Master Thesis

Phenomena in Engineering Science

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Date:
25 April 2011

Abstract

In this thesis I investigate what phenomena in engineering science are. Engineering science is the field of science that deals with the scientific understanding of engineering—designing, constructing, and maintaining of constructions, machines, and materials. The aim of engineering science is the understanding of phenomena that determine the working of devices or materials for the purpose of application. This makes that the role phenomena play in engineering science differs from other sciences.

To come to a good understanding of phenomena in engineering science, my main question is: What is a phenomenon in engineering science? To answer to this question I investigate the possible roles and functions phenomena in engineering science can have. I address how phenomena are used, what the work they do is, what their characteristic are and why they are needed. I answer these questions based on a literature study in the philosophy of science and on a case study of five articles in engineering science and come to an overall answer, which will give an account of phenomena in the engineering sciences.

In the philosophy of science, Hacking was the first to define phenomena from a scientist's perspective. "A phenomenon is *noteworthy*. A phenomenon is *discernible*. A phenomenon is commonly an event or process of a certain type that occurs regularly under definite circumstances" (Hacking, 1983, p. 221). Bogen and Woodward (1988) took this definition and added to it the very relevant distinction between data and phenomena. A phenomenon is a potential explanandum for a theory, and data are the evidence for this explanandum. Based on the philosophical literature I defend a vision on phenomena in which they are both ontologically and epistemologically created. This is a combination of Hacking's (1983) view that physical phenomena are experimentally created, and Rouse's (2009) view that phenomena are conceptually articulated in language. Creating a phenomenon is both an epistemic and ontological achievement.

With this vision of phenomena I try to overcome the realism discussion, which up till now has dominated the philosophical literature on phenomena. The discussion is whether we can make truth claims about unobservable phenomena—the realist say you can, the empiricists say you cannot. I use a Kantian perspective that says that both observable and unobservable phenomena are conceptualized in our minds on the basis of sense input from the outside

world.

For the case study I study five mechanical engineering articles that deal with heat transfer in fiber-reinforced composites. This case study shows some interesting characteristic of phenomena. First of all, engineering scientists focus their research on the target system. In the philosophy of science literature phenomena are always discussed in relation to theory; either in the context of discovery—as an initiator for the discovery of theories—or in the context of justification—as proof for theories. My case study shows that phenomena are used in the context of construction—they are experimentally created to intervene with the target system, and conceptually articulated in models to make predicting and thinking about the target system possible. Models are epistemic tools. When a phenomenon is modeled, hypotheses are made in the context of the target system.

Secondly, phenomena are specific to their target system. The target system creates the conditions of possibility for a phenomena to occur. Phenomena do thus not already exist in the world, as natural kinds, but their preconditions do. A third observation is that the engineering scientists in my case study use the regulatory principle of ‘same condition – same effect’ as presented by Boon (forthcoming). They do this in the way phenomena are experimentally created as in the way phenomena are conceptually articulated. Only the part op the experimental setup that is changed is responsible for a different outcome.

My conclusion from both the case study and the literature study is that in engineering science phenomena are ontological en epistemic creations that are used in service of the target system. The work a phenomenon does in modeled form is that they make hypothesizing and thinking about intervening possible; as a physical creation it makes physical intervening with the target system possible. This is also the reason why phenomena in engineering science are needed.

Table of Contents

> *Phenomena!* Now there's a word to conjure with. It is what our theories try to explain, and what we use to justify those theories. It is what instrumentalists try to save and realist try to get beyond[i].
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> (Brown, 1994, p. 117)

1 Introduction: Phenomena in Engineering Science

This master thesis is an investigation into what a phenomenon in engineering science is. In this introduction I will explain why this is an interesting subject, and how I am about to embark on this investigation. I will begin by explaining the philosophical and scientific landscape in which this research is relevant. Then I will introduce my thesis questions, followed by the methodology of this research. I will conclude this introduction with an overview of this thesis.

1.1 The Landscape

In this paragraph I give a description of the landscape and zoom in on the problem I want to address. The subject of this thesis—phenomena in engineering science—will be introduced from both the side of the philosophy of science as from the side of engineering science. This paragraph is by no means meant as a full overview of, or introduction into these fields. The purpose of this paragraph is to introduce my subject, to place it into context, and to explain why it is relevant to study.

1.1.1 Phenomena in the Philosophy of Science

The concept of phenomena has been an integral part of western philosophy almost forever.

> The word ‘phenomenon’ has an ancient philosophical lineage. In Greek it denotes a thing, event, or process that can be seen, and derives from the verb that means, ‘to appear’. From the very beginning it has been used to express philosophical thoughts about appearance and reality. The word is, then, a philosopher's minefield.
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> (Hacking, 1983, pp. 220-221)

Important branches of philosophy like epistemology, ontology, metaphysics, philosophy of mind, and philosophy of science all deal with phenomena as part of their theories or as part of what they try to explain or study. This makes ‘phenomena’ a word that is used often in philosophy, but also a word with many meanings.

Around a hundred to hundred-fifty years ago modern science evolved out of what was then called natural philosophy. Natural philosophy was, as the name indicates, a branch of philosophy. This meant that discussions on epistemology and ontology where an inherent part of it. This was the context in which philosophers like Kant expressed their ideas on phenomena. Kant marked the end of this scholastic period. Philosophy of science as a branch of philosophy came into existence with the birth of modern science; which in effect meant the separation of the act of doing science and philosophizing about science. In this new philosophy of science the concept of phenomena acquired a firm place in its foundations as ‘phenomena of nature’.

Since the beginning of philosophy of science, the concept of phenomena has always been an object of interest. Obviously for phenomenalism phenomena are a relevant subject. The logical positivists spoke about phenomena in the context of their idea of ‘observational terms’; observational terms refer to properties of phenomena (Ladyman, 2002). The constructive empiricists wrote about phenomena in the sense that they wanted to ‘save’ the phenomena as a means to prove theories. This idea of saving the phenomena tracks back to the pre-scientific natural philosophy. The Latin word for saving, *salve*, was in the seventeenth century turned into solving, which most probably indicates the origin of the idea of ‘saving the phenomena’ (Hacking, 1983). These many fields that write about phenomena have yielded many views on phenomena—as the quote or Brown at the beginning of this chapter shows.

Ian Hacking was the first who got attention for phenomena in the context of experimenting in his book *Representing and intervening* (1983). He defined phenomena from a scientists point of view. “My use of the word ‘phenomenon’ is like that of the physicists. I must be kept as separate as possible from the philosophers’ phenomenalism, phenomenology and private, fleeting, sense-data. A phenomena, for me, is something public, regular, possibly law-like, but perhaps exceptional” (Hacking, 1983, p. 222). This idea of phenomena as ‘phenomena to scientists’ was picked up by James Bogen and James Woodward (1988), who made an important distinction between data and phenomena. However, since Hacking and Bogen and Woodward wrote about phenomena in the 1980's, the subject has had little attention in the philosophy of science. Some very relevant pieces have been written about it, but it never became a very popular subject over the past 30 years. This does not make it an irrelevant subject, only a undeserved underexposed subject. Recently, how ever, it started to get the attention it deserves.

The idea of a scientific method has put much weight on the question of how science is done. The logical positivists gave us the idea of a context of discovery and a context of justification. Somehow discussions about the context of discovery and the context of justification have largely been played out without a proper understanding of phenomena—it focused mainly on observations, data, and theories. The strict positivistic distinction between observation and theory became undermined by ideas of theory-ladenness. This enlarged the interest in phenomena. (Hacking, 1983; Ladyman, 2002).

The constructive empiricists and the realists are involved in a discussion about realism in science that revolves for the main part around the observability of phenomena. For Van Fraassen the observability of phenomena is relevant in assessing truth claims (Van Fraassen, 1976); for realists observability is of no consequence for truth claims (Bogen & Woodward, 1988). To do this discussion justice, it must be clear what is observed; is it the phenomena, the data; or perhaps neither are directly observed (Massimi, 2007). This discussion has largely been played out without a good understanding of the concept of phenomena. Is it something we can point at, like an object? Or, rather, something that involves constructive activities, both in experimental set-up and in conceptualizing it. As a consequence there is no real discussion going on. Both parties base their ideas on what a phenomenon is on the basis of their stance on realism, and thus can never come to some middle ground. The philosophical discussion on what a phenomenon is, has been used to promote ideas on realism; which is not in the interest of a fruitful investigation into the concept of phenomena.

Since the 1980's there is a growing awareness that we need to include phenomena in our discussions of science. To do this correctly we need a common understanding of what a phenomenon is, or any discussion is moot. In recent years, phenomena are back on the agenda (Bailer-Jones, 2009; Bogen, 2009; Boon, forthcoming; Boon & Knuuttila, 2009; Falkenburg, 2009; Knuuttila & Boon, forthcoming; Massimi, 2007, 2008; McAllister, 2009; Rouse, 2009; Schindler, 2009; Woodward, 2009). Therefore it is urgent to work on a common understanding of this sometimes illusive term. The problem now is that over the years many different accounts about how phenomena should be used and what they are have been uttered.

In this thesis I want to compare, combine and polish the definitions of a phenomenon to come to one definition that is based on actual practice, in particular in the engineering sciences. With this new understanding we can move on in the discussion, and see how phenomena are relevant in understanding the practice of engineering science.

1.1.2 What are Engineering Sciences?

Science can be divided into many different categories depending on their field of study, like social sciences, natural science, or engineering sciences; but also on the way they study, like fundamental sciences, applied sciences, or laboratory sciences[ii]. The field of science to which I confine my research is engineering science. I choose this field for two reasons, this first is that I have experience in mechanical engineering—an engineering science—the second, and more important reason is that engineering sciences use phenomena differently than other sciences.

