1. Introduction

Human beings strive to understand the world they inhabit. Aiming and attempting to understand something is ubiquitous in our everyday lives. Every human has witnessed situations in which, for example, a child wants to understand why one has to pay money when buying groceries from the supermarket, why someone is sad, or why her parents stay awake longer in the evening while she has to go to bed already. The same is of course also true of adults, although they may want to understand different things than children. Adult humans want to understand why a colleague is in a very bad mood, why there was a financial crisis, or how it was possible that populist parties gained more and more influence. And scientists strive to understand phenomena in the natural or social domains they are researching. Understanding phenomena is viewed to be one aim of science, as scientists occasionally state themselves. In biology, for instance, "a model organism [that] is a non-human species is extensively studied to *understand* specific biological phenomena."[1]

Despite the pervasive presence of instances and attempts of human beings to understand something in the world, the concept of *understanding*, what understanding is and how it is actually achieved, is hard to explicate. The uncertainty and confusion concerning the concrete meaning of *understanding* is not bound to a specific domain. From personal conversations with educators, I know that one goal of educational science is to develop tools or methods to determine whether pupils have understood what they are supposed to learn and understand in school. However, educators do this without having any clear concept or notion of *understanding*. They want to be able to measure something of which they have no idea what it actually is.[2] The controversial nature of understanding also becomes apparent in such provoca-

1 Sakaguchi, K. et. al. (2019), "Comprehensive Experimental System for a Promising Model Organism Candidate for Marine Teleosts." *Scientific Reports*, 9 (4948), DOI: 10.1038/s41598-019-41468-8, my emphasis.

2 This is the personal assessment of a friend of mine working in education science. Other educators might have a different opinion on that matter. However, if a fixed conception of understanding were employed in education science, my friend probably would not have a problem with it.

tive claims as "I think I can safely say that nobody understands quantum mechanics"[3] famously posed by Richard Feynman.

This book is a contribution to the philosophical research on (scientific) understanding. Surprisingly, philosophy has not paid much attention to understanding throughout its history, although understanding seems to be an ubiquitous epistemic activity as well as an unclear and contested concept. A philosophical interest in understanding emerged only quite recently within the last 25 years. Why has understanding been neglected by philosophers for such a long time and why has it attracted attention in recent times?

1.1 Tracing understanding through the history of philosophy

Understanding was already a topic of interest in ancient philosophy. In fact, it is proposed by some contemporary scholars that the more appropriate translation for the ancient Greek word *epistēmē* may be understanding, and not knowledge. For example, Julia Annas argues that in Plato's view, a person who has *epistēmē* does not merely possess various truths, but rather a systematic understanding of things.[4] Jonathan Lear makes a similar claim for Aristotle, namely that "to have *epistēmē* one must not only know a thing, one must also grasp its cause or explanation. This is to understand it: to know in a deep sense what it is and how it has come to be."[5] These interpretations of *epistēmē* reflect, according to Stephen Grimm, the currently widely accepted view that knowledge is quite easy to gain, while it seems harder to achieve understanding.[6] For example, I can know that I have blond hair just by looking at it, but understanding why I have blond hair or how I came to have blond hair demands something in addition. A reason for this difference might be that pieces of knowledge can be isolated or atomistic, at least in principle. I can know that I have blond hair without knowing anything else about, for example, genetics, inheritance, and the hair colors of my parents and ancestors. By contrast, targets of understanding seem to be more structured and interconnected. Although this might be due to the complex nature of targets that we want to understand, like the Second World War or the evolution of species, a certain degree of interconnectedness is also present in the understanding of isolated events. Understanding why a glass shatters requires connecting it with other events, for example the bumping of my elbow. Admittedly,

3 Feynman, R. P. (2017 [1965]), *The Character of Physical Law*. Cambridge (MA), MIT Press, p. 129.

4 See Annas, J. (1981), *An Introduction to Plato's Republic*. Oxford, Clarendon Press, chapter 10.

5 Lear, J. (1988), *Aristotle: The Desire to Understand*. New York, Cambridge University Press, DOI: 10.1017/CBO9780511570612.002, p. 6.

6 See Grimm, S., "Understanding", *The Stanford Encyclopedia of Philosophy* (Summer 2021 Edition), Edward N. Zalta (ed.), forthcoming URL = https://plato.stanford.edu/archives/sum2021/entries/understanding/ (last accessed April 11th, 2022), section 1.1.

the Greek philosophers seem to have held a very demanding concept of understanding that exceeds such mundane cases of understanding, as the understanding of the shattering of a glass, by far. Nevertheless, *epistēmē* is more similar to our contemporary notion of *understanding* than to the contemporary concept of *knowledge*, due to its emphasis on systematicity and interconnectedness.[7]

So, *understanding* is by no means a new concept in philosophy. Still, it has very much disappeared from the philosophical stage, and epistemologists focused instead on propositional knowledge. Why did that happen? No one really knows. Grimm presents two hypotheses. Perhaps the shift from understanding to knowledge was a reaction to the rise of skepticism in Hellenistic philosophy.[8] Alternatively or additionally, the wars of religion in 16th and 17th century Europe necessitated a focus on knowledge, as it became important to differentiate between good and bad knowledge claims.[9] Despite these first attempts at explaining the lack of understanding in the field of philosophy, the disappearance of understanding from philosophical debates is an unexplored issue so far, and I hope that research in history of philosophy will shed more light on it in the future.

