future. In our project, we tried to take an inclusive approach to the development of scientific thinking in stimulating scholarly activity among students, treating those researching with us and those carrying out pedagogical research as participating colleagues, and encouraging them to become ambassadors for change. Only 12 students were involved in this way, but many of these have gone on to take leadership roles in developing undergraduate research internships and opportunities for further research among their peers, to complete PhDs and (in one case) a teaching qualification, to teach their own students in research-based learning ways, and to initiate further academic development initiatives related to undergraduate research. Student-led initiatives have continued to involve students who otherwise may not have had the chance to engage in research. However, sustainable funding and the willingness of staff to provide support present challenges.

*Scholarship*. In our programme we took the view that undergraduate students should be treated as scholars alongside academics and should be provided with opportunities to experience aspects of the four Boyer scholarships. Through working with us and developing scientific ways of thinking, they became effective members of working groups. We calculate that locally approx. 1000 students demonstrated aspects of the four Boyer scholarships directly through the opportunities our programme provided such as researching practice, and participating in organising and disseminating their research in conferences and in Parliament. In our own university 250 students directly benefitted in this way. These numbers are small in relation to the overall population of undergraduates. However, feedback suggests that the effects of participation for many of them have been profound, as illustrated by ACUR 2013 presenters:

> The conference gave me confidence in my study and new motivation

> I gained the understanding that the ability to conduct research is not restricted to academics at university, unlike a common perception that undergraduates only learn coursework and need to wait for higher level study to undertake projects. The great showcase of expertise in differing fields provides a great reason for more undergraduate students to answer their own questions as it is evident that we all are indeed capable of achievement in researching exciting and relevant issues.

Developers have an important role to play in encouraging academics to treat their students as scholars and in setting up initiatives in which students can work with them in scholarly ways. Where there are problems of academic practice including in curriculum and pedagogy that require a scholarly approach, students need to be involved in exploring issues and helping to address them.

*Communities*. Universities embody a number of distinct intersecting communities where academics and others shape their work and their lives in ways that meet institutional expectations (Brew, Boud, Crawford, & Lucas, 2018). Developers need to be aware of the different ways in which communities fail to connect or where there are opportunities for the development of new communities that meet specific needs. Our project built communities of undergraduate researchers in Australasia and of supervisors of undergraduate research through successive annual conferences. The intention is that the conferences will continue to be held annually. However, their sustainability is dependent upon the willingness of universities to host them and to make funding available for students to attend them. Our project has created a structure for future work to build on. This is an important feature of any development programme.

## Conclusion

In this chapter, we used the model of universities as inclusive scholarly knowledge-building communities to examine a wide-ranging programme of educational development. The programme aimed to promote undergraduate research opportunities and research-based learning as ways to develop scientific thinking. A whole-of-university approach we believe provides the ideal environment to enable and foster development of scientific thinking via pedagogy, curriculum, and scholarly communities. We have suggested further ways in which teaching, research, scholarship, knowledge building, inclusivity, and communities can be developed not just in the context of undergraduate research but within educational development more generally. The model provides a way of thinking about universities' educational development based on fundamental values of inclusivity, knowledge building, research, scholarship, and the development of university communities. As such the programme outlined in the chapter merely scrapes the surface of this much larger vision. We hope this work provides a blueprint for future development and inspires other managers and developers.

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