# 2. Different views on scientific understanding

As already mentioned in the introduction, understanding has attracted the attention of epistemologists and philosophers of science only within the last 25 to 30 years. Since then, more and more philosophers have engaged with the investigation on understanding, be it scientific understanding in particular, or understanding in general. As it can be expected, philosophers of science are primarily concerned with scientific understanding, whereas epistemologists turn to understanding as a general phenomenon or aim of human beings. However, these two philosophical disciplines talk to and with each other. Even epistemologists refer to scientific understanding quite often, as they take scientific understanding to be an especially valuable kind of understanding, maybe even the best kind of understanding one could achieve. The dialogue between philosophers of science and epistemologists is, hence, a very fruitful one. However, as this book focusses on scientific understanding, I will primarily rely on work done by philosophers of science, while I will also give epistemology its proper space in the course of my investigation.

In this chapter, I give an overview of three very important and influential accounts of scientific understanding. These are the accounts developed by Henk de Regt, Kareem Khalifa, and Finnur Dellsén. Based on this overview, I will highlight common assumptions shared by those three scholars, as well as disagreements among them concerning characteristics and the nature of understanding. The identification of commonalities of the three accounts will provide a basis for my own work on scientific understanding. And the detection of dissent and conflicting arguments will allow me to spotlight two questions that are of central importance for any analysis of scientific understanding.

Why do I only address these three accounts, although de Regt, Khalifa and Dellsén are by far not the only philosophers engaged in the discussions about understanding? While more and more epistemologists and philosophers of science join the debate about understanding, most of them focus on specific features of understanding, like its relation to truth, to idealizations or to explanations, to mention just some examples. To my knowledge, de Regt and Khalifa are the only scholars so far who developed full-fledged and detailed philosophical accounts of scientific understanding that they presented, defended and published in form of monographs. Since

their accounts are the most elaborated ones on the market, they certainly need to be considered in any philosophical investigation on scientific understanding. Additionally, I also include the account of scientific understanding developed by Dellsén. The reason to add this third account to the discussion in this section is that de Regt and Khalifa, despite all their differences, agree in one central aspect: they take explanation to be necessary for understanding. Their accounts only accommodate what is often called explanatory understanding. However, as I show in section 2.3 and especially in chapter three, there is no universal agreement that understanding requires explanation. On the contrary, accounts of understanding without explanation, most often called objectual understanding, are developed and defended in the literature. Therefore, I need to take an account of objectual understanding into consideration, and the one developed by Dellsén is a good representative for such accounts. Taken together, the accounts of scientific understanding from de Regt, Khalifa and Dellsén sufficiently represent the range of views concerning features that most scholars in the debate take to be crucial for understanding: abilities in general, grasping in particular, knowledge and explanation.

I do not address any account of understanding developed by epistemologists in this section, because epistemologists are usually interested in accounts of understanding in general, not with scientific understanding in particular. So, epistemologists aim at accounts that should accommodate understanding that any human agent could gain, not only scientists. While I do think that it might be possible to develop a unified or holistic account of understanding and that it is reasonable to expect some commonalities of scientific understanding and, let's say, laypeople's understanding, it is also plausible to expect some differences between scientific and other types of understanding. It is not the goal of this book to develop a general account of understanding that human beings can gain of anything. I happily leave this task to epistemologists. Instead, I want to develop an account of scientific understanding, the understanding that scientists achieve of the phenomena they are researching. Hence, I focus and only introduce three accounts of scientific understanding put forward by philosophers of science in this chapter. However, I will let epistemologists engaged in understanding have their say, especially in chapters three and four, where I discuss the relation of understanding and explanation as well as the nature of understanding.

But first, let us have a look what other philosophers of science think about scientific understanding. I start with Hend de Regt's account in section 2.1, followed by Kareem Khalifa's account in section 2.2, and by Finnur Dellséns's account in section 2.3. Finally, in section 2.4, I highlight in which aspects concerning understanding those three scholars agree, and on which they disagree and in what way. By doing so, I will point out that two crucial questions arise, and that I am going to answer these two questions in the course of this book. So, let's get started.