Engineering science is the field of science that deals with the scientific understanding of engineering. Engineering in this context means the designing, constructing, and maintaining of constructions, machines, and materials. The aim of engineering science is the understanding of phenomena that determine the working of devices or materials for the purpose of application. On the one hand, engineering science is an experimental science that acquires knowledge and understanding from the devices and materials it studies, on the other hand it is an applied science that focuses its knowledge on use in designing and constructing. This combination of experimenting and applying makes that phenomena play a central role in engineering science. Phenomena are needed to provide knowledge about the target system, and to make intervening with this target system possible.

> The engineering sciences aim at both furthering the development of devices and materials meeting certain functions and optimizing them. Through modelling the engineering scientist seek to gain understanding of the behaviour and properties of various devices and materials. More often than not, this involves conceiving the functioning of the device, often in terms of particular *physical phenomena* that produce the proper or improper functioning of the device[iii].
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> (Boon & Knuuttila, 2009, p. 688)

The knowledge base of engineering science are phenomenological laws. In engineering science it is often not possible to make useful deductions from fundamental laws to gain understanding. Understanding is commonly acquired via models of phenomena. These modeled phenomena also make thinking about intervening with the target system possible. To be able to correctly model phenomena, the proposed models have to be checked against experimental data. In engineering science phenomena play a central role in this process of experimenting, modeling and intervening.

1.1.3 Scientists and Phenomena

What philosophers of science call a phenomenon, scientists may call a property, a problem, a case, or an effect. Scientists often do not even label their phenomena as such. In scientific language calling something a phenomenon often indicates something extraordinary or striking, not the regularity (Hacking, 1983). The fact that scientists do not express the concept of phenomena or may even indicate something slightly different with it, does not mean that a clear understanding of what a phenomenon is, is not relevant to them. The question why we need phenomena may seem odd for scientists, but for philosophers of science it is a very real question, digging into why we need the concept of a phenomenon, and whether there is a difference between the concept and the thing in itself. For the field of science a clear understanding of what phenomena are and how they are used is as relevant as the whole field of philosophy of science is relevant to science. This is especially true for engineering science. As I stated above, engineering science and phenomena have a special bond. From all the technical sciences, engineering science is the one most focused on phenomena because harnessing phenomena is what engineering is.

A better understanding of phenomena may explain how scientists do their research; how they come to their conclusions. Falkenburg (2009) shows us that what Newton indicated as a phenomenon in his *Principia* is not the same as what is indicated as a phenomenon in his *Optics*. It is important to understand the categories—data, theory, model, phenomenon—they work with. Not for positivistic purposes of describing how science ought to be, but to describe how science is. Better understanding the role of phenomena play in the engineering sciences may also contribute to these practices.

1.1.4 What is a Phenomenon?

The question what a phenomenon in engineering science, is the subject of this thesis. Phenomena as I will discuss them in this thesis can be something ontological, but also something epistemological. When I discuss the ontology of a phenomenon, I discuss the way the phenomenon is. It may be something that exists, or occurs in the world; it may be a conceptualization; or it can be something you can observe—either directly or indirectly. A phenomenon as an epistemological item is something that can give us knowledge, something we can think about or use for thinking about other things. It is an expression in language, a representation or a conceptualization.

This discussion can get quite abstract at times. To give some idea of what I see as a phenomenon I will give some examples of phenomena. One example of a phenomenon I will use in this thesis comes from Bogen and Woodward (1988), who in turn borrowed it from Nagel. This phenomenon is the boiling point of lead. Bogen and Woodward use this example to illustrate the difference between data and phenomena. I use it for the same purpose in 4.3.1. The outcome of a measurement of the boiling point of lead is dependent on external conditions like pressure, and multiple measurements will not all give the same result. Still, phenomenon of the boiling point of lead is described as something happening at 327°C; the external conditions are given implicitly.

Another example I use is the phenomenon of solar neutrinos. This example I obtained from an article by Pinch (1985). Pinch uses this example to illustrate the externality and evidential significance of observation reports. I use this example in a slightly different way, in 2.1.1, to illustrate what can be directly observed and what can not. Solar neutrinos are a theoretical entity in physics, which cannot be observed directly. An elaborate experiment, which involves a lot of theoretical assumptions, is needed to detect them. Even if the experiment for detecting solar neutrinos gives a positive outcome, their existence is still open for discussion.

The example of a phenomenon I use in my case study, is the heat transfer in composite materials. Contrary to the example of solar neutrinos—which is a example typical for theoretical physics—the heat transfer in composites example is characteristic for engineering sciences. As will be explained in Chapter 4, this example shows that phenomena can be general like ‘the heat transfer in composite material’ or very specific, like ‘the axial heat transfer in a polymer with C-shaped carbon fibers. Something else this example shows is that the phenomena is linked to the target system. The target system is the material, machine, or construction that is under study; and which is governed by the phenomenon. The target system in the case study is the composite material.

1.2 Thesis Questions

What can be concluded from this introduction is that there are many different opinions on what phenomena are and how they are used in the context of discovery and the context of justification. The philosophical definition of what a phenomenon is and what it does may differ from what scientist see as a phenomenon. And then there is a difference between phenomena in social sciences, fundamental natural sciences, and engineering sciences (Bogen & Woodward, 1988). What then is a phenomenon exactly? Bogen and Woodward and many authors after them (Bailer-Jones, 2009; Basu, 2003; Kroes, 1994; McAllister, 1997, 2009) lean heavily on Hacking's (1983) definition of what a phenomenon is. This definition demarcates a turn in the philosophy of science, for it is a definitions based on how scientist see phenomena, not on how philosophers see them. The word 'phenomenon' "has a fairly definite sense in the common writings of scientists. A phenomenon is *noteworthy*. A phenomenon is *discernible*. A phenomenon is commonly an event or process of a certain type that occurs regularly under definite circumstances[iv]"(Hacking, 1983, p. 221). This definition is not strictly a definition, it is more a description of characteristics. It clearly shows the intuitive characteristics of a phenomenon of scientists, but it leaves much open for discussion; especially what the function of a phenomenon is, what the work is a phenomena does, and how and where to find one.

In extension to Hacking other philosophers of science have tried to give a definition of the characteristics of a phenomenon. According to Falkenburg "the phenomena of physics have the following features. They are (i) spatio-temporally individuated objects and events in the world, i.e., *concrete*; (ii) given by observation or measurement, i.e., *empirical*; and (iii) explained in terms of laws and causal stories, i.e., *typical*, *regular*, or *law-like*" (Falkenburg, 2009). The first and the last feature given are food for a discussion on realism. The second feature links phenomena clearly to empirical science. Bailer-Jones perhaps has the most simple definition of a phenomenon: she suggests "to identify a phenomenon with recognizing that something has the potential to be theoretically explained" (Bailer-Jones, 2009, p. 167).

The goal of my thesis is to investigate the different characteristics and functions ascribed to phenomena in the engineering sciences by both philosophers of science and engineering scientists. I will concentrate on engineering sciences because it seems to me that phenomena in the engineering sciences and other sciences are quite different. In the social sciences Glymour (2000) might be right in claiming that all phenomena are just statistics. What makes engineering science special in the exact sciences, I think, is the way physical phenomena and scientific models of them are used, and phenomena are conceptually articulated. Often phenomena are used in engineering works before they are theoretically explained. Part of what I will conclude about phenomena will therefore be true for all exact sciences, but some attributes of phenomena will only apply to the engineering sciences.

To come to a good understanding of phenomena in engineering science, my main question will be:

- What is a phenomenon in engineering science?

An answer to the main question requires a more substantial picture of phenomena in the engineering sciences. To develop this I will look into the possible roles and functions phenomena in engineering science can have. I will address how phenomena are used, what the work is they do, what their characteristic are and why they are needed. Therefore the main question will be divided in four sub-questions which will address the different aspects of phenomena in engineering science. These sub-questions are:

- How are phenomena used in engineering science?
- What is the work that phenomena do in engineering science?
- Why do engineering scientists need phenomena?
- What are the characteristics of a phenomenon in engineering science?

I will answer these questions based on a literature study in the philosophy of science and on a case study of five articles in engineering science. This will generate multiple answers to these sub-questions from different perspectives. My aim is to compare, rate, and filter these answers to come to an overall answer, which will give an account of phenomena in the engineering sciences.

1.3 Methodology

As said, I will answer my research questions based on two sources of information. The first will be a literature study into phenomena as they are mentioned in the philosophy of science. The second will be a case study of five articles written in engineering science.

1.3.1 Philosophical Approach

My thesis will be begin with a overview of what has been said about phenomena in the philosophy of science. This will be a literature study which gives a stage to all the different opinions and discussions. I will start out my literature study with the article 'Saving the Phenomena' by Bogen and Woodward (1988). Other authors central in this literature study will be Hacking (1983, 1992), McAllister (1997, 2003, 2004, 2009), Glymour (2000), Bailer-Jones (2009), Rouse (2009) and Boon (Boon, forthcoming; Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming). Most of the literature was obtained by making use of the snowball principle; I looked at authors referred to by, and at authors that referred to relevant literature I already had. This way I gained insight in the most relevant discussions and standpoints in the field.

As is clear form the literature I have chosen, I will only focus on the resent discussion on phenomena in the philosophy of science. As said in 1.1.1, the concepts of phenomena has been a part of philosophy for a very long time. To make a demarcation I have chosen to only look at literature in the philosophy of science and only to resent literature. The reason I do this is because the focus of my thesis is on phenomena in engineering science. Engineering science is a relatively recent science and it is a science involved in experimenting. Therefore I have chosen literature that is part of the resent revived interest in phenomena, which views phenomena in the light of experiments, but more importantly its views phenomena as a focal-point rather than a supporting role of proving theories.

When all the different standpoints and discussions of phenomena in the philosophy of science are clear I will go a step further. I will explore background assumptions and unspoken presuppositions of the philosophers discussed. This way I can connect their stance on phenomena to their general philosophical ideas about how the world is. This information gives me an instrument to place the different standpoints into context and to valuate them. Philosophical work will be to come to my own definition of phenomena on the basis of the philosophical literature. My definition aims to overcome the longstanding discussion on realism in the philosophy of science. I take it that only if this definition avoids the realism versus empiricism discussion can it lead to new insights.

