# 7. Conclusion

Understanding is an intellectual achievement to which human beings permanently aspire, in their everyday and professional lives. The understanding that scientists want to achieve of the empirical phenomena they investigate in their research is no exception. Gaining understanding of phenomena is a central epistemic aim of science, as is the understanding of phenomena, experiences, or situations in other domains of human life. This book is targeted at scientific understanding, the understanding that scientists *qua* scientists achieve of the phenomena they are researching. It provides a novel account of scientific understanding that answers the questions what scientific understanding is and how scientists achieve it. While it was not the goal of this book to provide an account of understanding in general, i.e. understanding that any human agent can gain of anything in any context, the insights about scientific understanding presented in this book will be meaningful for the investigation of understanding in general, and of scientific understanding in particular. In this final chapter, section 7.1 provides a summary of the arguments and results obtained in this book, before I present an outlook on follow up questions concerning (scientific) understanding future research could address.

## 7.1 Summary

This book was driven by two main question: what is scientific understanding and how do scientists achieve it? I developed an account of scientific understanding that answers these questions by providing necessary and sufficient conditions for understanding. Let me recap how I arrived at my account.

I started with a survey of the current philosophical literature on scientific understanding and presented three elaborate and prominent accounts of scientific understanding provided by Henk de Regt, Kareem Khalifa, and Finnur Dellsén in chapter two. The comparison of these positions revealed common ground, as well as disagreements between these scholars. Regarding the common ground, I identified four shared intuitions or assumptions: first, the topic of interest is that of understanding gained in science in general, and not in specific scientific disciplines. Second, the author's accounts focus on understanding that individual scientists can achieve, and not on a form of collective understanding that a group or bigger community could gain. Third, it is agreed that understanding of worldly phenomena is an ultimate aim of science, and hence more important and interesting for philosophical analyses than understanding of theories or models used to achieve understanding of phenomena. And last but not least, while all three scholars formulate accounts of understanding gained in science in general, they are all aware that contextual factors, such as specific historical or disciplinary circumstances or local constraints, have an impact on understanding. Therefore, any account of scientific understanding must leave room for contextual variation. I adopted these assumptions as the basis for developing the "Grasping and Explaining"-account of scientific understanding, or GE-account for short.

Regarding the disagreements among de Regt, Khalifa and Dellsén, I detected two central controversial questions concerning scientific understanding:

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

These questions needed to be addressed for an account of scientific understanding to be provided. Hence, I first turned to these two questions identified in chapter two, before I actually developed answers to the two main questions of this book.

Chapter three engaged with the relation of scientific understanding and scientific explanation. I presented and discussed several positions according to which understanding and explanation can be distinct, that understanding does not (always) require explanation, and several counterarguments. Following a clarification of my conception of *explanation* in section 3.1, I engaged with Peter Lipton's view in section 3.2. Lipton defends a separation of understanding and explanation and argues for this by using four examples in which understanding and explanation apparently fall apart. I argued that Lipton fails to show that understanding is achieved without explanation in his examples. Section 3.3 was devoted to Jonathan Kvanvig's influential differentiation between objectual and explanatory understanding, and Kareem Khalifa's reductionist counterarguments against Kvanvig's conception of this differentiation. After a consideration of additional arguments in favor of as well as against a differentiation of objectual and explanatory understanding in section 3.4, I concluded in section 3.5 that scientific understanding does require explanation, that a differentiation between objectual and explanatory understanding is not feasible in the case of scientific understanding.

This is the case because, first, all proponents of a separation of understanding and explanation employ a very narrow notion of explanation that is restricted to causal explanation. Since extensive work on scientific explanations done by philosophers of science revealed the legitimate presence and use of various different types of explanations across the sciences, an explanatory monism, i.e. any restriction to one specific type of explanation, e.g. causal explanation, is unjustified. In contrast, a pluralist position concerning scientific explanation should be adopted. Second, and related to the previous point, explanations are omnipresent in and an undeniable goal of science. Therefore, it is much more plausible to conceive scientific understanding as requiring scientific explanation, since such a conception does naturally relate two aims of science, achieving understanding and achieving explanation. Tearing scientific understanding and scientific explanation apart is an implausible move in light of these two goals and the ubiquity of explanation in science.