## 2.1 Henk de Regt: Understanding phenomena through theories

Henk de Regt was among the very first philosophers of science who were interested in understanding as a topic worthy of analysis for its own sake. Hence, he is something like a founding father of the philosophical engagement with understanding in contemporary philosophy. Any work on scientific understanding should consider de Regt's contribution. In his analysis, de Regt differentiates between two kinds of understanding crucial in science, which he characterizes as follows:

> **UP:** understanding a phenomenon = having an adequate explanation of the phenomenon (relating the phenomenon to accepted items of knowledge)
>
> **UT:** understanding a theory = being able to use the theory (pragmatic understanding)[1]

Additionally, he differentiates between three levels of science: the macro-level (that refers to science as a whole), the meso-level (that characterizes scientific communities) and the micro-level (corresponding to individual scientists). UT is intended to allow for micro-and meso-level variations, which means that different explanatory strategies are applied to achieve the macro-level aim UP.[2]

At the core of de Regt's account of understanding lies the thesis that scientists need intelligible theories if they want to gain scientific understanding of phenomena. If a theory is not intelligible for scientists, they will not be able to use the theory to construct an explanation of a phenomenon on the basis of the theory. Without understanding a theory, understanding a phenomenon is impossible.[3] This leads de Regt to his criterion for understanding phenomena:

> **CUP:** A phenomenon P is understood scientifically if and only if there is an explanation of P that is based on an intelligible theory T and conforms to the basic epistemic values of empirical adequacy and internal consistency.[4]

Whether a theory is intelligible or not depends on the epistemic framework that is accepted and provided by a scientific community. The available background knowledge and acquired skills determine whether a theory is intelligible. In different disciplinary, historical or social contexts, different theories are judged as being intelligible by scientists. To restrain the scientist's freedom to choose or construct any

1 De Regt, H. W. (2017), *Understanding Scientific Understanding*. New York, Oxford University Press, DOI: 10.1093/oso/9780190652913.001.0001, p. 91.

2 See ibid. pp. 90f.

3 See ibid. pp. 91f.

4 Ibid. p. 92.

kind of explanation based on any theory taken to be intelligible, de Regt adds the two epistemic values of empirical adequacy and internal consistency. Although it is not always obvious how these values should be applied, some degree of adequacy and consistency has to be reached by any explanation to secure a minimal scientific standard.[5]

De Regt anticipates possible critique to CUP in the form of putting too much emphasize on theories in the process of achieving understanding. Sometimes, scientists achieve understanding merely by experimentation that is independent of any theory. Additionally, there are scientific disciplines where explicit theories are absent. Finally, models constructed and used in science seem to provide understanding independently of any theory. De Regt's answer to these objections is that he does not require any theory to be full-fledged or explicitly articulated. Instead, he follows Giere[6] and views a theory to be a collection of principles, which guide every form of observation, experiment, or model-construction. No scientific discipline works without some theoretical framework, no matter how explicit that might be.[7]

The account of scientific understanding developed by de Regt accommodates solely explanatory understanding, the understanding that is produced by a scientific explanation. Although he mentions that other forms of understanding exist, he does not cover or address them in his account. Rather, he simply presupposes their existence and characterizes them as types of knowledge. Since it is not possible in de Regt's framework to achieve explanatory understanding if there is no theory (no theoretical principles at all), theories are also viewed as a part of knowledge. De Regt employs a generic conception of explanation, which characterizes every explanation as an argument that presents a systematic line of reasoning that connects a phenomenon to accepted theoretical and empirical background knowledge. Hence, theories have to be part of the background knowledge. Otherwise, there will be nothing a phenomenon could be connected to, therefore there will be no explanation and, hence, also no explanatory understanding. An intelligible theoretical context is required for achieving explanatory understanding.[8]

Another argument that understanding and intelligibility are deeply intertwined is rooted in the fact that scientists understand the phenomena of their research by interacting and communicating with each other. If the theoretical principles, assumptions or models used by some scientists are not intelligible for others, science as a community will not make any progress. In most cases, scientists address and solve problems together in cooperation. Therefore, everything that contributes to the common activity of scientific research has to be intelligible for its members. De

5 See ibid. pp. 92f.

6 See Giere, R. N. (2006), *Scientific Perspectivism*. Chicago, University of Chicago Press, pp. 59–69.

7 See de Regt (2017), pp. 95ff.

8 See ibid. pp. 96–99.

Regt also describes the connection between his notion of intelligibility and the account of Humphreys[9], who introduces primary and secondary understanding. Primary understanding is achieved by an individual or group of scientists in isolation (would be identical to UT, having constructed an explanation), whereas secondary understanding requires communication and making the new constructed explanation intelligible to other individuals.[10]