It was not until the 19th century that the notion of understanding gained attention again in philosophy. Johann Gustav Droysen and Wilhelm Dilthey (re-)introduced understanding together with the *Verstehen-Erklären* dichotomy. It was their goal to elucidate the difference between the humanities (*Geisteswissenschaften*) and the natural sciences (*Naturwissenschaften*), and the *Verstehen-Erklären* dichotomy was taken to fulfill this purpose. For Droysen and Dilthey, understanding is the goal of the humanities, as the humanities are concerned with the intentions of (historical) actors and the interpretation of artefacts like texts or works of art. Therefore, understanding is subjective, according to Droysen and Dilthey. The natural sciences, in contrast, aim at uncovering the causes and general laws that are the basis of observed natural phenomena. Finding explanations of natural phenomena was, for Droysen and Dilthey, a purely objective endeavor.[10] Both scholars aimed at constituting an adequate theoretical as well as methodological basis for the "human sci-

7 See ibid.

8 See Zagzebski, L. (2001), "Recovering Understanding." In Steup, M. (ed.), *Knowledge, Truth, and Duty: Essays on Epistemic Justification, Responsibility, and Virtue*, pp. 235–252, New York, Oxford University Press, DOI: 10.1093/0195128923.003.0015.

9 For a systematic reconstruction of the history of epistemology, see Pasnau, R. (2017), *After Certainty: A History of Our Epistemic Ideals and Illusions*. New York, Oxford University Press, DOI: 10.1093/oso/9780198801788.001.0001.

10 See Beiser, F. C. (2011), *The German Historicist Tradition*. New York, Oxford University Press, DOI: 10.1093/acprof:oso/9780199691555.001.0001, chapter seven and eight; and Makkreel, R., "Wilhelm Dilthey", *The Stanford Encyclopedia of Philosophy* (Spring 2021 Edition), Edward N. Zalta (ed.), URL = https://plato.stanford.edu/archives/spr2021/entries/dilthey/ (last accessed April 11th, 2022).

ences", covering the humanities, to establish them as distinct from, but equally "scientific" as the natural sciences.[11] The *Verstehen-Erklären* dichotomy had a strong and complex influence on the Vienna Circle, and therefore on logical empiricism in general, and would maintain a long lasting impact on the philosophy of science.[12] However, apart from its prominent status in the debate about the *Verstehen-Erklären* dichotomy in the 19th century, understanding has never been seen as or taken to be an interesting or important topic for philosophers since antiquity. No one really cared about understanding.

1.2 The neglect and (re-) discovery of understanding …

Given the absence of the notion of understanding from philosophical controversies for millennia, why has it become a topic for philosophy within the last few decades? Why do philosophers nowadays care about understanding? Baumberger, Beisbart & Brun identify three reasons for this trend:

> Understanding seems to be a central good that we try to realize when we think about the world. More specifically, the value of understanding seems to surpass that of knowledge. We can know something without understanding it. […] The second reason for devoting attention to understanding is that understanding is a central goal of science. String theorist Greene goes so far as to characterize science in terms of understanding: "Science is the process that takes us from confusion to understanding in a manner that's precise, predictive and reliable." […] The third reason to look at understanding derives from developments within epistemology.[13]

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11 See for example Meinefeld, W. (1995), *Realität und Konstruktion. Erkenntnistheoretische Grundlagen einer Methodologie der empirischen Sozialforschung*, Wiesbaden, VS Verlag für Sozialwissenschaften, pp. 31–35, DOI: 10.1007/978-3-663-11243-3.

12 For more details on this relation, see for example Apel, K.-O. (1982), "The Erklären-Verstehen controversy in the philosophy of the natural and human sciences." In Fløistad, G. (ed.), *La philosophie contemporaine / Contemporary philosophy*, International Institute of Philosophy / Institut International de Philosophie, vol 2, pp. 19–49, Dordrecht, Springer, DOI: 10.1007/978-94-010-9940-0_2; or Uebel, T. (2010), "Opposition to *Verstehen* in Orthodox Logical Empiricism." In Feest, U. (ed.), *Historical Perspectives on Erklären and Verstehen*, pp. 291–309, Dordrecht, Springer, DOI: 10.1007/978-90-481-3540-0_15.