1.3.2 Case Study

I consider it important to not only base my conclusions on what has been said in the philosophy of science. It has been a long tradition for philosophers of science to philosophize in their armchair on how science would, or should work; without investigation what science actually does. Therefore I will also look at science as it is practiced, to come to an answer to my research questions. The way I will do this is by doing a small case study. In this case study I will look at five articles about the phenomenon of heat transfer in fiber-reinforced composites; this is a sub-field of mechanical engineering.

I am aware of the fact that this case study represents only a very small part of the whole body of work that is done in engineering sciences. One should always be cautious when drawing general conclusions based on case studies (Bailer-Jones, 2009). However, I do believe that the articles I have chosen to study are representative for the work done in mechanical engineering. I have studied these articles myself during my mechanical engineering bachelor, and hence know that they are not atypical. The conclusions I draw from this case study are both fitting and explanatory about my experiences in mechanical engineering.

1.4 Overview of this Thesis

My approach will be divided into two parts. The first part consists of chapter 2 and 3, and will answer the research questions from a philosophical perspective. I will start in chapter 2 with a literature study into the philosophy of science. This study will focus on what philosophers of science have written about what phenomena are and how they are used. Topics that will be discussed are: the difference between data and phenomena; how models and theories connect to phenomena; the role of phenomena in the context of discovery and the context of justification; whether phenomena exist independently in nature; theory-ladenness of phenomena; phenomena and statistics; phenomena as ‘same condition-same effect’; and whether phenomena are natural kinds or conceptualizations. Chapter 3 will connect the visions on phenomena as presented in Chapter 2 to philosophical views on science of the different authors. This will be done on the basis of the discussion on realism; the questions why we need phenomena in explaining scientific research, in particular experiments; whether we see phenomena as physical phenomena or phenomena in language; and what the function of a phenomenon is.

The second part is presented in Chapter 4 and will consist of an investigation into how engineering researchers in the field use phenomena. For this part I will analyze scientific articles in the engineering sciences. First the articles studied will be discussed, guided by nine aspects that clarify how the phenomena are present and used. After this I will go into how experiments, target system, data and phenomena connect; that the phenomena presented are specific to a target system; how phenomena are modeled; and how this all connects to the notion of 'same condition – same effect' and the conceptual articulation of phenomena.

I will conclude this thesis with Chapter 5 with answering my research questions. I will do this on the basis of the insights acquired from both the first and the second part. In this section I will give a definition that I think best covers phenomena in engineering science.

2 Phenomena in Philosophy of Science

Phenomena have only really been an issue in the philosophy of science since the 1980's, and from then to now it's importance grew only slowly. This does not mean that there have not been some very important and illuminating publications about phenomena. This chapter will give an overview of what has been written about phenomena these past three decades. It will start with an introduction of some important categories as data, phenomena, models and theories. After this introduction the concept of phenomena will be investigated in different settings; phenomena in the contexts of discovery and justification, the existence of phenomena in nature opposed to creation in the laboratory, theory-ladenness of phenomena, phenomena as statistics and I will end with some views on phenomena that are less common in the philosophy of science.

2.1 Phenomena, Data and Theories

Since the birth of the philosophy of science the distinction between theory and data has been acknowledged. Data are what is observed, and a theory—for the Logical Positivists at least—is a logical statement. The Logical Positivists made a strict distinction between observational statements and theoretical statements. Hacking (1983) was one of the philosophers who disputed this distinction, by arguing that the role of experiments must be taken into account: “the truth is that there is a play between theory and observation, but that is miserly quarter-truth. There is a play between many things: data, theory, experiment, phenomenology, equipment, data processing” (Hacking, 1992, p. 55). Next, Bogen and Woodward (1988) made an important distinction between data and phenomena. After these authors the focus of the philosophy of science shifted from the theory-observation distinction to the role of phenomena.

In the following paragraphs I will discuss the important notions in the philosophy of science that are needed for a discussion about phenomena and try to place them in the bigger picture. I will do this in a bottom-up way by starting with observation and experiments, then coming to data and phenomena, to continue upwards via models to theories.

2.1.1 Observation and Experiments

Contemporary philosophy of science inherited most of their ideas of what is explained by theories from the Logical Positivists. The Logical Positivists distinguish between an observational and a theoretical vocabulary, this distinction is an either/or distinction; a distinction in kind, not in degree. Observational terms were considered expressions like ‘it is cold’, or ‘it is heavy’, theoretical terms were expressions like ‘gold has atomic number of 79’ and ‘this is a force’. The observational/theoretical distinction is a purely linguistic distinction and should not be confused with the activities of observing and theorizing (Newton-Smith, 1981, pp. 19-28). Logical Positivism says that via correspondence rules a theoretical vocabulary can be deduced from an observational vocabulary, and so explanations can be given, theories can be tested and predictions can be made (BonJour, 2005; Ladyman, 2002). According to the inductivists and falsificationists the observational/theoretical distinction in both language and activity was needed because the separation of observation and theory made sure theories could explain observations without circular references.

Since the introduction of the Kuhnian relativism these ideas are no longer upheld. Kuhn (1962) stated that all observations are theory-laden, either in a strong—an observation always heavily depends on its paradigm in set up and outcome bias—or a weak sense—observation setups and ideas are always based on background assumptions and available knowledge, this is sometimes also called theory-drivenness. Nevertheless, the authors who take part in this discussion maintain that scientific theories explain what is observed. From this they conclude that the role of phenomena is to prove theories, because phenomena are that which is observed. (Bogen & Woodward, 1988; Hacking, 1983; Ladyman, 2002; Newton-Smith, 1981; O'Hear, 1989).

It is important to understand the difference between observing and experimenting. “Observation—seeing with the naked eye—is not the test of existence. … Experiment is. Experiments are made to isolate true causes and to eliminate false starts” (Hacking, 1983, p. 7). Observing is but a very small part of experimenting. Often creating the ideal experimental setup takes much more time, effort, and experience than the actual observing. A good observer is not necessarily a good experimenter (Hacking, 1983). This difference between observing and experimenting has been neglected by many philosophers of science. In much of the literature (see for example Friedman, 1974; 1972; Van Fraassen, 1976; and the Logical

Positivists) what is observed is seen as something 'given by the world[v]'. Even authors (like Bailer-Jones, 2009; Bogen, 2009; Bogen & Woodward, 1988; McAllister, 1997, 2009; Woodward, 2009) who focus on data production in experiments and the context of discovery seem to ignore this point. Only very few (especially 1983, 1992) focus on how experiments are done, and how this influences what is observed.

This neglect of the difference between observation and experimenting goes hand in hand with the positivistic idea that, although observation is an essential part of science, it is so self-evident that it does not require any further study. Scientists just observe something in an experiment, and then they have data. In this view the relevant part of philosophy of science is to explain how scientists come to a theory. The only reason scientists do experiments is to verify their theories. This positivistic view probably seems very alien for a scientist. As Hacking (1983, 1992) notes, most of the work for scientists goes into doing experiments. Making a good experimental setup costs a lot of time and hard work. A scientists starts with a hypothesis of which experiment will result in the sought after phenomenon, or thinks up an experiment of which the outcome might be interesting[vi]. Then an experimental setup will have to be made, which may involve the production of specialized equipment. This setup will be tested to see if it produces the desired results. If this is not the cases, which it often is not, the setup will be modified. This process continues until useful data are created. The data are often already processed, into graphs for instance, before any observations are done.

With these complex preparations of experiments and data production it is hard to say what is actually being observed. Lets look at Pinch's (1985) example of the detection of solar neutrinos. Solar neutrinos, it has been conjectured, are emitted by the sun's core and have only a very weak interaction with matter, which makes that they are assumed to be a reliable information sources for gaining knowledge about the sun's core, but makes them very hard to detect. One particular branch of solar neutrinos can be 'observed' with a rather elaborate experiment. Because solar neutrinos are supposed to be mass-less and charge-less, only indirect detection is possible. A basin with dry-cleaning fluid (C_2Cl_4) has to filled a mile under the earths surface, to shield from other radiation. The neutrinos passing through this tank will react with the isotope Cl^{37} and create Ar^{37}. After a period of time the accumulated Ar^{37} will be swept out of the tank using helium gas and trapped on a supercooled charcoal trap. This is then placed in a Geiger-counter, where the decay is measured by the emission of Argon electrons. The counts of the Geiger-counter are then plotted in a graph. This graph will be the first thing that the scientist can actually observe; neither the solar neutrinos, nor its replacement, the Argon isotope, can be observed directly.

2.1.2 The Distinction between Data and Phenomena

Hacking (1983) was one of the first to give the phenomenon a stage. In the second part of his book *Representing and intervening* (1983) he focuses on how science is done and especially on experiments. For a true study of experimental science it is not enough to only look at data and theories, the notion of phenomena is needed. The phenomenon is what it is all about in an experiment, and therefore in science.

According to Bogen and Woodward (1988) the Logical Positivists ideas that theories are verified (or falsified) by observations is fundamentally flawed. If by 'observe' we mean 'perceive', than that which is observed is not that which is explained by theories. In their influential article 'Saving the phenomena' (1988), they introduce a third kind of entity—phenomena—in the step from data to theory; data are observed, but phenomena are explained by theory.

> Our argument turns on an important distinction, ... the distinction between data and phenomena. Data, which play the role of evidence for the existence of phenomena, for the most part can be straightforwardly observed. However, data typically cannot be predicted or systematically explained by theory. By contrast, well-developed scientific theories do predict and explain facts about phenomena. Phenomena are detected through the use of data, but in most cases are not observable in any interesting sense of that term. ... Facts about phenomena may also serve as evidence, but typically such facts are evidence for the high-level general theories by which they are explained. ... With respect to their evidential role what distinguishes data from phenomena is *not* that only facts about data may serve as evidence, but rather that facts about data and facts about phenomena differ in what they serve as evidence *for* (claims about phenomena versus general theories)[vii].
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> (Bogen & Woodward, 1988, pp. 305-306)

A phenomenon is a potential explanandum for a theory, and data are the evidence for this explanandum. Thus, theories explain phenomena, and phenomena explain data.