Since achieving scientific understanding depends on intelligible theories, de Regt has to determine under which conditions a theory is intelligible. He wants to set some restrictions so that scientists do not decide on a purely subjective basis which theory is intelligible under which circumstances. If a theory is intelligible, i.e. if scientists understand the theory, they will have to have some idea of how the theory functions or how it produces certain outputs. Since de Regt allows for a wide variety of theories (for various degrees of exactness), he allows for a variety of criteria to assess the intelligibility of a theory.[11] He offers one possible criterion:

> **$CIT_1$:** A scientific theory *T* (in one or more of its representations) is intelligible for scientists (in context *C*) if they can recognize qualitatively characteristic consequences of *T* without performing exact calculations.[12]

By including the individual scientists and the specific context, $CIT_1$ accommodates the pragmatic and context-dependent nature of the intelligibility of theories, and, hence, also of UT and UP, since both notions depend on the intelligibility of theories. Besides the particular qualities of the theory in question, the combination of established scientific practices in a certain field, the developed abilities or skills of the individual scientists, and the established and available background knowledge determine whether a theory is intelligible for an individual scientist or group of scientists, or not. Certain qualities of a theory provide tools only if the skills of a scientist are attuned to these qualities.[13]

The two criteria proposed by de Regt, CUP and $CIT_1$, constitute the basis of his philosophical theory of understanding. Understanding, explanation, and prediction are viewed to be interrelated goals of science. He claims that prediction is not possible without understanding. If a scientist does not understand the important features and structure of a theory, if the theory is not intelligible to her, she will not be able to produce successful predictions. Instead, she will merely be guessing. A successful prediction that can be explained by a scientist shows that she understood a

9 See Humphreys (2000), p. 269.
10 See de Regt (2017), pp. 99f.
11 See ibid. pp. 101f.
12 Ibid. p. 102.
13 See ibid. p. 103.

theory. Hence, predictions enter de Regt's account of understanding through $CIT_1$, according to which scientists must be able to recognize qualitative characteristic consequences of a theory. And crucially, both kinds of understanding, UT as well UP, cannot be achieved by performing a rule-following procedure. Instead, tacit skills, the know-how to make use of a theory or an explanation, are required. Which skills a scientist needs to make a theory intelligible to her depends on the qualities of the theory. By applying $CIT_1$, it is possible to check whether the appropriate skills for a specific theory are present.[14]

In making decisions or performing reasoning, humans often refer to intuitions. Intuitions, in de Regt's view, can be defined as judgements whose underlying reasons are not fully accessible for a subject and which are results of heuristics that have been developed in an evolutionary process. The human cognitive system has produced these heuristics in response to environmental influences. It is possible to develop reliable intuitive skills in an environment that is sufficiently stable to make successful predictions if a subject has the opportunity to learn these regularities through practice. These conditions are usually fulfilled in science. Therefore, the skills acquired by scientists allow them to intuitively recognize theoretical consequences of a theory. For achieving scientific understanding, skills and intuitive judgements are crucial.[15]

> If a theory is intelligible to scientists because its theoretical qualities match their skills, they can reason "intuitively" with it. Like our everyday intuitive skills, scientists' skills are the outcome of a complex learning process in which they find themselves (that is, the historical and disciplinary context of their science).[16]

As de Regt has already mentioned, the construction of models or of explanations more generally is a matter of skill, of pragmatic decisions which lead to the desired result. Scientists have to have the know-how, the ability, to address and solve a new problem.[17] There are no fixed general rules that guide every possible construction process, or so many different rules that it is impossible to pick the right ones out of a big catalogue. Various theories as well as models of scientific explanation provide different tools for understanding, and all of them might be legitimately used in certain circumstances or contexts.[18] Hence, de Regt is an explanatory pluralist.