13 Baumberger, C., Beisbart, C. & Brun, G. (2017), "What is Understanding? An Overview of Recent Debates in Epistemology and Philosophy of Science." In Grimm, S., Baumberger C. & Ammon, S. (eds.), *Explaining Understanding. New Perspectives from Epistemology and Philosophy of Science*, pp. 1–34, New York and London, Routledge, pp. 2f; and Greene, B. (2008), "Put a Little Science in Your Life." New York Times, Open Ed., June 1, https://www.nytimes.com/2008/06/01/opinion/01greene.html (last accessed October 3rd, 2023).

Concerning the third reasons, the authors are referring to arising difficulties for and criticisms of justification conditions in accounts of knowledge. As these three reasons indicate, the two philosophical disciplines that are primarily concerned with understanding these days are philosophy of science and epistemology. Let us take a closer look at why understanding has not been worthy of inquiry for these disciplines for a long time, and why and how that changed.

1.2.1 ... in philosophy of science

The impact from the *Verstehen-Erklären* dichotomy, in which understanding was viewed as something subjective while explanation as something objective, became most apparent and was even amplified through the work of Carl Gustav Hempel in the 1960s. Due to his influential work, the notion of understanding was actively downplayed in philosophy of science for a long time. Essentially, Hempel was worried that understanding would be a threat to the objectivity of science. In Hempel's days, understanding was viewed as a subjective and psychological concept that – although it cannot be eliminated from science as science is conducted by human beings – should not be taken as a constitutive component of science. Explanation, on the contrary, is essential for science in Hempel's view. In a nutshell, the mere fact that some individual scientist does not understand some explanation of a phenomenon says nothing at all about the objectivity of the explanation. A good and objective scientific explanation of a phenomenon should be correct independently of any specific audience or context. As Hempel himself puts it:

> For scientific research seeks to account for empirical phenomena by means of laws and theories which are objective in the sense that their empirical implications and their evidential support are independent of what particular individuals happen to test or to apply them; and the explanations, as well as the predictions, based upon such laws and theories are meant to be objective in an analogous sense. This ideal intent suggests the problem of constructing a non-pragmatic concept of scientific explanation.[14]

Only few philosophers offered resistance to Hempel's subjectivist view of understanding, but there were some. As early as 1974, Michael Friedman argued that just because understanding seems to have some psychological element, it does not follow that understanding is purely subjective, uninteresting or unimportant for philosophers of science.[15] Eventually, knowledge has a psychological element, too, because

14 Hempel, C. G. (1965), *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*. New York, Free Press, p. 426.

15 See Friedman, M. (1974), "Explanation and Scientific Understanding." *Journal of Philosophy*, 71 (1), pp. 5–19, DOI: 10.2307/2024924.

of the belief condition, but this does not amount to a degradation of knowledge as being purely or mainly subjective. And Jaegwon Kim pointed out that humans aim at explaining things because we want to understand them. Hence, in Kim's view, it is a grave mistake to separate accounts of explanation from understanding.[16]

However, proponents of understanding could not remove the reservations about this notion in philosophy of science for a significant period of time. Even in the early 2000s, suspicions concerning understanding were actively endorsed, for example by John Trout, who defended the Hempelian objectivist account of explanation as well as his subjectivist view of understanding. According to Trout, understanding merely is a *Eureka!* or *Aha!* feeling, a product of types of biases known in cognitive psychology: "This sense of understanding alone is not necessarily a reliable guide to truth, nor is it a necessary condition for good explanation. Still less is it sufficient for good explanation."[17] A significant change of this situation was only brought about by the distinction between the "feeling" or phenomenology of understanding and genuine understanding introduced by Henk de Regt.[18] He also extensively engaged with Hempel's work in order to argue that understanding should not be taken as purely subjective and pragmatic. De Regt should be successful. By now, understanding is receiving more and more attention within philosophy of science, it is viewed as a legitimate and interesting topic for philosophers of science, and de Regt can be seen as the most important founding father of the contemporary debate on understanding in this discipline.

While understanding is a respected topic within philosophy of science by now, specific questions or issues concerning understanding receive special attention. According to Grimm, philosophers of science are particularly interested in the relation of understanding and explanation, as well as the relation of understanding and idealization, where the notion of idealization is intended to cover idealized models and representations.[19] Concerning the first issue, "the relationship between explanation and understanding remains controversial."[20] Grimm differentiates between two main approaches to this topic, which are the "understanding-first" approach versus the "explanation-first" approach. The "understanding-first" approach takes understanding to be "conceptually prior to, or more basic then, the notion of expla-

16 See Kim, J. (1994 [2010]), "Explanatory Knowledge and Metaphysical Dependence." *Philosophical Issues*, 5, pp. 51–69, Reprinted in Kim, J. (2010), *Essays in the Metaphysics of Mind*. New York, Oxford University Press, DOI: 10.1093/acprof:oso/9780199585878.001.0001.

