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

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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

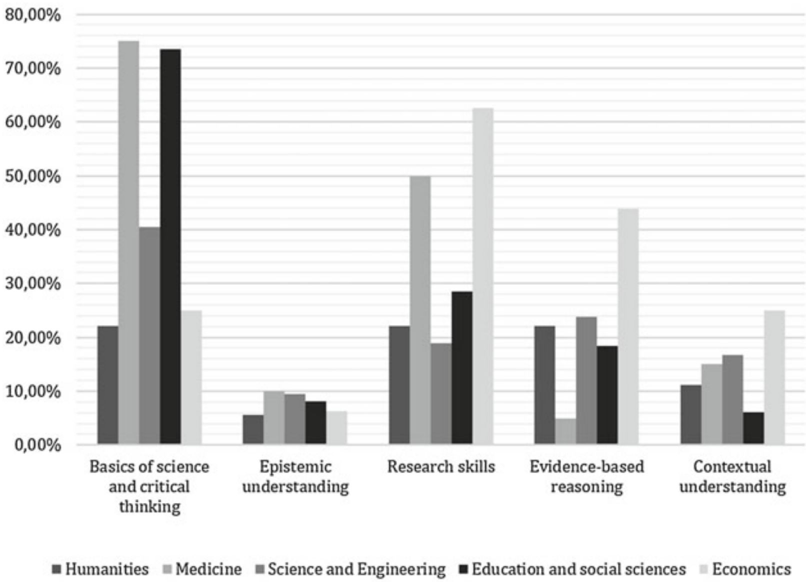

Fig. 2.1 Students' views (% of the students in discipline) of scientific thinking

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

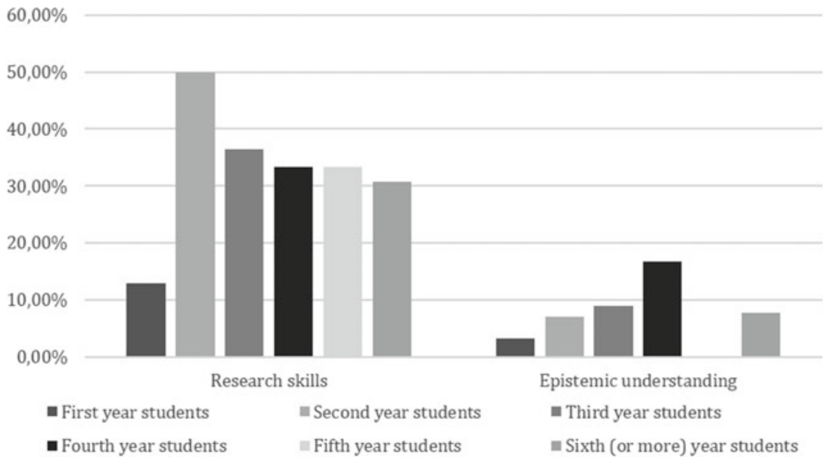

Fig. 2.2 Epistemic understanding and research skills in students' scientific thinking conceptions by the phase of study

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.

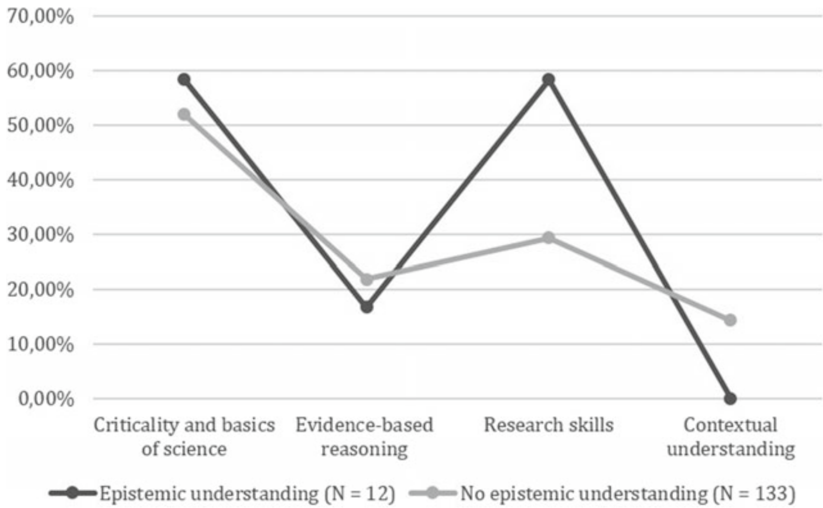

Fig. 2.3 Epistemic understanding in relation to other aspects of scientific thinking

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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