De Regt wants to clarify in the framework of his theory how precisely understanding and intelligibility are related to certain contexts. In short, the context determines which tools are available or deemed suitable. Which contextual factors are

14 See ibid. p. 107f.
15 See ibid. pp. 109ff.
16 Ibid. p 110.
17 See ibid. p. 112.
18 See ibid. p. 115.

important? According to de Regt's theory, certain qualities of a theory are conducive to its empirical success because they enhance the intelligibility of a theory for those scientists who possess the skills to use the conceptual tools that are associated with these qualities. Since science is a community activity and scientific understanding is a community achievement, the conceptual tools are mostly established at the level of scientific communities (meso-level). In a sense, understanding a theory means to become familiar with it. As soon as a scientist has developed the relevant skills to use the theory in an intuitive way (CIT), the theory is familiar to her. More specifically, the tools have to be familiar to the users. If scientists have developed the relevant intuitive skills to use these tools, the tools are familiar to the scientists and they are able to make successful predictions, which improves the intelligibility of the theory.[19]

Within the literature on scientific explanation, one finds pragmatic theories of explanation, which also allow for a plurality of explanatory strategies in scientific practice.[20] Such theories are based on the idea "that explanations are given and received by particular people in particular contexts for particular purposes. Different contexts, people, and purposes may require different types of explanation."[21] De Regt focuses on the pragmatic theory of Bas van Fraassen[22], who considers explanations to be answers to why-questions. But a why-question alone cannot determine what kind of answer is asked for. Additionally, the context has to be taken into consideration to make sense of the question and to know what kind of answer is adequate. Philip Kitcher and Wesley Salmon[23] have criticized van Fraassen's theory because he does not give criteria on when a factor is explanatorily relevant. Although van Fraassen states that explanatory relevance requires scientific relevance and explicates under which conditions an answer is scientifically relevant, he also states that not all scientifically relevant factors are explanatorily relevant, which leaves the problem unsolved. The context determines which scientifically relevant factors are also explanatorily relevant. By adding the two basic epistemic values, de Regt wants to solve van Fraassen's problem. Only if an explanation conforms to internal consistency and empirical adequacy, will it be explanatorily relevant.[24]

Summing up, de Regt covers two different kinds of scientific understanding with his theory, which are UT and UP. Scientists need to have intelligible theories, need to understand theories, if they want to understand phenomena. On the basis of an intelligible theory, scientists can construct explanations of phenomena, and

19 See ibid. pp. 116–119.

20 See ibid. p. 123.

21 Ibid. p. 124.

22 See van Fraassen, B. C. (1980), *The Scientific Image*. Oxford, Clarendon Press, DOI: 10.1093/0198244274.001.0001, especially chapter 5.

23 See Kitcher, P. & Salmon, W. C. (1987), "Van Fraassen on explanation." *Journal of Philosophy*, 84 (6), pp. 315–330, DOI: 10.2307/2026782.

24 See de Regt (2017), pp. 125–128.

hence understand them. Whether any theory is intelligible for some scientist and which type of explanation is constructed depends on the context, the skills of the individual researcher as well as the practices accepted by the respective community. De Regt presents three extensive case studies from the history of physics to substantiate and illustrate his theory of understanding.

The analysis of scientific understanding provided by Henk de Regt focusses on explanatory understanding, which is legitimate, but he does not give explicit arguments on whether, and if so why, explanatory understanding is the most important or general kind of understanding or how explanatory understanding is related or incorporated into other forms of understanding. In contrast to de Regt, Kareem Khalifa explicitly addresses the relation between explanatory and objectual understanding. So, let us have a look at Khalifa's account of scientific understanding, which varies significantly from de Regt's theory in several ways.

## 2.2 Kareem Khalifa: Scientific understanding is scientific knowledge of an explanation

Khalifa develops a model of understanding that he labels EKS model of understanding (explanation, knowledge, science model), since these three concepts are crucial for his account. Before talking about the details of this model of understanding, it is important to recognize two crucial features of it: First, Khalifa explicitly includes the fact that understanding is gradual in his account. That is, he provides a framework that incorporates the fact that understanding comes in degrees. De Regt's theory does not accommodate this. Khalifa's theory of understanding shall allow for the possibility to compare the understanding of different individuals, he develops a comparative account of understanding, while he does not provide a quantitative analysis of degrees of understanding. This is probably impossible. Rather, he takes it to be sufficient that in certain situations it is possible to decide which subject has a better understanding.[25] Second, Khalifa is only concerned with explanatory understanding, or understanding-why.[26] This is a common aspect of the theories of de Regt and Khalifa.