17 Trout, J. D. (2002), "Scientific Explanation And The Sense Of Understanding." *Philosophy of Science*, 69 (2), pp. 212–233, DOI: 10.1086/341050, p. 213.

18 See de Regt, H. W. (2004), "Discussion Note: Making Sense of Understanding." *Philosophy of Science*, 71 (1), pp. 98–109, DOI: 10.1086/381415.

19 See Grimm (2021), section 4.

20 Ibid.

nation."[21] That is, explanation serves the end of understanding, and the goodness or "explanatoriness" of any explanation is assessed in terms of its capacity to generate understanding. Proponents of the "understanding-first" approach include Daniel Wilkenfeld, Paul Humphreys, and Angela Potochnik, among others.[22] By contrast, according to the "explanation-first" approach, most prominently endorsed by Kareem Khalifa, the discussion of understanding is nothing but a repacking of existing theories of explanation:

> All one needs for a plausible account of understanding is a plausible account of what counts as a good or correct explanation, combined with a plausible account of knowledge. Understanding therefore amounts to *knowing a correct explanation*. But then nothing new or special is needed to theorize about understanding; our accounts of explanation and our theories of knowledge do all the important theoretical work.[23]

Intuitions regarding these two approaches vary significantly, as the basic issue concerns the question of whether or not understanding *why p* does in some way exceed knowing *why p*.

The second interesting issue for philosophers of science, according to Grimm, is the relation of understanding and idealizations. Like explanation, idealization is a long-standing central and established topic in philosophy of science. Explanation as well as idealization are ubiquitous in science. The central challenge posed by idealization is to account for their capacity to provide real epistemic benefits without adhering to the truth (at least not in a strict or straightforward sense). All idealizations misrepresent or falsify the world in some way, e.g. by appealing to fully rational agents or frictionless planes, or through omitting certain factors, e.g. long range intermolecular forces.[24]

> Yet if idealizations provide epistemic benefits, and we cannot readily think of the benefits in terms of truth, then how exactly should we think about them? According to some philosophers, we should think not in terms of truth but rather in terms

21 Ibid.

22 For more details, see e.g. Wilkenfeld, D. A. (2013), "Understanding as Representation Manipulability." *Synthese*, 190 (6), pp. 997–1016, DOI: 10.1007/s11229-011-0055-x; and Humphreys, P. (2000), "Analytic Versus Synthetic Understanding." In Fetzer, J. (ed.), *Science, Explanation, and Rationality: The Philosophy of Carl G. Hempel*, pp. 267–286, Oxford, Oxford University Press, DOI: 10.1093/oso/9780199334872.003.0017; and Potochnik, A. (2017), *Idealization and the Aims of Science*. Chicago (IL), University of Chicago Press, DOI: 10.7208/9780226507194.

23 Grimm (2021), section 4.1; see especially Khalifa, K. (2017b), *Understanding, Explanation, and Scientific Knowledge*. Cambridge, Cambridge University Press, DOI: 10.1017/9781108164276.

24 See Grimm (2021).

> of understanding. Understanding is the epistemic benefit we receive from idealizations, and understanding and truth can come apart. On this view, understanding (unlike knowledge) can therefore be "non-factive".[25]

Concerning the details of how exactly idealizations might provide understanding, different accounts have been offered, for example by Angela Potochnik, Catherine Elgin, and Michael Strevens.[26] Furthermore, there is no general consensus that understanding can be non-factive. To put it differently, it is highly contested whether a representation that does not (somehow) answer to the facts can enable (genuine) understanding.[27]

Thus, the core topics surrounding understanding (although not the only ones) that philosophers of science are interested in relate to two traditional, central issues within the field, explanation and idealization. However, the second philosophical discipline that has also (re-)discovered understanding as a topic of interest is epistemology. Why did epistemologists become interested in understanding?

1.2.2 ... and in epistemology

In epistemology, the notion of understanding has not been actively devalued as in the philosophy of science, but rather neglected or ignored, according to Grimm.[28] As stated in section 1.1, the reasons for this disinterest in understanding throughout the history of western philosophy are not really known, but it is possible to identify reasons why this situation changed, i.e. why epistemologists started to be interested in understanding towards the end of the 20th century (again). Grimm identifies three reasons for this development. These three reasons are in line with, though not identical to, the reasons that Baumberger, Beisbart & Brun present for this trend, mentioned in section 1.2.

The first observation by Grimm is that, as especially Elgin argued, some of the greatest intellectual achievements of humanity, which can be found, for instance, in the sciences and arts, are actually not targeted at what epistemologists traditionally view as knowledge, but rather at something that is more plausibly conceptualized as

25 Ibid, section 4.2.

26 See Potochnik (2017), Elgin, C. Z. (2017), *True Enough*. Cambridge (MA), MIT Press; and Strevens, M. (2017), "How Idealizations Provide Understanding." In Grimm, S., Baumberger C. & Ammon, S. (eds.), *Explaining Understanding. New Perspectives from Epistemology and Philosophy of Science*, pp. 37–49, New York and London, Routledge.