The distinction between data and phenomena will not always be perfect and sharp, but there is an important difference. Data are idiosyncratic to a specific experimental context. If you set up two similar tests the data from these two test will never be exactly the same. Even if you retest the same setup, your test results, your data, will differ. A theory could never explain data, due to the desired characteristics of data. Data must come in sufficient quantities and with a sufficient frequency; it must be easily accessible for our senses; it must be easily classifiable and identifiable. These characteristics are what make data idiosyncratic, and because of the complex interactions and the unpredictability of the exact outcome theories cannot explain data. A phenomenon, on the other hand, is not idiosyncratic to a specific experimental context. Repeated testing will show the constant characteristics of a phenomenon. This is what theories explain; the characteristics of a phenomenon that are shown as constant in the data-sets of repeated experiments[viii] (Bogen & Woodward, 1988).

From a satisfactory systematic explanation we expect two features. First it must explain; not just say a certain event is caused by some general principle. For an explanation to be systematic and satisfactory it must "show how the features of the explanandum-phenomenon systematically depend upon the factors invoked in the explanans of that explanation" (Bogen & Woodward, 1988, p. 323). Secondly it "should unify and connect a range of different kinds of explananda" (Bogen & Woodward, 1988, p. 325). An explanation of data will not satisfy this second feature and therefor is not a satisfactory and systematic explanation. Only "facts about phenomena are natural candidates for systematic scientific explanation in a way in which facts about data are not" (Bogen & Woodward, 1988, p. 326).

McAllister (1997, 2009) points out that there is one important problem with the account of Bogen and Woodward. They do not explain how they come from data to phenomena. Bogen and Woodward claim that scientist just 'see' patterns in the data-set given by an experiment. According to McAllister there is not just one pattern in the data-set that distinguishes the phenomenon. Because data are idiosyncratic and phenomena are not, there is a difference between the data that indicate the phenomenon and the total data-set, this difference is noise. The data that are produced by the phenomenon will always be the same, the noise will never be the same; this makes data idiosyncratic. But the data points that are produced by the phenomenon are not ontologically different from the ones indicated as noise. In fact noise is also produced by—mostly unwanted—phenomena. In a data-set there are innumerably many patterns, which can all indicate different phenomena. McAllister argues that Bogen and Woodward cannot give a reason why scientists pick one pattern out of the data-set and not another, other than that they have some predisposition towards this pattern or that it is a coincidence.

As said, Bogen and Woodward, base their idea of what a phenomenon is on the definition Hacking gave. The first two characteristics—that they are noteworthy and discernible—are what scientists ascribe to phenomena, this is especially clear if we agree with McAllister on how phenomena are found in data-sets. Phenomena are patterns that are picked out of a data-set. The last characteristic—that it is an event or process that occurs regularly under different circumstances—is the most important one. It links close to Bogan and Woodward's idea of the distinction between data and phenomena. Phenomena are not idiosyncratic, which means that there are independent of the experimental setup. Hence, a phenomenon does not depend on an experiment like data do, this makes the phenomenon the stable factor theories rely upon for explanation.

2.1.3 Models and Theories

In a more classical view on science, like for instance Logical Positivism, it is all about theories. Hypotheses are proposed by scientists, and are confirmed or refuted by comparing predictions—or models—with an experimental outcome. This top-down view of doing science can also be found in the Semantic View. The New Experimentalists (like Hacking, 1983, 1992) responded against this theory centered approach with a firm focus on experiments. Experiments bring us new knowledge, which can lead to theories, but experiments do not have to be motivated or inspired by theories. Experiments are not only done to confirm theories, but also out of pure interest. Schindler (2009) tries to reconcile both parties by saying that they are both right part of the time; both ways are practiced in science.

But what then is a theory? About this question a similar thesis as this one can probably be written. But for the purpose of the thesis at hand we can follow the Logical Positivists and say that epistemologically a theory is a deductive, or inductive statement which can either be true or false[ix]. Ontologically a theory is something abstract or analytical, opposed to something practical like experiments. Theories can be seen as tools for making predictions and for understanding and explaining. They can encompass laws, regularities and axioms. Often theories are seen as axioms or fundamental laws.

In the Received View of science, models did not get much attention. They were seen as a way to come via a hypothesis to a theory. Models were seen as only temporary. Models are often seen as preliminary versions of what after conformation becomes a theory. This implies that theories are lasting while models come and go (Bailer-Jones, 2009). A pragmatic view on what a theory is can be that a theory is a model as long as it is still a hypothesis. This pragmatic view gives more credit to the model as it is part of the theory in its development, but still the models can retire after the theory is accepted. Cartwright (1983) and Bailer-Jones (2009) don't adhere to the idea that models can retire after the theory is proven and the work is done. Models are always needed as interpretations of abstract theories.

Nancy Cartwright (1983) tells us that fundamental laws can tell us nothing about phenomena. Only a model of a fundamental law can describe or predict a phenomenon. This is because fundamental laws do not describe the types of phenomena. First the fundamental law must be modeled—mostly mathematical—to show these patterns. Not the fundamental laws are present in nature, but capacities of the existence of phenomena are. Phenomenological laws are the laws that describe these phenomena. According to Cartwright these laws are more true than fundamental laws, because they do not need the translation via a model. Models are needed to make it possible for a theory to establish a relation with reality; to make it possible for a theory to be applied to the world.

Bailer-Jones (2009) endorses Cartwright's positions that theories cannot be compared to the empirical world and elaborates Cartwright's idea further. Saying that a model explains a phenomenon, while a theory does not is only half the truth. The subject of a model is not any odd phenomenon, but a class of phenomena; often represented by a prototype. “The prototype has all the properties of the real phenomena; it is merely that the properties are selected such that they do not deviate from a ‘typical’ case of the phenomenon. It is this prototype that is addressed in the modeling effort” (Bailer-Jones, p145). Because this prototype could exist just the same way as a real phenomenon, the prototype still counts as concrete. Theories, like for instance Newtons law F=m*a, do not say anything about concrete phenomena. A model, like that of the harmonic oscillator, must be made before something can be said about the concrete prototype of a class of phenomena.

Models[x] are intermediaries that connect phenomena to theories. This idea is present in both the bottom-up New Experimentalist view as in the top-down Semantic View. Hacking tells us that

> a natural idea would be that the models are doubly models. There are models of the phenomena, and there are models of the theory. That is, theories are always too complex for us to discern their consequences, so we simplify them in mathematically tractable models. At the same time these models are approximate representations of the universe. … The models are intermediaries, siphoning off some aspects of real phenomena, and connecting them, by simplifying mathematical structures, to the theories that govern the phenomena.
>
> (Hacking, 1983, pp. 216-217)

According to the Semantic View the verification of theories is found in the comparison between the abstract model and the data model. The abstract model is a mathematical instantiation of the theory or axiom. The data model is a pattern in a data-set given by an experiment; this can be seen as equivalent to the phenomenon of Hacking and Bogen and Woodward. If the abstract model and the data model are isomorphic, then the experiment proves the theory. In the Semantic View models should be considered as double models.

In their book *Models as Mediators* Morrison and Morgan (1999) claim models to be autonomous agents that mediate between theory and phenomenon. The difference with the Semantic View and their vision is that it takes work to create a model. Models cannot simply be deduced from theories. They see models as partly independent from both theory and data. Rouse describes their standpoint as follows:

> Theories do not confront the world directly, but instead apply to models as relatively abstract representations of various phenomena; the models are often developed and used independently of specific theories; moreover, the models then sometimes serve as the proximal object of investigation, standing in for the phenomena themselves.
>
> (Rouse, 2009)

In the Semantic View there would always need to be a connection between a model and a theory, and between a model and the world. Bailer-Jones takes a stance in the middle, she finds the idea of models as autonomous agents misleading, because this would imply that they act on their own. Although models are not deductions from theories, there must always exist some connection between them. “There always exists constrains for the relationship between model and theory and model and phenomenon" (Bailer-Jones, 2009, p. 135).

Rouse (2009) has offered a critique to Morgan and Morrison and some of the New Experimentalists. He argues that there seems to be more interest in the relation between theories and models than there is for the relation between phenomena and models. He wants to go back to the idea of the Semantic View of double models. Not only the theory must be modeled, but also the data and phenomena side[xi]. Where these two models come together, the empirical and the theoretical can be compared.

Boon and Knuuttila (Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming) go a step further, and view models as epistemic tools. They see models not as just an accurate representation of a phenomenon, but as independent epistemic structures. "The key to the epistemic value of models does not lie in their being accurate representations of some real target systems but rather in their independent systemic construction that enables scientist to draw inferences and reason through constructing models and manipulating them" (Boon & Knuuttila, 2009). Models, especially in engineering, are thus not just a way to represent phenomena and theory but are tools to think about intervening with phenomena and systems.

Whichever position of the model between the theory and the data is taken, it may be clear that models are needed. This does not mean they are not often overlooked. Bogen and Woodward (1988) in their discussion of the inference from data via phenomena to theory, skip over models very quickly. Cartwright's (1983, 1998) observation that fundamental laws do not indicate patterns in data is important. It is not possible to compare these fundamental laws to the world without models.

2.2 Phenomena in the Context of Discovery and the Context of Justification

With the introduction of the empirical sciences, and with it the method of induction, it became necessary to have a way to determine the validity of discoveries. For this Hans Reichenbach and Karl Popper drew attention to the distinction between the context of discovery and the context of justification. According to them the validity of a discovery does not depend on who, why and how the hypothesis for this discovery was thought up. The validity of the discovery depends on the theoretical justification it can provide (Ladyman, 2002). Phenomena can both play a role in the context of discovery and in the context of justification. It is interesting to see that the emphasis on discovery or justification go hand in hand with an emphasis on experiments or theory.