His principle of better understanding, how Khalifa calls it, takes the following form:

25 See Khalifa (2017b), chapter 1.

26 See ibid. pp.2f.

*EKS*$_1$: $S_1$ understands *why p* better than $S_2$ if and only if:
(A) *Ceteris paribus*, $S_1$ grasps *p*'s explanatory nexus more completely than $S_2$; or
(B) *Ceteris paribus*, $S_1$'s grasp of *p*'s explanatory nexus bears greater resemblance to scientific knowledge than $S_2$'s.[27]

Let's consider the EKS-model in more detail. The first principle (A) is called *Nexus Principle*. Khalifa starts with the idea that the subject's understanding of a phenomenon increases if she knows more correct explanatory factors that contribute to the phenomenon, and if she knows more of the relations that exist between these factors. On this basis, Khalifa defines the explanatory nexus of a phenomenon *p* as "the set of correct explanations of *p* as well as the relations between those explanations."[28]

If the explanatory nexus of *p* only includes correct explanations, how can it be determined whether an explanation is correct? Khalifa presents these four conditions:

*q* (correctly) explains *p* if and only if:
(1) *p* is (approximately) true
(2) *q* makes a difference to *p*
(3) *q* satisfies your ontological commitments (so long as they are reasonable); and
(4) *q* satisfies the appropriate local constraints.[29]

Notice that *q* denotes the explanans, the statement that does the explaining of *p*. The fourth condition is crucial: like de Regt, Khalifa explicitly allows for an explanatory pluralism. He does not give a strict definition of explanation. In fact, he even allows to identify 'explanation' with 'explanatory information'. With local constraints he refers to the specific interest of the researcher, the established standards of the discipline, and so on. Local constraints are context-dependent. Like de Regt, Khalifa wants to formulate an account of understanding that is universally valid, but allows for contextual variation. Khalifa reaches this goal by formulating three global conditions and one local condition for understanding.[30]

The explanations belonging to one explanatory nexus can stand in in many varying relations to each other, and the grasp of an explanatory nexus is more complete if more explanations and inter-explanatory relations are grasped, if the quality or importance of the explanations and inter-explanatory relations are grasped, or if more details of the explanations and inter-explanatory relations are grasped. Again,

27 Ibid. p. 14.
28 Ibid. p. 6.
29 Ibid. p. 7.
30 See ibid. pp. 6ff.

this model of understanding is not supposed to offer a quantitative analysis of understanding. All the dimensions just mentioned, quantity, quality and the level of detail of explanations and inter-explanatory relations, figure into understanding, and it depends on the specific context or situation which dimension of one's grasp is more important.[31]

The second principle (B) is the *scientific knowledge principle*. This principle captures everything Khalifa takes to be necessary for a characterization of grasping. He defines grasping as "a cognitive state bearing some resemblance to scientific knowledge of some part of the explanatory nexus."[32] This implies the question: what is scientific knowledge? Khalifa offers this definition: "*S* has scientific knowledge that *q* explains *why p* if and only if the safety of *S*'s belief that *q* explains *why p* is because of her scientific explanatory evaluation."[33] In short, knowledge counts as scientific knowledge if it has been gained by a scientific explanatory evaluation, SEEing. According to Khalifa, SEEing consists of three components: the consideration of plausible potential explanations of the phenomenon of interest, the comparison of the potential explanations, and finally of the formation of (doxastic) attitudes based on the comparisons. SEEing ensures the safety of one's explanatory commitments and therefore the status of this kind of knowledge as scientific. The grasp of a subject bears greater resemblance to scientific knowledge along the following dimensions: the number of plausible potential explanations the agent has considered, the number of considered explanations that have been compared using scientifically acceptable methods and evidence, the scientific status of these methods and evidence that has been used, the safety of the agent's beliefs about explanations, the accuracy of the agents beliefs about explanations, and finally the variety of ways that the agent can use explanatory information so as to achieve different scientific goals.[34]

To avoid that principles (A) and (B) of the EKS-model could come into conflict with one another, the *ceteris paribus* clause is used.[35] Either $S_1$ grasps more items of *p*'s explanatory nexus (i.e. she knows more items that belong to the nexus) than $S_2$, while both are equally competent in a specific scientific field, or the grasp (i.e. knowledge) of $S_1$ is more scientific than the grasp of $S_2$, e.g. if $S_1$ is a professor in a certain domain and $S_2$ a very interested lay person.

In sum, Khalifa's account of scientific understanding stands in the tradition of the "received view" of understanding, as Khalifa calls it,[36] and he provides this definition of the received view:

31 See ibid. pp. 9f.
32 Ibid. p. 11.
33 Ibid. p. 12.
34 See ibid. p. 11ff.
35 See ibid. p. 15.
36 See ibid. p. 16.

> *S* understands *why p* if and only if there exists some *q* such that *S* knows that *q* explains *why p*.[37]

That is Khalifa's view on scientific understanding. Let us now look at a third alternative.