Chapter four addressed the question of whether scientific understanding is an ability or a type of (propositional) knowledge. These are the two options currently discussed in the philosophical debate on understanding. I consent to the first view and take understanding to be an ability, for which position I argued in this fourth chapter. I started with a clarification of the notion *ability* in section 4.1. After having explained what I mean by *abilities*, namely dispositions to succeed, I used section 4.2 to argue that understanding should plausibly be conceived as an ability, and not as a type of (propositional) knowledge. I claimed that understanding is the ability to make sense of a phenomenon or other entities that someone wants to understand, e.g. experiences, situations, theories, poems and so on. If understanding is an ability, a disposition to succeed, it needs to be manifested somehow.

Hence, section 4.3 was devoted to the manifestation of the ability to understand something. Based on discussions of the very prominent notion of grasping within the philosophical debate on understanding and my demand that scientific understanding requires explanation, I argued that scientific understanding is manifested in the process of grasping relations the object of understanding stands in (may it be a phenomenon, situation, experience, theory, or poem) and in articulating the grasped relations in form of explanations. In the first part of the manifestation process, through grasping, an agent establishes some connection between her mind and the thing in the world she wants to understand. Through grasping, an agent recognizes, becomes aware of, or "sees" some relation the thing stands in. And in the second part, by articulating an explanation, she applies knowledge and concepts she already possesses to the relation she grasped in order to clarify or work out what exactly she grasped, what kind of relation it is and what the relata are.

So, understanding, or making sense of, something manifests in the process of grasping some relation of the thing that shall be understood and in sorting out what precisely is grasped through articulating the grasped relation in an explanation. This conceptualization of the manifestation of understanding does not only accommodate the intuitions most people (including philosophers) have when thinking about understanding, namely that understanding is something like 'seeing how things hang together', it also resolves conflicting and confusing ideas about the nature and relation of understanding towards knowledge and explanation. Understanding and explanation cannot be torn apart, since explanations are the products of the manifestation of understanding. And understanding and knowledge are inextricably intertwined, as one cannot understand anything in the world without resorting to some already existing knowledge, and new (explanatory) knowledge is also produced via understanding.

Then, I presented an episode from scientific practice and my philosophical analysis of it in chapter five. This episode was about the introduction of a new model organism into biological research, the zebrafish, and how this model organism enabled scientific understanding of the genetic regulation of vertebrate development. In section 5.1, I first depicted the episode from research practice in biology by describing the historical context, aims, challenges, and developments that ultimately resulted in the establishment of zebrafish as a new model organism, the emergence of a new research discipline, and new insights into genetic regulations underlying vertebrate development. Following the historical overview, in section 5.2 I analyzed how exactly the scientists involved in this research episode gained understanding of the phenomenon that was the target of their investigations, the genetic regulation of vertebrate development, as well as which contextual factors had an impact on the understanding or enabled understanding at all. I argued that the episode from scientific practice does not only second my claims devised in the previous two chapters, that understanding is an ability that requires explanation, but also brings three additional insights about scientific understanding to the fore.

First, scientists needed specific knowledge, research skills, and equipment for understanding the specific phenomenon they were interested in. Second, in order to gain all these necessary resources, scientists had to establish an appropriate infrastructure or community that could provide all its members with these resources. And third, the scientific episode spotlighted the iterative nature of the manifestation process of understanding. This means that scientific understanding is (usually) not manifested in a two-step process of first grasping and then explaining, but rather in several subsequent steps or instances of grasping some relation or aspects of a relation, articulating the grasped aspect in an explanation, which enables grasping of further aspects of this relation or an additional relation, which is articulated in an explanation again, and so on and so forth. That is, the manifestation process of scientific understanding is much more demanding and complex than it appeared given my argumentation in chapter four. Thus, the episode of biological practice can be deemed useful in providing important and novel insights for a philosophical analysis of scientific understanding.