27 For an overview of different positions and arguments in favor of and against (moderate) factivity and non-factivity, see Baumberger, Beisbart, & Brun (2017).

28 See Grimm (2021), section 1.2.

understanding.[29] Second, he argues that the interest in understanding was driven by virtue epistemologists. For example, Linda Zagzebski maintained that the focus of epistemology on knowledge as one epistemic good is too narrow, as it does not do justice to other highly valued epistemic goods like e.g. wisdom or understanding.[30] And third, Jonathan Kvanvig influentially argued that understanding is distinctively valuable, while knowledge is not.[31] Grimm concludes that all the different lines of arguments accused the field of epistemology of having a too narrow and one-sided focus on knowledge and that "epistemology needed to be broadened so that goods such as understanding could be given their proper due, and their claims resonated with other epistemologists."[32]

The first observation presented by Grimm supports the second reason for the new interest in understanding presented by Baumberger, Beisbart & Brun, namely that understanding is a central goal of the sciences (and potentially also of other areas of human action). Grimm's second and third observation concerning the views from (virtue) epistemology resembles the first reason provided by Baumberger, Beisbart & Brun, which is the (potential) special epistemic value of understanding. Whatever understanding is, it seems to be something that goes over and above knowledge (and the same could be argued for wisdom, for example). If this is the case, then understanding is epistemically more valuable than knowledge, and the traditional focus on knowledge in epistemology becomes questionable.

> [In this context, it has been noted several times that] knowledge may easily be acquired through the testimony of experts; understanding, by contrast, seems more demanding and requires that an epistemic agent herself puts together several pieces of information, grasps connections, can reason about causes, and this too suggests an added value. […] The problem of accounting for a supposed special value of knowledge is now called *the value problem for knowledge*. Epistemology escapes this problem if it turns to understanding.[33]

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29 See particularly Elgin, C. Z. (1991), "Understanding: Art and Science." *Midwest Studies in Philosophy*, 16, pp. 196–208, DOI: 10.1111/j.1475-4975.1991.tb00239.x. For a more recent elaboration of her ideas concerning understanding, see Elgin (2017).

30 See Zagzebski, L. (1996), *Virtues of the Mind. An Inquiry into the Nature of Virtue and the Ethical Foundations of Knowledge*, New York, Cambridge University Press, DOI: 10.1017/CBO9781139174763; and Zagzebski (2001).

31 See Kvanvig, J. L. (2003), *The Value of Knowledge and the Pursuit of Understanding*. New York, Cambridge University Press, DOI: 10.1017/CBO9780511498909.

32 Grimm (2021), section 1.2.

33 Baumberger, Beisbart & Brun (2017), p. 3, original emphasis. For a detailed discussion of *the value problem for knowledge*, see Pritchard, D., Millar, A. & Haddock, A. (2010), *The Nature and Value of Knowledge: Three Investigations*, Oxford, Oxford University Press, DOI: 10.1093/acprof:oso/9780199586264.001.0001. Jonathan Kvanvig also explicity advocates the special value of understanding in comparison to knowledge, see for example Kvanvig (2003).

However, and quite unsurprisingly, the alleged special epistemic value of understanding is not universally accepted and objections are put forward.[34]

Investigations on and discussions about the possible special epistemic value of understanding are related and intertwined with the third reason that Baumberger, Beisbart & Brun identify for the interest in understanding, namely other developments within epistemology that concern the notion of justification. Apparently, strong intuitions persist that a justification for a belief, which would turn the belief into knowledge, is on the one hand accessible for the epistemic agent, is internal to her, and on the other hand that the belief is justified through being embedded in a coherent web of beliefs. These views on justification for beliefs are called internalism and coherentism.[35]

> [Baumberger, Beisbart & Brun observe that while] intuitions supporting internalism and coherentism seem deep-seated, it has been proven difficult to save them in an account of knowledge. Internalism about epistemic justification is threatened by a regress problem. Coherentists have a hard time to show how coherence is related to truth, which is supposed to be the aim of belief and a central feature of knowledge. However, an immediate access to the reasons for a belief and the ability to connect a belief with others seem to be central for understanding.[36]

Hence, they conclude that internalist and coherentist intuitions can appropriately account for understanding, while they are (or might be) inapplicable to knowledge. Again, such views that allocate internalist or coherentist intuitions to understanding, and additionally intuitions from virtue epistemology, are contested as well.[37]

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34 See for instance Carter, J. & Gordon, E. (2014), "Objectual Understanding and the Value Problem." *American Philosophical Quarterly*, 51 (1), pp. 1–13; or Khalifa (2017b), chapter 8.