2.2.1 Context of Justification

The Semantic View branch of philosophy of science, to which Suppe (1972) and Van Fraassen (1976) can be counted, views phenomena in the context of justification (see illustration 1 semantic view). They start from the top with an abstract theory; this can be a mathematical formula or an axiom. In order to justify the theory, a model is created; this model is an instantiation of the theory. From the bottom-up, the world is mapped out as a data structure via an experiment or an observation. This data structure represents the phenomenon. A data structure can be abstracted to a model, or physical system as Suppe calls it. '"Physical systems, then, are highly abstract and idealized replicas of phenomena, being characterizations of how the phenomena *would have* behaved *had* the idealized conditions been met" (Suppe, 1972, p. 12). This physical system is an idealized version of the phenomena which should correspond with the model based on the theory. The phenomenon or data structure is needed to verify the model that was distilled from the theory; this way the theory can be justified via data about the real word. The role of the phenomena is to verify (or falsify) a theory by comparing models: models of the theory and models of data.

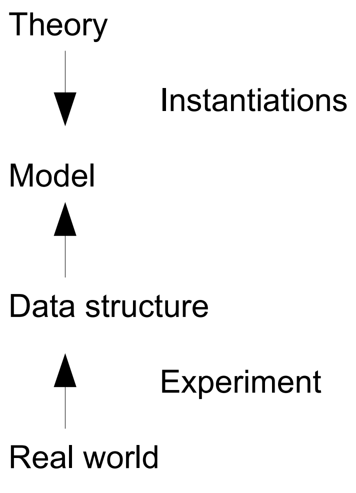

Illustration 1: semantic view

Bogen and Woodward, although they paint a bottom-up picture, do struggle with justification. An objection that can be made against Bogen and Woodward is that if theories would not explain data, then it is not possible to make an assessment of the reliability of the data in the way that it is done in the Semantic View. Bogen and Woodward disagree, they say that “it is simply false that an assessment of the reliability of data requires the construction of systematic explanations of facts about such data” (Bogen & Woodward, 1988, p. 326). The reliability of data can be ensured by minimizing and controlling confusing factors, empirically investigating the equipment, and using statistical analyses[xii]. These ways of ensuring the reliability of data do not require a detailed fundamental understanding or explanation of the data. Phenomena on the other hand do require systematic explanation; this explanation should neither be ad-hoc nor piecemeal (Bogen & Woodward, 1988).

2.2.2 Context of Discovery

New Experimentalists, like Bailer-Jones (2009) and Hacking (1983, 1992), talk about phenomena in light of the context of discovery. Hacking warns us that although we have the feeling that we do not create phenomena, but we discover them, it is not so that “the phenomena revealed in the laboratory are part of God's handiwork, waiting to be discovered” (Hacking, 1983, p. 225). To isolate a phenomenon is hard work; phenomena do not just present themselves to the scientists.

The engineering sciences are interested in phenomena for two reasons: first to harness specific qualities, and second, to isolate unwanted other effects. In the first case scientist want to understand a sought after phenomena so they can optimize them. In the second case scientists want to understand certain unwanted phenomena, so they can eliminate or account for them. In both cases phenomena occur in experiments or in the workings of a machine; or are predicted in design. Once the effect of a phenomenon is clear, the contribution of that phenomenon to a process or system can be distinguished. In a particular system the outcomes of all the phenomena at work can be stacked; together they form the behavior of the process or system. In the case of engineering science proving abstract theory is not the main purpose, it is all about discovering and understanding the phenomena that govern the process or system, so they can be used[xiii].

Although the phenomenon is placed in the light of discovery the actual discovery of the phenomenon is still a problematic point. Bogen and Woodward (1988) say that scientists just ‘see’ the phenomena as a pattern in a data-set. McAllister (1997, 2009) expands this by saying that all possible patterns in data-sets are phenomena. Hacking (1983, 1992) tells us that phenomena are not discovered, they are created. Schindler (2006, 2009) tells us that discovery of phenomena is theory-laden in multiple ways. But they all seem to skip over what it actually means to discover a phenomenon. And they have good reasons for it, since the actual discovery of a phenomenon is a difficult and problematic point. When do data stop to be just data en does the phenomena starts to shine through? This is one of the natural processes in the workings of science which are hard to describe. Perhaps it is as Schindler (2006) says not the description—or re-description—of data that makes the phenomena, but it is a true Gestalt shift[xiv].

2.3 Phenomena in Nature and in the Laboratory

Although Bogen and Woodward base their idea of what a phenomenon is on Hacking, there is much difference."It should be clear that we think of particular phenomena as in the world, as belonging to the natural order itself and not just to the way we talk about or conceptualize that order. Beyond this, however, we are inclined to be ontologically non-committal[xv]" (Bogen & Woodward, 1988, p. 321). For Bogen and Woodward phenomena exist in the world; they are out there to be found by scientists. They also believe that there a finite number of phenomena (Bogen & Woodward, 1988). Bogen and Woodward are scientific realists concerning phenomena. Phenomena for them are part of a knowable real world that exists outside of us. Phenomena have always been there and will always be there and scientists can only find what is already there. Although they claim to be ontological non-committal beyond the fact that phenomena are in the world, their work seems to tell they are direct realists about science.

Hacking (1983) thinks about this very differently; to him phenomena are created by means of experiments. He goes against the idea that scientists try to explain the phenomenon that they discover in nature. According to him the scientists often create a phenomenon, which then becomes the pinnacle of their theory. That scientists create their phenomena, does not mean they actually make them, but that they must make a fair amount of effort to be able to observe a phenomenon. As explained earlier observing is something very different than experimenting. Most phenomena are not just out there to be seen. As a counter example Hacking gives some planetary phenomena whom can be seen with the naked eye[xvi]; something that is not true for most phenomena. For most phenomena to be discovered a vast laboratory setup is needed and incredible computing power. Phenomena are not just detected in nature, nature must be manipulated and stressed to make her give up her phenomena; or as Francis

Bacon supposedly said the lions tail has to be twisted[xvii] (Hacking, 1983). He even goes as far as to claim that certain phenomena do not exist outside of the laboratory. He does not adhere to theory-dominated view of science which says that

> since our theories aim at what has always been true of the universe—God wrote the laws in His Book, before the beginning—it follows that the phenomena have always been there, waiting to be discovered. I suggest, in contrast, that the Hall effect does not exist outside of certain kind of apparatus. … The effect, at least in a pure state, can only be embodied by such devices.
>
> (Hacking, 1983, p. 226)

Kroes (1994) does agree with Hacking that phenomena can be created, but for him that does not make them less natural. The natural/artificial distinction goes hand in hand with the discovery/creation distinction. The traditional theory-driven view depends highly on these distinctions. And the natural/artificial distinction of objects is reflected in a natural/artificial distinction of data. But according to Kroes, Hacking is not that far apart from the traditional philosophy. The expression 'to create phenomena'

> can be interpreted in a weak and a strong sense. In the weak sense it means that the experimentalist creates the proper conditions for a phenomenon to take place, but does not create its specific characteristics. In the strong sense he not only causes the occurrence of the phenomenon, but also creates the specific features of the phenomenon itself. … In my opinion, there can be no doubt that Hacking uses the expression 'creating phenomena' in the weak sense. … Creating phenomena, therefore, means that the experimentalist creates the right boundary conditions for the phenomenon to occur[xviii].
>
> (Kroes, 1994, p. 435)

What Kroes wants to tell us is that even if phenomena are in the world, it still can be a lot of work to make them appear. The fact that you have to create an elaborate experimental setup does not mean that the phenomenon does not naturally occur under these circumstances; only the chance of the occurrence of these circumstances in nature is very small.

2.4 Theory-ladenness of Phenomena

Theory-ladenness is a concept brought to us by Thomas Kuhn (1962). The idea is that you can never do science with a blank mind. When scientists observe something, what they see will always be influenced by what they already know. A strong version of theory-ladenness is that you can only find that which you were looking for; a weaker version says that in explaining observations background knowledge will always play a role (Ladyman, 2002).

2.4.1 Theory-ladenness of Observation

Bogen and Woodward do not think that what they say merely repeats common ideas about theory-ladenness of evidences. Phenomena would then be more theory-laden observations and data less theory-laden observations. They take a stance against the objection that their distinction is just a degree of theory-ladenness.

> Our reply to this objection is that if ‘observation,’ ‘observation-sentence,’ and related terms are given a definite enough interpretation to make the traditional view a substantial characterization of scientific activity, then phenomena for the most part cannot be observed and cannot be reported by observational claims.
>
> (Bogen & Woodward, 1988, pp. 342-343)

McAllister thinks that the denial of theory-ladenness in the account of Bogen and Woodward is not realistic. “I suggest that the claim that phenomena correspond to patterns in data sets renders Bogen & Woodward’s account of phenomena incoherent. More specifically, it is incompatible with their claim that what phenomena there are is not a matter of stipulation” (McAllister, 1997, p. 219). According to Bogen and Woodward a scientist can ‘spot[xix]’ a phenomenon as a pattern in a data-set. But any given data-set will hold many different patterns and noise. Even after error reduction and cleansing of the data[xx] it will still contain noise and infinitely many distinct patterns. If their account is truly not theory-laden, they must explain why one specific pattern is chosen as representing a phenomenon, without relying on the scientific theory. They have to provide a property that the patterns whom indicate phenomena have and other patterns lack. Beside this they have to specify their noise level either as zero or at a given non-zero maximum. Both of these preconditions cannot be given by Bogen and Woodward. This makes that they cannot answer the question of how the scientists ‘spot’ a pattern corresponding with a phenomenon. All the responses they can give would either lead them straight back to theory-ladenness—arguing that scientists have some preset ideas on what phenomena exist, based on background knowledge, or arguing that patterns that indicate phenomena are those that adhere to the scientific common knowledge of this age—or would give an incomplete explanation—arguing that the patterns which indicate phenomena are those that are caused by phenomena (McAllister, 1997).