Having everything we need, chapter six finally provided the space for the account of scientific understanding I developed based on the work done in the previous chapters. This account, the "Grasping and Explaining"-account of scientific understanding (or GE-account for short), as I have termed it, is my answer to the main questions I want to answer with this book: what is scientific understanding and how do scientists achieve it? The GE-account takes the following form:

> A scientist *S* has scientific understanding of an empirical phenomenon *P* in a context *C* if and only if
>
> i.) *S* grasps (details of) relations that *P* stands in and articulates these relations in the form of new explanations of (aspects of) *P* (*manifestation condition*),
> ii.) *S* possesses and uses (material) equipment, relevant knowledge and research skills provided by *C* and required for understanding *P* (*resource condition*), and
> iii.) *S* is a member of a scientific community that enables *S* to understand *P* and parts of that community approve *S*'s understanding of *P* (*justification condition*).

In section 6.1, I elaborated on the scope and the three conditions of the GE-account, which I called *manifestation condition*, *resource condition*, and *justification condition* and take to be necessary and sufficient for scientific understanding. In a nutshell, the GE-account only captures scientific understanding of an empirical phenomenon gained by an individual scientist who is situated in a specific context, which impacts the understanding in several ways that are spelled out in the three conditions. The *manifestation condition*, as its name already suggests, expresses the manifestation process of understanding, namely grasping relations and articulating explanations. The necessary resources that a scientist needs if she wants to manifest her understanding of some phenomenon are covered by the second condition, the *resource condition*. Finally, the *justification condition* gives the respective scientific community of a researcher its proper due, as it is the scientific community that, first, provides any researcher with the resources necessary to do research in the respective field at all, and second, assesses and eventually approves the understanding that researchers gain. In other words, no scientist is justified in thinking that she understood some feature of a phenomenon if no other members of her community accept the explanation articulated by her, and hence her ability to understand the phenomenon, as legitimate or appropriate.

Finally, in section 6.2, I demarcated the GE-account of scientific understanding from the other accounts introduced in chapter two and highlighted its advantages in comparison to these other accounts. Since scientific theories do not play a decisive role in the GE-account, it has a greater flexibility and can better accommodate cases from scientific practice in which theories were either completely absent or had no crucial function for the understanding. This is an advantage of the GE-account in comparison to de Regt's account of scientific understanding, according to which phenomena cannot be understood without theories. Contrary to Khalifa, who defines understanding as knowledge of explanations, I argued that any account that conceptualizes understanding as an ability and not as knowledge, like the GE-account, can better capture what we intuitively expect from someone who has understanding of some phenomenon. That is, we expect such persons to be able to somehow engage with the phenomenon, to work with or on it, to generate novel insights about it, and the like. None of these activities can be captured by accounts that view understanding as a type of (propositional) knowledge. Lastly, I argued against Dellsén that it is implausible to conceptualize scientific understanding as not requiring or being independent from explanation. Since Dellsén and I employ the same conception of grasping, I held that grasping is not sufficient for understanding, as grasping does not comprise the process of working out what exactly has been grasped. Understanding or making sense of phenomena requires the application of available knowledge or concepts to the features of the world that were grasped, and this second step, the articulation of an explanation, exceeds grasping.

## 7.2 Outlook

While this book hopefully provides answers to the questions what scientific understanding is and how scientists achieve it, there are, of course, many unresolved issues that arise around understanding in general and scientific understanding in particular. I will provide a short outlook on some questions that derive from the GE-account developed in this book.