## 2.3 Finnur Dellsén: Understanding as dependency modelling

The third account I want to introduce is the one offered by Finnur Dellsén. His account differs significantly from the other two accounts just presented, since Dellsén argues for understanding without explanation, namely an account of objectual understanding. To begin with, Dellsén points to some features of objectual understanding. First, he specifies objectual understanding as understanding of phenomena. Dellsén is not interested in understanding topics, subject matters or theories, as some other advocates of objectual understanding do[38], because he wants to avoid the slip form understanding something to understanding a discipline that studies or an account that refers to the thing or phenomenon that is to be understood. Second, understanding is gradual in a way that propositional knowledge is not. Subjects can understand a phenomenon to different degrees and the degree of understanding of a phenomenon of one subject can change over time. This is a widely, I would even say universally, accepted feature of understanding. And third, Dellsén assumes that paradigmatic cases of objectual understanding can be found in the empirical sciences. Therefore, he takes his account to be an account of scientific understanding.[39] Given these characterizations of the kind of understanding that Dellsén is concerned with, it is justified to assume that Dellsén is dealing with the same kind of understanding as de Regt and Khalifa: the understanding of phenomena achieved by scientists.

Dellsén's "account of understanding […] holds that to understand a phenomenon is to grasp a specific kind of model of that phenomenon's dependence relations."[40] He calls his account 'dependence modelling account', DMA for short. Models, in

37 Ibid. p. 18.

38 Like Christoph Baumberger for instance, see Baumberger, C. (2011), "Types of Understanding: Their Nature and Their Relation to Knowledge." *Conceptus*, 40, pp. 67–88, DOI: 10.1515/cpt-2014-0002; and Baumberger, C. & Brun, G. (2017), "Dimensions of Objectual Understanding." In Grimm S. R., Baumberger, C. & Ammon, S. (eds.), *Explaining Understanding. New Perspectives from Epistemology and Philosophy of Science*, pp. 165–189, New York and London, Routledge.

39 See Dellsén, F. (2020), "Beyond Explanation: Understanding as Dependency Modelling." *Brit. J. Phil. Sci.*, 71, pp. 1261–1286, DOI: 10.1093/bjps/axy058, pp. 1263f.

40 Ibid. pp. 1264f.

Dellsén's view, are information structures of some kind that are interpreted so as to represent the target.

> These information structures can be concrete, as in Watson and Crick's original model of DNA, or abstract, as in mathematical or computational models like the Lotka-Volterra model of predation in ecological systems. In both cases, the structures are associated with an intended interpretation that specifies how the different parts of the structure correspond to different elements and relations in the phenomenon – a 'key'.[41]

Importantly, no information structure, may it be a material object or a system of equations, is a model in itself. Only through the interpretation of (parts of) these concrete or abstract information structures do they become part of a model.[42] Parts of the information structure must be associated with specific parts of the phenomenon in order to be a model of that phenomenon. Additionally, as understanding takes place in the mind of individuals, the models that are used for understanding a phenomenon must somehow be related to (human) thought. Dellsén does not analyze in detail what the relation between models and mind might be, but rather uses the term 'grasp' for referring to this relation.[43] That is, in the opinion of Dellsén, "understanding consists of grasping a certain kind of model of the understood phenomenon."[44]

"What kind of model must an understanding agent grasp?"[45] Since models are always incomplete or inaccurate representations, which aspects of a phenomenon must be represented in a model that enable understanding? Based on former work that relates understanding-why with dependence relations, Dellsén states "that the aspects of a phenomenon that matter for understanding are the dependence relations that the phenomenon, or its features, stands in towards other things."[46] He

41 Ibid. p. 1265. Dellsén uses the notion of a 'key' from Frigg and Nguyen, see Frigg, R. & Nguyen, J. (2016), "The Fiction View of Models Reloaded." *The Monist*, 99, pp. 225–242, DOI: 10.1093/monist/onw002.

42 Dellsén is following Weisberg in viewing models as interpreted structures. The kind of modelling that Dellsén is thinking of resembles Weisberg's 'target-directed modelling'. For more information, see Weisberg, M. (2013), *Simulation and Similarity. Using models to understand the world*, Oxford, Oxford University Press DOI: 10.1093/acprof:oso/9780199933662.001.0001, especially chapter 5.