McAllister comes with an answer to the question of how phenomena are recognized in data-sets. “Far from denoting a small number of fundamental constituents of the world, the term ‘phenomenon’ is on my account a label that investigators apply to whichever patterns in data-sets they wish to so designate. Thus, on my account, which patterns count as those corresponding to phenomena is entirely a matter of stipulation by investigators”(McAllister, 1997, p. 224). For McAllister phenomena are theory-laden in such a way that they cannot be found in data-sets without a predefined idea about what you are looking for. Every possible pattern in a data-set indicates a possible phenomenon. Even the noise is caused by phenomena. Which ever pattern the scientists pick will be a phenomenon, just because they picked it.

McAllister’s account differs from Bogen & Woodward’s in ontology, epistemology, as well as methodology. In McAllister's account the world is complex and adheres to causal mechanisms which causes it to produce data with infinite patterns in a data-set; in this data-set a scientist can discover all the different patterns, but will stipulate that only some correspond to the phenomenon (McAllister, 1997, 2009). Seeing ‘phenomenon’ as a label that scientists can put on a specific patterns makes that McAllister does not have to find a reason, independent of the scientist, to make a distinction between patterns that indicate phenomena, and those which do not, as Bogen & Woodward have to do; because all patterns indicate phenomena. McAllister believes his account connects better with the practice of science. The data-sets of an experiment are for all scientists the same, still each may spot a different phenomenon. Based on theories and expectations specific patterns are singled out to count as indicators for phenomena.

Bailer-Jones states that McAllister and Bogen and Woodward might be wrong to indicate phenomena as essentially patterns in data-sets. She suggests to “identify a phenomenon with recognizing that something has the potential to be theoretically explained” (Bailer-Jones, 2009, p. 167). Any set of data might potentially be interesting to theoretically explain. But there need not be data to start with. A system or something significant can occur to a scientist. To identify a phenomenon then, data must be collected, and examined. Background knowledge can change what is regarded as having a potential of being theoretically explained. Hacking takes this a step further when he talks about ‘creating a phenomenon’—here phenomena are ‘created’ in very specific, human-made laboratory settings (Bailer-Jones, 2009; Hacking, 1983, 1992).

2.4.2 Other Forms of Theory-ladenness

Besides the theory-ladenness of observations, there can also be theory-ladenness of evidence. What phenomena are included and excluded as good evidence? Schindler (2001 2009) claims there are strong forms of theory-ladenness at work in regarding phenomena as evidence.

> *The principled neglect of data* due to theoretical predispositions, and theoretical reasons for belief in the reality of phenomena, which can prove to be critical in *the assessment of the reliability of the data* and the eventual acceptance of this phenomenon as being real[xxi].
>
> (Schindler, 2009)

Sometimes scientist do pick one phenomenon out of a data-set, but not another. What is regarded as evidence in the search for a possible theory may depends on which phenomena scientists deem relevant. Besu (2003) thinks that Bogan and Woodward should have included some kind of theory-ladenness of evidence, because without it they cannot explain revolution[xxii] in science. One and the same data-set can be evidence for different theories; sometimes even rival theories.

Yet another form of theory-ladenness can be found in the way we represent phenomena. If a scientist publishes about the phenomenon he or she has ‘seen’ in the data, he or she must represent it so others will understand. Often a representation of a phenomenon will be a table, a graph, a schematic picture, or sometimes only a description in text. Brown (1994) warns us that these representations are not free of theory; a representation suits a purpose. A graph, for example, will show how the phenomenon perfectly fits with the theory. This graph is obviously a styled representation of the real data.

2.4.3 Theory-drivenness

Bogen (2009) and Woodward (2009) have responded, separately, to the critique on their statement that phenomena are not theory-laden. In this later work Bogen defines phenomena as “processes, causal factors, effects, facts, regularities and other pieces of ontological furniture to be found in nature and in the laboratory. They exist and are as they are independently of interests, concepts, theoretical commitments of scientists, and political, historical, social, and cultural factors that influence them[xxiii]” (Bogen, 2009). This definition is more elaborate that their vision on phenomena from their original article (Bogen & Woodward, 1988), but it is still a realist view on phenomena, and a denial of theory-ladenness.

Where Bogen's 2009 article was mostly a restatement of their data and phenomena distinction in a critical response to Logical Empiricism, Woodward (2009) responded directly to his critics[xxiv]. He tells us that the reasoning from data to phenomena is a form of inductive reasoning. Since data are not the same as phenomena, some “substantial empirical assumptions” (Woodward, 2009) must be added. These assumptions go beyond the data, to spell out the phenomena.

> However, that such assumptions “go beyond the data” does *not* mean they are arbitrary, empirically unfounded, untestable, or matters for stipulation or convention. … Our view is that such assumptions are *always* required in data to phenomena reasoning. … In addition to substantive empirical assumptions, inductive inference (including data to phenomena reasoning) often relies on (or is guided by) evaluative considerations having to do with the investigator’s choice of goals, interests, and attitudes toward risk[xxv].
>
> (Woodward 2009)

This quote shows that Woodward can no longer uphold the claim that data to phenomena reasoning is not theory-laden; at least a mild form of theory-ladenness must be accepted. He does not accept that coming to a phenomenon is just arbitrarily picking one pattern out of the innumerable patterns in a data-set as McAllister claims, but he does accept that data to phenomena reasoning is theory-driven. This means that auxiliary assumptions play a role, and that these assumptions are based on theory, but not on the theory at hand. According to

Woodward saying that data to phenomena reasoning relies on the theory under study would lead to a circular reasoning[xxvi].

2.5 Data Patterns and Statistics

Glymour (2000) has a very different view on phenomena and the distinction between data and phenomena.

> While I think McAllister has recognized a serious flaw in the distinction advanced by Bogen and Woodward, and that their account simply does not work very well, I argue that no such distinction between data and phenomena is needed, and that the distinction which is needed, and is already well established in the relevant literature, does not entail the sort of relativism required by McAllister's version of the distinction between data and phenomena.
>
> (Glymour, 2000, p. 32)

What Glymour refers to is sample statistics. He admits that he does not exactly know what Bogen and Woodward and McAllister mean by 'pattern', but that their accounts are meant to be general and therefore ought to involve some form of sample statistics.

For Glymour the epistemological difference between data and phenomena as given by Bogen and Woodward is an illusion.

> Certain entities have both the epistemically foundational status of data and are susceptible of explanation by theory in just the way phenomena are. … So sample statistics have the same epistemic status as the observation reports comprising the data in the sample.
>
> (Glymour, 2000, p. 33)

According to him it is precisely this statistical feature of data which is explained by theories. Hence data and phenomena do not differ in the way envisioned by Bogen and Woodward, at least not as sharp as they ought to. For Glymour the lack of distinction between data and phenomena is not a problem, for he is not convinced that such distinction is needed. The distinction between data and phenomena is nothing but the distinction between sample and population structure. This means that for him there is raw data and reduced data, and the data-reduction is done by statistics.

Statistical inference from data is theory dependent because it may rely on causal assumptions and assumptions about noise levels, and the choice of statistical method is based on theoretical assumptions. This is not the theory-ladenness McAllister advocates, but more theory-drivenness; only knowledge about statistics is required. “If data points are not theory laden, then neither are sample statistics, and the latter are both theoretically explicable and replicable” (Glymour, 2000, p. 36).

2.6 Other views on Phenomena

More recently the standard view on phenomena in the philosophy of science, as introduced by Bogen and Woodward (Bogen & Woodward, 1988), no longer satisfies everybody. The basic ideas of the importance of the concept of phenomena are cherished, but the notion of what makes a phenomenon changes. In this paragraph I will discuss two of these divergent views on phenomena. The first is the concept of same condition – same effect, the second the idea of descriptions of phenomena as conceptualizations.

2.6.1 Phenomena as ‘Same Condition – Same Effect’

In an attempt to overcome the problematic notion of truth in the philosophy of science, Mieke Boon (forthcoming) describes science in terms of robustness. According to her, robustness is what makes science work. Science encompasses different robustness-notions at different levels. Robustness can be a property of knowledge—the ability of knowledge to give reliable predictions—which makes it an epistemic notion. It can also be an ontological notion, in which case it is a property of phenomena, processes or objects. And since we believe that our world is robust—the same conditions will always give us the same effect—robustness is a metaphysical notion as well. Boon sees this ‘same condition – same effect’ as an important regulative notion of science.

According to Boon in engineering science the purpose of research is the development of materials, technological devises and processes.

> Usually, the proper (or improper) functioning of devices, processes, and materials is understood in terms of phenomena that produce (or deteriorate) the desired behaviour. By experimentation and scientific

> modelling, the engineering sciences strive to respectively understand and produce the specific behaviour of devices and processes, and/or the properties of materials.
>
> (Boon, forthcoming, p. 6)

To make this possible, scientists make use of scientific instruments and experimental techniques which can create and intervene with phenomena responsible for wanted or unwanted effects in the technological applications. To produce these desired effects scientists use “rule like knowledge” (Boon, forthcoming) and models about these phenomena and about the functions of these experimental techniques and scientific instruments. This process is governed by the regulative robustness-notion of ‘same condition - same effect’.