35 See for example Pappas, G., "Internalist vs. Externalist Conceptions of Epistemic Justification", *The Stanford Encyclopedia of Philosophy* (Fall 2017 Edition), Edward N. Zalta (ed.), URL = https://plato.stanford.edu/archives/fall2017/entries/justep-intext/ (last accessed April 11th, 2022); and Olsson, E., "Coherentist Theories of Epistemic Justification", *The Stanford Encyclopedia of Philosophy* (Fall 2021 Edition), Edward N. Zalta (ed.), URL = https://plato.stanford.edu/archives/fall2021/entries/justep-coherence/ (last accessed April 11th, 2022).

36 Baumberger, Beisbart & Brun (2017) pp. 3f.

37 See for instance Grimm, S. (2017), „Understanding and Transparency." In Grimm, S., Baumberger C. & Ammon, S. (eds.), *Explaining Understanding. New Perspectives from Epistemology and Philosophy of Science* pp. 212–229, New York and London, Routledge; and Khalifa, K. (2017a), „Must Understanding be Coherent?" In Grimm, S., Baumberger, C. & Ammon, S. (eds.), *Explaining Understanding. New Perspectives from Epistemology and Philosophy of Science*, pp. 139–164, New York and London, Routledge.

1.2.3 The current state of play

Where does all this leave us? In sum, various reasons have led to the recent interest of philosophers in understanding. Most fundamentally, it has been acknowledged that understanding is a central epistemic good that humans try to and want to achieve, in science as well as elsewhere. Because of the recognition of this central value of understanding, philosophers of science and epistemologists began paying attention to the concept. The engagement with understanding has opened up new possibilities to solve already known problems and answer open questions in the respective disciplines. For philosophy of science, the examination of understanding enables analyses of a crucial (or potentially the most important) scientific aim and the function of idealizations in scientific research, among others. In epistemology, the work on understanding offers solutions to central issues in the field, such as *the value problem for knowledge*, or problems concerning different accounts of epistemic justification.

Furthermore, the topic of understanding has yielded an extensive exchange between these two philosophical disciplines, which is a rare phenomenon. Philosophers of science and epistemologists engage with and criticize each other's work in this area. This interdisciplinary research on the topic of understanding has resulted in a fruitful dialogue between the two philosophical disciplines, each of which contributes their own main interests, questions, and respective methods. Philosophy of science is interested in the understanding that scientists achieve of the phenomena they are researching or of the theories that they use, how scientists achieve this understanding, and how scientific understanding relates to other core concepts in science, such as theories, explanations, and models, among others. Epistemology, in contrast, is interested in the understanding that (human or rational) agents generally can gain.

Despite their differences, philosophers of science and epistemologists share the common ground in that the concept of understanding should be analyzed and provide each other with important insights. On the one hand, epistemologists (usually) take scientific understanding to be a special or in some sense distinctively valuable type of understanding, and hence they are interested in what philosophers of science have to say about it. On the other hand, any general inquiry into understanding in epistemology might reveal important insights for philosophers of science.

This dialogue between the two philosophical disciplines amounts to ever new research questions on understanding, including the following:

- What is understanding? Is it a kind of knowledge or an ability?
- What types of understanding exist and how might they relate to each other (e.g. objectual, explanatory, symbolic, practical, moral understanding …)?
- Does understanding require explanation?
- How does understanding relate to truth?

- What is the role of models or representations in or for understanding?
- How should the graduality of understanding be accommodated?
- …

This list is not meant to be exhaustive, it shall just exemplify the diversity and amount of questions concerning understanding which puzzle philosophers.[38] This book is a contribution to this thriving and new 'hot' topic and debate in philosophy.

1.3 Outline of this book

The goal of this book is to provide a philosophical account of scientific understanding. That is, I develop and defend necessary and sufficient conditions for the understanding that scientists achieve of the phenomena they are studying through their research. To put it differently, I provide answers to these two main questions:

I) What is scientific understanding?
II) And how do scientists achieve understanding?

My starting point is the existing philosophical debate on understanding, including work on scientific understanding in particular, as well as on understanding in general. As I have stressed throughout the previous section, understanding is a topic of interest for philosophers of science as well as for epistemologists for the last three decades. Hence, perspectives and insights from both disciplines need to be considered in any analysis on understanding. Chapters two, three and four cover, therefore, abstract and normative philosophical discussions and positions concerning characteristics of understanding and related concepts, such as explanation and ability or knowing-how. The philosophical literature already has a lot to offer for clarifying the notion of understanding, and I could only scratch the surface of the variety of topics and issues around understanding that are addressed in philosophy by now in the previous section.

Engaging with different and opposing views and arguments allows for the identification of core topics concerning understanding, together with underlying assumptions or intuitions regarding certain issues. A thorough examination of the existing philosophical literature on understanding provides an important navigation through the debate. It enables structuring the debate into more or less controversial or important topics with regard to specific questions, together with the genesis of certain camps within the debate, the arguments developed by proponents of

38 Further summaries of the philosophical debate on understanding and the questions that occupy philosophers are provided by Baumberger, Beisbart & Brun (2017) and Grimm (2021).

different views, and also the intuitions that are uphold within and across different camps. Taking already developed philosophical arguments and theories about aspects of understanding enables me to clarify my intuitions concerning understanding, why I agree with some scholars and not with others, and developing my own normative position on questions such as why scientific understanding should require explanation or why understanding should be conceptualized as an ability.