43 See ibid. p. 1265.

44 Ibid. p. 1265.

45 Ibid. p. 1266.

46 Ibid. p. 1266. Dellsén is referring here to Kim, J. (1974), "Noncausal Connections." *Noûs*, 8, pp. 41–52, DOI: 10.2307/2214644; and Greco, J. (2014), "Episteme: Knowledge and Understanding." In Timpe, K. & Boyd, C. A. (eds.), *Virtues and Their Vices*, pp. 285–302, Oxford, Oxford University Press, DOI: 10.1093/acprof:oso/9780199645541.003.0014; and Grimm, S. (2014), "Un-

does not limit the notion of dependence relations to causality, but allows for various kinds of dependence relations to hold between (parts of) phenomena, for example grounding relations or mathematical relations.[47] "The kind of model that [he] think[s] is involved in understanding is one that aims to capture the network of dependence relations that a phenomenon stands in, whatever these relations turn out to be. [He] will refer to this as a 'dependency model'."[48]

However, Dellsén does not take grasping any dependency model of a phenomenon as being enough for understanding that phenomenon. "Rather, the model must in some sense be a 'good' representation of the relevant dependence relations."[49] The straightforward suggestion is that the quality of a model depends on the extent to which the model correctly depicts the network of dependence relations of a phenomenon. Yet, a dependency model can fail in two respects in depicting the network of dependence relations, either by incorrectly representing (misrepresenting) some aspects of the network (idealization) or by not representing certain aspects at all (abstraction). Hence, Dellsén recognizes two distinct criteria: accuracy and comprehensiveness. These criteria might come into conflict, the increase of the one might require the sacrifice of the other. As understanding depends on both criteria, it is possible to increase one's understanding by sacrificing one of the two criteria sometimes, given that this brings sufficient benefit in terms of the other criterion, according to Dellsén. Thus, his model-based account can explain the gradual nature of understanding in terms of two other gradable notions, namely accuracy and comprehensiveness.[50]

A final important concept in Dellsén's account of understanding is context, which has several functions. First, any context determines a threshold for the degree of understanding. Attributing understanding of a phenomenon to a subject requires that the subject grasps a sufficiently accurate and comprehensive model of the phenomenon, so that the understanding exceeds the contextually determined threshold. Second, any context specifies which parts of a complex phenomenon have to be sufficiently understood in order to understand the phenomenon itself. Ecologists, physicians and psychologists will all understand human mating, but in different ways. And third, the context also designates which (parts of) other phenomena are striking enough so that their dependence relations to the target

derstanding as Knowledge of Causes." In Fairweather, A. (ed.), *Virtue Epistemology Naturalized: Bridges between Virtue Epistemology and Philosophy of Science*, pp. 347–360, Dordrecht, Springer, DOI: 10.1007/978-3-319-04672-3_19. Dellsén argues that objectual understanding can come apart from explanation, which is not possible in the view of Greco and Grimm, at least not according to Dellsén's reading of their work.

47 See ibid. p. 1266.

48 Ibid. p. 1266.

49 Ibid. p. 1267.

50 See ibid. p. 1267.

phenomenon, or lack thereof, become relevant for the understanding of the target phenomenon. For example, one does not need to consider the whole history of western societies to understand the length of the shadow of a flagpole at a certain time, but one should have some basic knowledge from physics and geometry.[51]

In short, Dellsén proposes the following dependency modelling account (DMA) of understanding:

> DMA: *S* understands a phenomenon, *P*, if and only if *S* grasps a sufficiently accurate and comprehensive dependency model of *P* (or its contextually relevant parts); *S*'s degree of understanding of *P* is proportional to the accuracy and comprehensiveness of that dependency model of *P* (or its contextually relevant parts).[52]

DMA does not require explanation, although Dellsén takes dependence relations to usually undergird explanations. He contrasts his DMA with explanatory accounts of understanding, which he summarizes in the following way:

> *U→E*: *S* understands *P* only if *S* grasps enough of an adequate explanation of *P* (or its relevant features); other things being equal, *S* has more understanding of *P* to the extent that *S* grasps more of an adequate explanation of *P* (or its relevant features).[53]

*U→E* is intended to capture any account of explanatory understanding that takes explanation as a necessary requirement for understanding. Dellsén then discusses three cases in which, according to him, *U→E* fails to accommodate the understanding that scientists achieve, whereas DMA can cope with such types of cases. I will engage with these three cases in detail in section 6.2.3, but now, let's recap the three different accounts of scientific understanding.