“Robustness, invariance, stability, and reliability often are used as synonyms—other notions with a similar meaning are, reproducibility, empirical adequacy[xxvii], and ‘same conditions - same effects’” (Boon, forthcoming, p. 7). ‘Same condition – same effect’ is a regulative principle in the sense that it governs the way in which engineering science is done and it gives philosophical ground to the other robustness-notions. It is also a presupposition for experimental science. We have a metaphysical belief how the physical world is. We expect to find the same result if we do the same experiment—this is the foundation of experimental science. As a metaphysical principle ‘same condition – same effect’ cannot be proven, but as a regulative principle it is essential to experimental science. Science would be impossible if this pragmatic regulative principle would not be followed. “An important aspect of ‘same conditions – same effects’ as a regulative principle is that it ‘guides and enables’ inductive inferences” (Boon, forthcoming, p. 15).

Inductive inference is logically unjustified, but is indispensable for experimental science. The ‘same condition – same effect’ principle justifies this move from a finite number of observations, to a ceteris paribus rule: all other things being equal, then $A \rightarrow B$. The only problem with this is that scientists do not know when and whether all things are equal, because they do not know ‘all things’. ‘Same condition – same effects’ applies to both the universe as a whole as to physically isolated phenomena and experimental data. In manipulating phenomena scientists are thus also guided by this principle. The ‘same condition’ aspect implies that a phenomenon cannot just be described as $A \rightarrow B$. The correct description Boon gives us is $A + C_{device} \rightarrow B$, unless ($K_1$, … K_n and/or X); in which C_{device} are the conditions of the phenomena-producing device, K_1, … K_n are other known causally relevant conditions, and X are unknown causally relevant conditions[xxviii].

> The explanation of 'same conditions – same effects' as a regulative principle points to a different idea about the character of phenomena than the commonly accepted ideas, such as articulated by Hacking (1983), Bogen and Woodward (1988), and Bailer-Jones (2009). Contrary to what philosophers often suggest, phenomena usually are not the point of departure of scientific research. Identification and reproducible technological (or experimental) production of physical phenomena described by A→B is a central activity of scientific practices, in particular of those practices that do research in the context of applications. Essential to my account of 'same conditions – same effects' is that phenomena described by A→B must themselves be recognized, not only as technological achievements, but also as ontological and epistemological achievements.
>
> (Boon, forthcoming, p. 19)

Boon proposes that we talk about the phenomenon described by A → B, and not the phenomenon P (Boon, forthcoming). A phenomenon does not exist on its own, it is dependent on the physical conditions—it will occur at specific conditions, or it will disappear at specific conditions. For phenomena to be of use in engineering science, they must be reproducible and stable. A phenomenon must have ontological status, which means that when the same physical circumstances occur, the same phenomenon will occur. Thus, the regulative principle 'same condition – same effect' guides scientists in ontologically creating and epistemologically articulating a phenomenon.

2.6.2 Phenomena as Natural Kind or as Conceptualizations

Although most authors discussed in this chapter agree in broad terms what the characteristics of a phenomenon are—noteworthy, reproducible—they still have very different ideas on what a phenomenon is ontologically. Some see phenomena as a real entity in the world; others see it as a conceptualization to work with. Brown's definition of phenomena is that "phenomena are abstract entities which are (or at least correspond to) vizualizable natural kinds" (Brown, 1994, p. 125). For Bogen and Woodward (1988) phenomena belong to the natural order of the world. This view—also called Scientific Realism—sees phenomena as real entities in the world; phenomena are as real as trees are. This also means that phenomena exist independently of investigation, they are in the world, waiting to be discovered (Bailer-Jones, 2009).

Bailer-Jones (2009), Hacking (1983), Rouse (2009) and Boon (forthcoming) see phenomena not as real entities in the sens of natural kinds, but as ontological creations or epistemological conceptualizations. They reject the idea that phenomena are entities out there in the world waiting to be discovered. According to Hacking, phenomena can be created in the laboratory by combining the right physical laws with the right boundary conditions. Phenomena are not "gods handiwork," waiting to be discovered; they do not exist outside of the apparatus (Hacking, 1983). Bailer-Jones sees phenomena in terms of their function, and their function is to have "the potential to be theoretically explained" (Bailer-Jones, 2009, p. 167). In her view, phenomena are conceptual means to an end and clearly not real entities. And because phenomena are conceptual means, they take shape in accordance to their function. "In order to capture a phenomenon, the phenomenon is modeled, and the way the phenomenon is modeled will influence how the phenomenon is defined" (Bailer-Jones, 2009, p. 170). For Rouse phenomena are needed to give conceptual understanding. Phenomena arise in our need to articulate. He views phenomena thus not from an ontological, but from an epistemological perspective. These ideas of phenomena as conceptual articulations connects with McAllister's view that the phenomenon is that pattern which you pick. The users of the phenomenon—the scientists—create the phenomenon, by providing conceptual understanding.

Massimi (2007) takes an interesting stance between the two positions of phenomena as natural kinds and phenomena as conceptualization. She connects the ontological status of a phenomenon to is epistemological purpose and views phenomena from a Kantian perspective.

> According to this mild form of realism, phenomena are neither ready-made in nature nor mere images of real objects, but they are instead objects of experience, that is, the only objects we have epistemic access to and scientific knowledge of. … Phenomena as objects of experience are all that we can meaningfully talk about and have scientific knowledge of.

(Massimi, 2007, pp. 240-241)

These different interpretations of the ontological and epistemological status of a phenomenon give it a different value. If a phenomenon is a natural kind and a real item in the world, it has intrinsic value. Is it seen as a conceptualization, then its value is in its function; for instant the function of finding a theory. To these two ontological positions a third can be added, that of Glymour (2000). For him phenomena have no function, and therefore no value. This shows that the idea of what a phenomenon is, is connected to what the different authors think a phenomenon does. In the next chapter I will explain how the different vision on how the world—and especially science—works connects to what the different philosophers thinks the characteristics of a phenomenon are.

3 Ideas About the World, Ideas About Science, and Ideas About Phenomena

In this chapter I will address how the different accounts of phenomena given by the various authors link to their epistemic and ontological visions of the world, and therefore of science. The authors have very different ideas on how knowledge relates to the world—epistemology—and how the world is—metaphysics and ontology. In this chapter I will unravel these different ideas and link them to the accounts of phenomena mentioned in the previous chapter and the case study I will present in chapter 4. Some characteristics of phenomena are interconnected. This makes that if an author endorses on one characteristic, other characteristic will automatically follow.

I will start with discussing phenomena in the realism/empiricism discussion. Here I will show that many of the ideas about phenomena are linked to ideas about causality. Then I will discuss the need for phenomena and whether phenomena are physical entities or language concepts. This chapter will be concluded with the philosophical views on what the function of a phenomenon is.

3.1 Metaphysical Issues: Realism vs. Anti-Realism

In studying how the different epistemic views connect with ideas about phenomena the discussion of realism versus anti-realism is especially important. Some of the features appropriate to phenomena cannot be seen separately from the degree of realism ascribed to phenomena by the different philosophers. The question at hand here is whether phenomena exist as real objects in the world. Realists about phenomena[xxix] believe that phenomena exist out there in the world, anti-realists do not. According to Newton-Smith (1981) scientific realism has three ingredients: one ontological: depending on how the world is theories are either true or false; one causal: a true theory implies that there are entities causing a phenomenon; and one epistemological: we are justified to believe these theories and entities are real. Scientific realism is the idea that what scientific theories tell us about the world is literal and true and the entities they envision are real. Against scientific realism two forms of anti-realism can be formulated. The first form says that what science tells us, or aims to tell us is true, however not literally true, but properly true. This argument is called instrumentalism.

The second form says that what science tells us, or aims to tell us is literal, but not true; and is called empiricism (Hacking, 1983; Van Fraassen, 1976). In the coming discussion about realism, I take the empiricism stance for the anti-realism position.

3.1.1 Observability

In section 2.1.1 I talked about observation. A very important question in the discussion between realists and empiricists is whether something is observable. When we look at a tree and say that we observe that tree, this will not lead to much discussion, at least not in the philosophy of science. But when we perform the experiments such as described in 2.1.1 and claim we have observed solar neutrinos, this statement is not uncontroversial. The actual problems starts when we look at the reflexion of a tree in the water, do we then observe the tree? This discussion about observability is relevant, because it is about what we can know to be true or false.

Bogen and Woodward claim that “data … for the most part can be straightforwardly observed” (B&W p305). This literally means that data can be directly registered by the senses. But if we go back to the solar neutrino example, we can conclude that the only thing we observe directly is the graph which represents the counts of the Geiger-counter. Van Fraassen states that there is data that can be observed and data that cannot be observed. We can directly observe a number of birds in a tree, but we cannot observe a number of solar neutrinos. For Van Fraassen, and the constructive empiricists who followed his footsteps, this distinction between observable en unobservable is relevant for determining truth. Observable for empiricists means observable to humans, which means that it is restricted to the human senses.

This distinction between observable and unobservable is one of the major points of debate between realists and empiricists—the first do not see a problem in unobservability. The dispute between realists and empiricists thus only concerns the realm of the unobservable phenomena. They both agree that observable data and phenomena can give truth; they only disagree on whether unobservable phenomena can. For both, observations are the basis of science. Although the distinction between observable and unobservable is essential to empiricism, this distinction is not always very clear. Is a very small bug that can be detected with the naked eye, but can only be seen clear with a magnifying glass observable or not? Even though Van Fraassen admits that there is no strict line to be drawn, he rejects the idea of a continuum. One might debate where the fence should be, but there should be a fence (Hacking, 1983; Ladyman, 2002).

3.1.2 Realism

Scientific realists say that the aim of science is to give us a literal, true account of how the world is. This means that if accepted scientific theories tell us that such entities as electrons exists, then we have good reason to believe that they exist. “Scientific realism says that entities, states and processes described by correct theories really do exist” (Hacking, 1983, p. 21). Solar neutrinos are as real as trees, if they are endorsed by theory. This implies that realists think the world is knowable. Specific theories can be found to be erroneous and will be replaced by better once, but we must believe that our best theories give us true and real knowledge about the world. And because of this we are justified to believe unobservable entities exist independent of our mind. As Van Fraassen describes the positions of scientific realism: “Science aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true” (Van Fraassen, 1980, p. 8).