However, while abstract philosophical theorizing and argumentation is of course important, it is not sufficient for generating a meaningful account of scientific understanding. I am a philosopher of science and, hence, have acquired the specific methods and practices of my discipline. Since the Practice Turn in 1980s, through which philosophical as well as historical and social studies of science paid much more attention to the social, psychological, and material dimensions of scientific research, philosophy of science is (often) characterized by in-depth and detailed case studies or episodes from past or present scientific practice. I adhere to this practice, as it is my deepest conviction that philosophy has to take scientific practice seriously if it wants to generate and contribute any relevant or important insights about science.[39] The most consistent and intuitive philosophical theory or argument will be meaningless if it cannot capture real and actual science.

Thus, while I draw on shorter examples from scientific as well as none-scientific contexts throughout my abstract philosophical discussions to support my claims, these examples cannot replace in-depth analyses of research episodes. Examples serve the purpose of illustrating or supporting claims or arguments. Analyses of research episodes shall, additionally, provide novel insights into the topic of interest, scientific understanding in this case. Hence, an analysis of an episode from scientific practice will follow my abstract philosophical discussions. Thereby, I can reassess the plausibility of my claims developed before, and also highlight novel insights about how scientists gain understanding that philosophical theorizing cannot deliver on its own. Taken together, the insights from my detailed engagement with the abstract philosophical debate and from the analysis of the concrete research episode allow me to generate a novel account of scientific understanding that will be meaningful for science in general.

Let me be more specific about the structure of this book. While insights from philosophy of science as well as epistemology need to be taken into account in any

39 For more information about the engagement of philosophy of science with scientific practice, see e.g. Soler, L., Zwart, S., Lynch, M. & Israël-Jost, V. (eds.) (2014), *Science After the Practice Turn in the Philosophy, History, and Social Studies of Science*. Studies in the Philosophy of Science 14, New York and London, Routledge. For insights into the relation between history and philosophy of science in particular, see Schmaltz, T. & Mauskopf, S. (eds.) (2012), *Integrating History and Philosophy of Science: Problems and Prospects*. Dordrecht, Springer, DOI: 10.1007/978-94-007-1745-9.

analysis on understanding, this does not prohibit placing an emphasis on one of the respective disciplines. Again, I am a philosopher of science by training and approach the topic from the corresponding perspective. Thus, I start by introducing already existing accounts of scientific understanding put forward by the three philosophers of science Henk de Regt, Kareem Khalifa and Finnur Dellsén in chapter two. Presenting their accounts provides the basis for my analysis and allows for identifying central issues, question, and also shared assumptions related to scientific understanding. I restrict myself to the accounts of scientific understanding developed by philosophers of science in chapter two because this book focusses on scientific understanding. While I hope that my work will also be of value for epistemologists, I do not aim at providing an account of understanding in general. Hence, while I give epistemology its earned space throughout this book, especially in chapters three and four, I do not introduce any epistemological account of understanding at the beginning of my investigations in chapter two. Instead, I highlight the agreements and disagreements among de Regt, Khalifa, and Dellsén concerning scientific understanding and argue that two questions are especially striking:

1) Does scientific understanding require explanation or not?
2) Is understanding an ability or a type of knowledge?

These two questions provide partial answers to one of the main questions of this book, namely what scientific understanding is. The answer to the second main question, how scientists can or do achieve understanding, depends, in turn, on what scientific understanding is. In order to clarify what scientific understanding is and how scientists achieve it, which is the ultimate goal of this book, I first need to figure out whether understanding requires explanation and whether it is an ability or a type of knowledge. Thus, this book is structured as follows:

Having provided a starting point in chapter two, chapter three turns towards the question of whether scientific understanding requires explanation or not, a core question for philosophers of science, as I have indicated in section 1.2.1. Answering this question is not possible without clarifying what I mean by explanation. A clarification of the notion of explanation will be the first step to take in this chapter. Following that, I engage with several arguments and examples put forward to defend a separation or possible independence of understanding from explanation and challenge their plausibility for scientific understanding in particular. One line of thought is that understanding and explanation can fall apart, as the former is something tacit, while the latter is something explicit. Is it really that simple, is this straightforwardly the case? Furthermore, the philosophical literature on understanding intensively engaged with two types of understand so far: explanatory and objectual understanding. Explanatory understanding is viewed to require explanation. Objectual understanding, in contrast, is either independent of explanation or exceeds

explanatory understanding in some sense. How exactly do different scholars distinguish between these two types of understanding? And do the proposed distinctions really show a difference between two kinds of understanding, or do the differences merely point towards a difference in the degree of understanding? In other words, can objectual understanding be conceptualized as being independent of explanation? And finally, in light of the discussions conducted in this chapter, does it make sense to view scientific understanding as being possibly independent of explanation?