### 7.2.1 Understanding and representation

First, the GE-account only captures understanding that scientists gain of the phenomena they are researching. It does not address the question of what it means for scientists to understand the various representations that are used in research in order to achieve the ultimate goal, understanding of phenomena. As I stated in the introduction to this book, the two major issues that are of interest to philosophers of science, at least according to Stephen Grimm, are the relations of understanding to explanation and to idealizations or models.[1] While I intensively worked on the relation of understanding and explanation, I did not engage with the relation of understanding to other types of models used in science.

Representations are very diverse, ranging from explanations and theories to classificatory systems like the periodic table, graphical depictions, to various kinds of models, abstract or concrete ones, and to computer simulations and artificial intelligence systems. While there is widespread agreement that, in most cases, scientists have to understand the representations through or with which they

1 See Grimm (2021).

understand some phenomenon, it is not at all clear how the understanding of representations relates to the understanding of real world phenomena, especially when complex computer simulations or AI systems are involved.[2] In short, one question is whether the understanding of some phenomenon necessarily requires the understanding of the representations used for understanding this phenomenon. And if this question is answered in the affirmative, a follow-up question will be whether there are any differences between understanding a representation on the one hand, and understanding some phenomenon through or with that representation on the other.

These questions are already intensively addressed in the debate on understanding. If it is the case that understanding some or specific representations is necessary in order to understand phenomena (for instance, that a physicist must understand electromagnetic theory based on the Maxwell equations if she wants to understand electromagnetic phenomena), is understanding these representations in any way different from understanding the phenomenon? And how might understanding a representation then be related to understanding a phenomenon? Henk de Regt provides one answer to these questions, as he conceptualizes understanding of phenomena (UP) and understanding of theories (UT) differently. I presented his view in section 2.1. In a nutshell, de Regt argues that UT and UP are necessarily intertwined. Scientist need to understand a theory in order to construct models, and hence explanations, of phenomena, and thereby understand said phenomena.[3] In the examples that de Regt discusses, scientists had to understand a theory first, before they could use the respective theory to construct explanations and understand a phenomenon.

In contrast, the GE-account does not address potential differences between understanding phenomena and understanding theories or other representations in science, and hence does not analyze the possible relations between these types of understanding (assuming that they can reasonably be viewed as two different types). While I argued for the advantage of this characteristic of the GE-account in section 6.2.1, namely that the GE-account can accommodate instances of scientific understanding of phenomena that were possible without drawing any specific theory or in which an involved theory did not deliver the crucial insights, theories are of course of crucial importance in many fields of scientific research. It might be interesting

2 For investigations on whether and how AI systems or artificial neural networks could or must (not) be understood in order to use them for understanding empirical phenomena, see for instance Sullivan, E. (2020), "Understanding from machine learning models." *The British Journal for the Philosophy of Science*, DOI: 10.1093/bjps/axz035; or Rudin, C., et al. (2021). "Interpretable machine learning: Fundamental principles and 10 grand challenges." *Statistics Surveys*, 16, pp. 1–85, DOI: 10.1214/21-SS133; or Chirimuuta, M. (2021). "Prediction versus understanding in computationally enhanced neuroscience." *Synthese*, 199 (1), pp. 767–790, DOI: 10.1007/s11229-020-02713-0.

3 See de Regt (2017), especially chapters two and four.

to analyze under which conditions and how exactly theories might be indispensable for achieving scientific understanding of phenomena.

Explanation is another central notion in science with which I extensively engaged in this project. According to the GE-account, a phenomenon is understood through grasping relations and articulating explanations. In other words, scientists understand a phenomenon for which there is no explanation through articulating one. Is there an intrinsic difference between understanding conceptualized like this, and instances in which some phenomenon is understood through an already available theory or explanation? If a theory or explanation is already available, will the ability to understand a phenomenon be manifested differently than in cases in which a theory or explanation is articulated during the manifestation process of understanding? For example, could it be that in instances in which an explanation is already available, the manifestation of understanding only comprises the grasping of relations represented by the explanation? If this is the case, what exactly is understood?