## 2.4 Two questions concerning scientific understanding

So, what shall we make of these three different accounts of scientific understanding? All of them share some common ground. First, they are all intended to conceptualize scientific understanding as an understanding that is gained in *science in general*, or in science as a whole, and do not distinguish between different scientific disciplines. Some fundamental unity of science seems to be assumed by de Regt, Khalifa, and Dellsén. In this book, I take up this assumption and will be concerned with a general

51 See ibid. pp. 1267f.

52 Ibid. p. 1268.

53 Ibid. p. 1269.

account of scientific understanding that will be able to accommodate all scientific disciplines, or as many as possible, by pointing out commonalities, while still leaving room for differences between disciplines. Second, however, the criteria, principles, or definitions of understanding presented by the three scholars refer to understanding that *individual* scientists achieve. The only exception is de Regt's CUP, which does not refer to individuals specifically. However, if one takes a look at the case studies that de Regt provides, one will see that he is investigating whether certain individual scientists understood some phenomenon, not only some theory. While de Regt does mention that science can be divided into a macro-, meso-, and micro-level, he does not analyze in which regards understanding of phenomena differs with respects to these three levels. So, all three scholars introduced in this chapter take understanding to be some achievement that can be gained or realized (primarily) by individuals. Third, all accounts address understanding of phenomena achieved in science or take understanding of phenomena as an ultimate aim of science. While other types of understanding might be necessary for understanding phenomena, like the understanding of theories or models used in research, the most important and interesting type of understanding in science is the understanding of the phenomena that are investigated. Hence, I will focus on the understanding of phenomena, too. And fourth, all three scholars agree that understanding is context-dependent, that the historical and disciplinary circumstances or local constraints have an impact on the achievement of understanding and the assessment of its quality. I will take this insight into account as well.

So much for the agreement and commonalities of the three accounts. Yet, they also differ in crucial respects. For instance, de Regt takes scientific understanding to be some kind of ability or know-how, since he argues that scientists need to *be able* to use a theory to construct an explanation of a phenomenon. If scientists are unable to construct an explanation, they will not have understood the phenomenon. Khalifa, in contrast, claims that scientific understanding is scientific knowledge of an explanation, and not an ability. And in Dellsén's view, scientific understanding is the ability to grasp a 'good' dependency model of some phenomenon, an ability that does not require explanation. So, de Regt and Khalifa agree that understanding requires explanation, a feature that is denied by Dellsén. However, de Regt and Dellsén both take understanding to be an ability and not a kind of knowledge, as Khalifa explicitly claims. The comparison of these accounts highlights that at least two questions about scientific understanding are of central interest, but not ultimately resolved within the debate. These two questions are:

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

In order to answer the main research questions of this book, what scientific understanding is and how scientists achieve it, I have to address the two questions identified through the comparison of the three accounts of understanding. That is because answers to my main research questions will depend on the answers one gives to the other two questions just mentioned. If understanding requires explanation, some explanation must somehow be involved or related to the understanding, may it be as a starting point or a product. If understanding does not require explanation, scientists will not have to draw on or produce any explanation for understanding, and hence might acquire the latter in quite a different way than if some explanation would be involved. Furthermore, if understanding is some ability, a type of knowing-how, it might have quite different characteristics than if it would be some form of propositional knowledge or knowledge-that. Moreover, the acquisition processes of knowing-how and knowing-that are very different from one another, as various scholars have already pointed out. This issue will be the topic of section 4.1.

So, in sum, depending on whether scientific understanding requires explanation in some way or not and whether understanding is an ability or a form of propositional knowledge, the way how scientists actually acquire understanding of phenomena will turn out to be fairly different. Hence, it is necessary to first provide answers to the questions concerning the relation of understanding and explanation and the nature of understanding, that is, whether understanding is an ability or a type of knowledge. Only then can the third question, how scientists actually achieve scientific understanding, be answered. Thus, these three questions are the ones I am going to answer in this dissertation. I will start with the question concerning the necessity of explanation for understanding, which will be answered in chapter three. I then turn to the nature of understanding in chapter four. The third question, which I take to be the most interesting one, will be answered in the course of chapters five and six. But first things first, let us start with looking at explanation and its potential role in understanding.