Chapter four addresses the question of whether understanding is an ability or a type of (propositional) knowledge. This chapter will probably be especially interesting for epistemologists, as it touches on central issues discussed in this field mentioned in section 1.2.2, including the demand for broadening epistemology's focus to other intellectual achievements than knowledge. Similarly to my approach in chapter three, I first need to clarify what I mean by ability. I will do that based on a broad literature survey covering work on abilities or knowing-how from philosophy of science, (virtue) epistemology, and metaphysics. Having generated a conceptualization of ability, the follow up question will be whether understanding should be viewed as an ability, or rather as a type of (propositional) knowledge. Can the notion of understanding and potential characteristics that are often intuitively ascribed to understanding be better accommodated by conceptualizing understanding as an ability, and not as a type of (propositional) knowledge? And if the answer to this question is affirmative, if understanding is taken to be an ability, how could understanding be manifested? In contrast to chapter three, where I mainly use and engage with the philosophical literature on understanding, my analysis in chapter four will be broader. Answering the questions of what abilities are, whether understanding should be conceived as an ability and if so, how understanding is manifested, requires a wider perspective that includes but also exceeds the debate on understanding, as more general questions concerning the nature of (propositional) knowledge and abilities need to be taken into account and then applied to discussions on understanding.

Chapter five then presents a change of perspective and differs significantly from the previous chapters, as it deals with an episode from scientific practice and the question how exactly scientists involved in this episode gained scientific understanding. The research episode covers the introduction of zebrafish as a new model organism into biological research through which biologists wanted to understand the genetic regulation of vertebrate development. A careful and detailed description of this research episode will, on the one hand, allow for testing whether the insights gained through abstract philosophical argumentation in chapters three and four have any meaningful implications for reals world science. On the other hand, analyzing the episode might allow for an identification of features of understanding that cannot be obtained by pure philosophizing detached from any real-

world cases. What do real scientists need in order to understand a phenomenon they are researching? How do they actually achieve understanding? How do they proceed? Which steps do they undertake? This chapter aims at providing answers to these questions.

Finally, in chapter six, I bring all the different lines of thought developed in the previous chapters together and present my account of scientific understanding. This account will be an answer to the main questions of what scientific understanding is and how scientists achieve it, and will go beyond the concrete episode discussed in the previous chapter. Of course, the episode from biology serves an important purpose, but one cannot straightforwardly generalize from that episode to science as a whole, given the variety of different scientific disciplines. That is, the concrete insights from chapter five need to be abstracted in order to be relevant for scientific understanding, generally speaking, and these abstracted insights still need to be connected to the results from chapters three and four. How are understanding and explanation related? How do understanding, knowledge, and abilities tie in together? What do scientists need in order to understand a phenomenon? Which roles do the respective context and the research community in which any particular scientists is embedded play for understanding? In short, I will explain what I take scientific understanding to be and how scientists achieve it. To make my account of scientific understanding even more appealing, I will come back to the accounts by Henk de Regt, Kareem Khalifa and Finnur Dellsén introduced in chapter two, and I will emphasize the benefits of my account in comparison to their alternatives. Ultimately, chapter seven will provide a summary of the findings of this book and an outlook by pointing towards further questions and issues concerning scientific understanding that lie beyond the scope of this book.

In short, this book can be divided, roughly, into two parts. In chapters two, three, and four, I provide a detailed account of the philosophical debate on understanding, highlight common assumptions and intuitions as well as opposing positions and arguments, and I also consider philosophical work on related topics, in order to develop my arguments and position concerning the respective issue addressed in these chapters. Chapters five and six make up the second part of the book, as I answer the two main questions guiding my project, namely what scientific understanding is and how scientists achieve it. While my results from the first part of course contribute to the second part, my analysis and argumentation in chapters five and six are not as closely tied to the existing philosophical debate on understanding as the three preceding chapters.

As a general outcome, this book will amplify and further support recent developments within epistemology and philosophy of science as regards (scientific) understanding. My aim is to second the currently dominant view that understanding is an important intellectual achievement and goal of scientific research worthy of philosophical attention and analysis. Viewing understanding as something purely

subjective or psychological that has no legitimate place in the natural sciences, as argued by Droysen and Dilthey in the 19th century and by Hempel and other philosophers of science throughout the 20th century, is unjustified in light of the importance attributed to understanding in scientific as well as everyday contexts. Valuing and researching understanding enables new perspectives and insights not only on scientific practice, but also the nature of knowledge and central epistemic goods more generally. But first things first, let us start by taking a look at some existing ideas and accounts of scientific understanding.