If a subject grasps relations presented by an explanation or theory, does she then understand the phenomenon that is represented, or does she merely understand the explanation or theory itself? Mark Newman, whose view I presented in section 4.3.2, distinguishes between three different types of understanding: knowing an explanation (i.e. understanding an explanation linguistically), understanding an explanation (having explanatory understanding of the phenomenon represented by the explanation) and theoretical understanding (understanding a theory).[4] Can these three types of understanding plausibly be separated? Is there a difference between understanding a theory or an explanation, understanding a phenomenon through a theory or explanation that is already available, and understanding a phenomenon through constructing a theory or explanation, which is the kind of understanding the GE-account captures?

These and similar questions become even more pressing if we do not only consider theories or explanations, which are often conceived of as having some propositional or explicit mathematical form, but other kinds of representations in science, especially models. While some scholars identify models with explanations or theories, there undeniably is a wide variety of models used in science of which one could ask whether these models have different functions for understanding or whether the understanding of phenomena varies in some sense when different kinds of models are used. How different kinds of models can be differentiated is another challenging question. One potential classification is provided by Weisberg, who distinguishes material or concrete models from theoretical or abstract models, as well as from computer models.[5] The Crick and Watson model of DNA that is built with real

4 See Newman (2017).

5 See Weisberg (2013), especially chapter two.

physical balls and sticks is a material model. The Lotka-Volterra model of predator-prey dynamics takes the form of four differential equations and is, hence, a theoretical model. And then there are computer models used for running simulations in, for example, climate science or epidemiology. Again, we can ask, and a considerable number of scholars already has,[6] whether scientists who use any such models must understand the model if they want to understand a phenomenon using the model, what exactly understanding any of these kinds of models amounts to, and whether this understanding is in some sense different from understanding a phenomenon with these models.

Originally, I wanted to address these kinds of questions in my project. My idea was to analyze two different scientific episodes, one on the use of model organisms in biology, and the other on research with computer models in climate science. Investigating the use of these two different kinds of models in the respective disciplines might have revealed significant differences in the understanding through material models versus the understanding by using computer models. Alternatively, the analyses would have shown that there is no significant difference. While I do not know the answer to this question, as I could not conduct the comparative analysis due to time constraints, my assumption is that there might be a difference. The reason for this assumptions is that in the case of model organisms, which can be considered as a special sub-type of material models, scientists directly intervene in the mechanism, i.e. the phenomenon they want to understand, as I explain in section 5.1. In studies of zebrafish, biologists directly manipulated biochemical pathways which they wanted to understand. Once identified and manipulated, they inferred inductively that the specific gene in question, or its orthologs, have the same function in the embryonic development of other species.

Nothing like this happens in climate science. While one could claim that humanity has been running one major experiment with our climate for decades, this is not what climate scientists do in their attempts to understand the mechanisms of the earth's climate. Rather, climate scientists use computer models to run simulations of the global climate, and through these simulation runs they gain information about the model world defined by the parameters used in the model. These insights need to be related to real world-climate, as any computer model is in some sense an inadequate representation of the real phenomenon. In a nutshell, climate scientists do not directly intervene in the world's climate, but merely in model worlds inscribed in the computer models. Whatever climate scientists learn about the model world

6 See for example Elgin (2007); Elgin (2017); de Regt, H. & Gijsbers, V. (2017), "How False Theories Can Yield Genuine Understanding." In Grimm, S., Baumberger, C. & Ammon, S. (eds.), *Explaining Understanding. New Perspectives from Epistemology and Philosophy of Science*, pp. 50–75, New York and London, Routledge; Reutlinger, Hangleiter & Hartmann (2018); or Strevens (2017).

needs to be translated to the real world. Thus, it seems that model organisms allow for a much more direct access to the phenomenon in question, while computer models can only provide indirect access that requires some additional step.

This additional step could be interpretation. Is interpretation just another term for understanding or are interpretation and understanding two different things? Could it make sense to argue that scientists need to *interpret* a theory or a model in order to *understand* a phenomenon? For Michael Polanyi, whose views on tacit knowledge and understanding I extensively used in chapter four, there is no fundamental difference between these notions. According to him, understanding and interpretation are basically one and the same thing, the only difference being that interpretation requires language.

Certain animals and very young children are able to understand things happening in the world without possessing or being able to use any articulate language. Polanyi claims that (some) animals and young children can gain understanding, but not interpretation, as he takes interpretation to be a more sophisticated type of understanding.[7] Analyzing the concept of interpretation in relation to understanding might be helpful in clarifying ideas about understanding representations and understanding the phenomena they represent, since interpretation is a crucial concept in the philosophical literature on scientific representation. For instance, Richard I. G. Hughes suggested his DDI account of scientific representation (denotation, demonstration, and interpretation), without really explicating what he means by interpretation, unfortunately.[8] His main idea remained influential nevertheless. Gabriele Contessa, for example, offered his interpretational account of scientific representation including a neat characterization of what he means by interpretation within his account.[9] In sum, my assumption is that the rich literature on scientific representation might provide important and relevant insights for analyzing the nature of understanding representations, its relation to understanding phenomena that are represented, as well as the notion of interpretation in this context.[10]

To conclude, I did not engage with the function of theories, models, or other types of representation for scientific understanding of phenomena in the course of my project. Therefore, the GE-account of scientific understanding does not capture the understanding that scientists might have of the theories or models they employ

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7 See Polanyi (1962 [1958]), especially chapter five.

8 See Hughes, R. I.G. (1997), "Models and Representation", *Philosophy of Science*, 64, pp. 325–336, DOI: 10.1086/392611.

9 See Contessa, G. (2007), "Scientific Representation, Interpretation, and Surrogative Reasoning", *Philosophy of Science*, 74 (1), pp. 48–68, DOI: 10.1086/519478.

10 For an overview on various accounts of scientific representation, see for example Frigg & Nguyen (2021).

in their research. However, since theories and various types of models are undoubtedly extensively used in science, their relation to, and function for, understanding phenomena should be taken into account and deserves further philosophical analysis.

### 7.2.2 Understanding and prediction

As I have claimed throughout this book, understanding and explanation are two central and interrelated goals of science. This view is widely shared and not seriously contested to my knowledge. However, one might be missing another central goal of science: prediction. I did not engage with the relation of understanding to prediction in this project, but I do think that this is a very important question. Hence, I would like to at least point towards discussing this issue.

With whom should I start, if not with the founding father of the philosophical debate on understanding? Henk de Regt also addressed the relation of understanding to prediction, although not as detailed as the relation of understanding to explanation. The notion of prediction sneaks into de Regt's account of understanding via his criterion of the intelligibility of theories. Again, according to de Regt, scientists can understand phenomena only through the understanding of theories, and specific scientists in specific contexts have understanding of a particular theory if that theory is intelligible to them. While de Regt admits that different criteria might be employed to determine the intelligibility of theories in different historical or disciplinary contexts, he proposes and discusses one specific Criterion for the Intelligibility of Theories, which he takes to be especially suitable to accommodate the physical sciences:

> **$CIT_1$:** 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.[11]

De Regt demands that if a theory is intelligible for scientists, the scientists will be able to make rough qualitative predictions that turn out to be correct to some degree when tested. Successful predictions allow for the construction and testing of explanations, and hence understanding, of phenomena. And some degree of understanding of phenomena, in turn, will enable new successful predictions. Therefore, according to de Regt, explanation, understanding, and prediction are interrelated goals of science and cannot do without each other:

11 De Regt (2017), p. 102.

> Compare a successful scientific theory with a hypothetical oracle whose pronouncements always prove true. In the latter case, empirical adequacy would be ensued, but we would not speak of a great scientific success (and perhaps not even of science *tout court*) because there is no understanding of how the perfect predictions were brought about. An oracle is nothing but a black box that produces seemingly arbitrary predictions. Scientists want more than this: in addition they want insights, and therefore need to open the black box and consider the workings of the theory that generates the predictions.[12]

Such a view on the interconnectedness of explanation, understanding, and prediction poses great challenges to branches of research in which some kinds of black box models, e.g. machine learning models, are used. However, de Regt's position is criticized, for example by Johannes Findl & Javier Suárez.[13]

Findl & Suárez argue that one can gain understanding of phenomena through purely statistical models without any causal knowledge, as these models provide predictions. Hence, the authors differentiate between predictive understanding, as they call it, and explanatory understanding and argue that understanding through prediction and without explanation is possible. The basis for this claim by Findl & Suárez is a case study on the use of epidemiological models in the COVID-19 pandemic:

> Early versions of such models based their predictions on statistical data that had been provided by other countries, rather than on a causal understanding of the disease. In other words, early COVID-19 models were what epidemiologists call *statistical models*, i.e., models that derive their estimations from a regression analysis that fits a curve to empirical data — such as the number of infections or deaths — rather than from causal data about the patterns of infection of the disease which were mostly unknown at the time. [...] While these [purely predictive] models did not include specific causal-mechanistic information about how the disease would spread or affect those infected, their primary function was to give estimates of what would most likely happen if counter-measures were introduced or removed.[14]

These statistical models were continuously modified and updated on the basis of newly available data from countermeasures and their effects in specific geographical regions. If predictions yielded by a model did not fit empirical data about, for example, the infection rate, incorrect or missing assumptions in the model had to be

12 Ibid. pp. 101f.

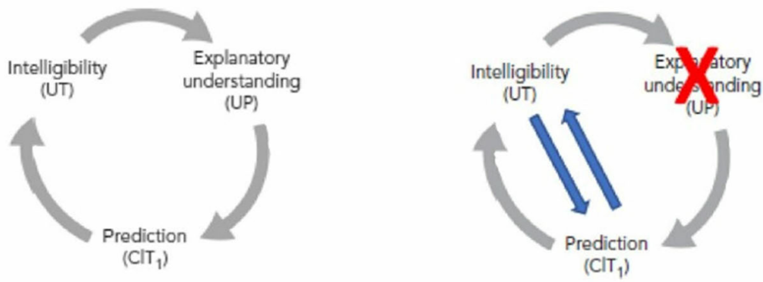
13 See Findl, J. & Suárez, J. (2021), "Descriptive understanding and prediction in COVID-19 modelling." *History and Philosophy of the Life Sciences*, 43 (4), pp. 1–31, DOI: 10.1007/s40656-021-00461-z.

14 Ibid. p. 3, original emphasis.

corrected or added. This procedure improved the predictive accuracy of the model as well as the understanding of variables determining the trajectory, without any knowledge or explanation about the concrete relation between the characteristics of COVID-19 and infection or death rates, as Findl & Suárez argue.[15]

Findl & Suárez identify two problems with de Regt's view on the interrelation between explanation, prediction, and understanding. First, de Regt does not provide any details about how these notions are related, how predictions allow for the refinement of explanations, how explanations enable predictions, and how and where understanding comes in. I agree with Findl & Suárez in this regard. Second, they are not convinced by de Regt's explication of the relation between understanding, explanation, and prediction, which might be due to the first problem identified, the lack of details in de Regt's account. By offering $CIT_1$, de Regt argues that having an intelligible theory, and therefore understanding of that theory, is necessary for generating predictions or characteristic consequences of that theory. Findl & Suárez agree, but they are not convinced that explanation is a necessary intermediate step between intelligibility and prediction, as de Regt argues.[16] Figure 5 depicts the disagreement between de Regt and Findl & Suárez.

*Figure 5: The relations of understanding, explanation and prediction.*[17]




By analyzing the development and use of the model from the Institute of Health Metrics and Evaluation (IHME model), one of the most prominent statistical COVID-19 models at the beginning of the global pandemic in the spring of 2020, Findl & Suárez argue that "[first,] the IHME model satisfies de Regt's intelligibility

15 See ibid. pp. 3f.

16 See ibid. pp. 7f.

17 The chart on the left shows de Regt's view on the relations between understanding, explanation, and prediction (de Regt (2017), p. 108, Fig. 4.1), while the chart on the right displays the criticism put forward by Findl & Suárez (Findl & Suárez (2021), p. 9, Fig. 2).

requirement (i.e., it provides understanding according to [their] terminology) and does so via its predictions; second, that no explanation mediates between intelligibility and predictions (as so-called explanatory understanding would have it), but rather descriptions do."[18]

I am not convinced that Findl & Suárez succeed in arguing that scientific understanding of the dynamics of the COVID-19 pandemic was achieved without explanation. They claim that statistical models provide regularity patterns for a phenomenon, but no causal or counterfactual dependencies, and should, therefore, not be viewed as explanatory.[19] However, bearing in mind my plea to accept an explanatory pluralism in science and my related criticism of narrow accounts of scientific explanation in chapter three, it is important to note that Findl & Suárez also employ an overly restricted notion of explanation. The generic conception of explanation I introduced in section 3.1 requires explanations to provide reasons for the phenomenon to be explained, not necessarily causes. Hence, it can be argued that the assumptions and technical frameworks that are employed by the statistical model and together constitute regularity patterns, or the fit to empirical data provide reasons or are the reasons as to why scientists think that the phenomenon will unfold in a certain manner.

But independently of disagreements concerning the nature of scientific explanation, the work of Findl & Suárez definitely provides important insights for clarifying the relations between understanding and prediction. Especially their finding that predictions were used "backwards", as tests for the assumptions underlying the model and for revising the descriptive understanding already gained at a specific point in time, is crucial for making sense of the role of prediction for understanding. When the model was updated because of incorrect predictions or newly available data, the understanding of the phenomenon gradually improved, too.[20] Hence, Findl & Suárez made a significant contribution to clarifying the relations between understanding and prediction, which can be directly related to issues concerning understanding and representations I pointed out in the previous section. So, there still is much to be learned about how understanding, prediction, explanation, and models are related.

### 7.2.3 The unexplored terrain and the merit of this book

All of these questions concerning the relation of scientific understanding of phenomena to theories, models, representations and prediction, are of course just suggestions in which directions research on scientific understanding might proceed

18 Ibid. p. 16.
19 See ibid. section 4.
20 See ibid. section 5.

from the results of my research project that I consider to be interesting. There are of course plenty of other questions as well. What exactly is grasping? Is understanding always and only an ability possessed by an individual, or can groups of agents have some other kind of understanding as well? Is it satisfying to have an account of understanding that is completely detached from truth? I could extend this list even more, but will leave it like that for the time being. There is still much work to do and many open questions to answer concerning understanding.

I hope that this book provides some helpful guidance and interesting perspectives on how scientists (and subjects generally) come to understand the world. In addressing and answering some of the so far central questions in the philosophical discussion on understanding, this book is a significant contribution in the attempt to resolve existing controversies in the field. By arguing that understanding is an ability that requires knowledge as well as further resources to be manifested, and that understanding manifests in grasping relations and articulating explanations, the GE-account developed in this book consolidates many of the most contested issues related to understanding, and presents a coherent answer how these different concepts are related. In doing so, this book not only offers a new viewpoint on the nature of (scientific) understanding and its relation to knowledge, explanation and scientific practice, but also a starting point to engage with further research questions on understanding in science and also in other contexts.