Some realists also think that phenomena are real entities and out there in the world. This kind of realism is called direct realism. “There are external objects that exist independently of our mind and which we directly perceive with the senses” (Ladyman, 2002, p. 139). Bogen and Woodward and Brown seem to defend direct realism regarding phenomena. Bogen and Woodward see phenomena as “in the world” (Bogen & Woodward, 1988, p. 321) and Brown calls phenomena “general natural kinds” (Brown, 1994, p. 125). Phenomena for them are real entities and not just some conceptualization. This realist view makes that Bogen and Woodward and Brown think that there are finite number of phenomena (Bogen & Woodward, 1988); Brown even states there are relatively few phenomena (Brown, 1994). For these realists, phenomena are real entities in the world, like ravens are real entities in the world. And although you would not dream of counting all ravens in the world, in theory you could, because there is a finite number of them in the world; the same goes for phenomena. This also implies that some day we may have discovered all phenomena present in the world. Phenomena, for these realists, are indeed truly discovered—in the sense that they are uncovered. Because phenomena are entities in the world, they are already present in the world, waiting to literally be discovered. When scientist do an experiment, they do not create a phenomenon, but they lay bare what is there to be found.

Being a realist is not as black and white as the text above may indicate. One can be a realist about entities—believing that theoretical entities truly exist—but not a realist about theories—believing that independent of what we know theories are either true or false (Hacking, 1983). In section 2.6.2 I have explained that Hacking does not believe phenomena are natural kinds, but he is a realist about entities. His position is called materialism, which can crudely be described as: if you can spray it, it is real. The fact that we can manipulate entities like electrons makes that we have reason to believe they are real, even though we cannot directly observe them. In his book Hacking (1983) describes that his conviction of being a scientific realist comes from a friend of his, who told him that in an experiment they sprayed niobium balls with positrons or electrons to change their charge. “From that day forth I've been a scientific realist. So far as I'm concerned, if you can spray them then they are real” (Hacking, 1983, p. 23). Phenomena cannot be sprayed, for Hacking they are not natural kind but experimental creations, valuable for their function. This does not mean that he thinks phenomena are not real in the sense that we just imagine them; they are real effects that occur when a part of the world is manipulated, but they just do not exist on their own.

3.1.3 Empiricism

Just as scientific realists, constructive empiricists believe that theories tell a literal story about the world—not a myth or an analogy. They, however, do not think that we should believe this story to be true. For empiricists like Van Fraassen (1976) the aim of science is to save the phenomena. He uses the word ‘saving[xxx]’ to indicate something that is neither explaining nor describing, but something in between. For a theory to save a phenomenon, that theory must be empirically adequate to the phenomenon. Empirically adequate means that for observable phenomena the theories are true, but for unobservable phenomena that the theories give a good and coherent description of the structure of the world. “A theory is empirically adequate exactly if what it says about the observable things and events in the world is true—exactly if it ‘saves the phenomena’” (Van Fraassen, 1980, p. 12). The definition of constructive empiricism that Van Fraassen gives is: “Science aims to give us theories which are empirically adequate; and acceptance of a theory involves a belief only that it is empirically adequate” (1980, p. 12).

For empiricists the truth of the unobservable world is not knowable. This does not mean that empiricists forbid to make claims about the structure of the world, as some authors accuse them of (for instance Bogen, 2009). Empiricists can make statements based on unobservables, as long as they are not truth claims. In their idea of the distinction between data and phenomena, Bogen and Woodward (1988) claim that data are proof for phenomena in the world; they make a distinction between measured data and observed phenomena. Constructive empiricists do not see a fundamental difference here. Their slogan could have been 'to save that data-patterns' in stead of 'to save the phenomena'.

With these data, or data-patterns, we can prove theories, but this does not make a theory true; it only makes it empirically adequate. Proving the theory is what 'saves' the phenomena, which means that we cannot make a truth statement about unobservable phenomena. Therefore phenomena can never be natural kinds, but do have a functional value—they need to be 'saved' to prove theories. Bogen and Woodward use their data-phenomena distinction as an argument against Van Fraassen. "While we agree with Van Fraassen that a successful theory should be 'empirically adequate,' we do not accept his construal of this notion. Empirical adequacy, as we understand it, means that theories must 'save' or 'be adequate to' the phenomena, which for the most part are not observed, rather than the data which are observed" (Bogen & Woodward, 1988, p. 351). They deny Van Fraassen's problem with truth statements about phenomena. As said the distinction between phenomena and measured data is not a distinction that is made by empiricists, which means that their observable/unobservable distinction goes for data and phenomena alike.

3.1.4 Causality, Hume and Kant

McAllister (1997, 2003, 2004, 2009) is not a realist about phenomena. His position that phenomena are just that which you pick, makes that for him phenomena have no intrinsic value at all, but he is a realist about causality. This means that he thinks that all the phenomena one can pick from a data-set are caused by something in the world. I assume that Hacking (1983) shares this realism about causality; otherwise his idea of creating phenomena would not be possible. To be a realist about causality thus means that you believe that the connection between cause and effect is real. This is also called causal or indirect realism —"there are external objects that exist independently of our mind and which cause our indirect perception of them via our senses" (Ladyman, 2002, p. 141).

Causality has been a problem for philosophy, and for the philosophy of science in particular, since the time of Hume. Hume said that we cannot observe causality directly and we cannot prove it (Ladyman, 2002). But without it there would be no use to science. The idea of causality is an inductive principle. We experience causality all the time, but the fact that jumping up until now has always resulted in coming back down does not prove beyond doubt that this will also be the case the next time you jump up.

As said in 3.1.1 both realists and empiricists think observation is unproblematic, their differences concern the realm of the unobservable. In my view their real dispute concerns causality. Direct realists like Bogen and Woodward are also realists about causality. An argument for realism, and thus for causality, is the success of science and scientific progress. Science seems to work, therefore there must be a truth to it[xxxi]. Constructive empiricism has a problem with causality. It says that you can only make a truth statement about something you have observed yourself—you cannot rely on a causal chain for truth. This makes that their outlook on what a phenomenon is, is different.

> For scientific realists, phenomena are the matters of fact in nature which are explained and predicted by physical theories. According to this view defended by Bogen and Woodward, the phenomena are what the physicists call effects. … But for empiricists like van Fraassen, the phenomena of physics are the appearances, that is, what can be observed or perceived by mere sensory experience. From an empiricist point of view, there are no unobservable phenomena of physics.
>
> (Falkenburg, 2009)

Massimi (2007, 2008) wants to get past this discussion on causality by leaving Hume behind and make the Copernican Turn[xxxii] with us to a Kantian epistemology. This Kantian epistemology tells us that phenomena are not out there in the world, they are not empirical manifestations of what there is; but phenomena are conceptualizations made in our minds, based on a combination of our knowledge and sensory input from the outside world. Kant makes a distinction between seeing something—perception—and seeing something as a specific object—phenomenon. “A phenomenon is a conceptually determined appearance. ... Phenomena are appearances brought under the concepts of the faculty of understanding so as to make experience finally possible” (Massimi, 2008, p. 10).

This Kantian epistemology turns upside down two basic presumptions of both realist and empiricists, namely: facts are a representation of the world, and principles of logic and mathematics are true and independent of experience. Kant tells us that facts are not a passive representation in our mind, but are conceptualized. Also knowledge principles are a priori and give the preconditions for synthetic a priori knowledge (personal communication with M. Boon and handouts by M. Boon). According to Massimi (2007) phenomena are not out there in nature as real entities, nor are they mere images of real entities, they are objects of experience. We conceptualize phenomena with our mind on the basis of sensory input, experience and knowledge.

> To scientific realists, who believe that science aims to give us a literally true description of the way things are in nature, Kant’s conception of phenomena shows that we should believe, for instance, in gravitational attraction not because it provides the best explanation for the success of Newtonian mechanics in predicting the motion of free falling objects. Instead, we should believe in gravitational attraction because without it, we would not have the very same kinematics of uniformly accelerated free-falling objects that Galileo found, to start with.
>
> (Massimi, 2008, p. 35)

Bogen and Woodward (Bogen, 2009; Bogen & Woodward, 1988; Woodward, 1989, 2009) gave us the idea that data and phenomena are two distinct things. McAllister (1997, 2003, 2004, 2009) made the realization that phenomena are not out there in the world to be found. The world can only provide us with data and the scientists make the phenomena by picking one of the many patterns in the data. Hacking (1983, 1992) also made the conclusion that phenomena are not out there in the world, but are made by scientist in their laboratory setups. They all see that there is something wrong with the empiricist and realist picture of phenomena. These authors pretend to be beyond the realism/empiricism discussion, but none of them tends to turn to Kant, accept Massimi (2007, 2008)[xxxiii]. Realists say that one can have true knowledge of all phenomena, empiricists say that one can only have true knowledge of observable knowledge, but Kant says that we cannot have true knowledge of phenomena since they are conceptualized by our own mind.

3.1.5 Are Engineering Scientists Realists?

The above discussion about realism is between philosophers, but what about the scientists? One argument sometimes given for scientific realism is that all scientists are realists and since they know science, we should follow them. But are they all realists? And do they have to be realists to do science?

Bogen and Woodward (Bogen, 2009; Bogen & Woodward, 1988) seem to agree to the idea that scientific realism is the explanation for the success of science. If the laws and phenomena of science wouldn't be true, how then can you explain the fact that it works so well. They then turn this argument around and state that to be a good scientist, one must be a scientific realist, which does not follow. Another argument by Bogen (2009) for scientists being realists and not empiricists is that they try to explain the things they find. Empiricists would have them be impartial to an explanation, because these would not give truth. Bogen does have a point here. Most philosophers of science (Bogen & Woodward, 1988; Brown, 1994; Cartwright, 1983; Friedman, 1974; Newton-Smith, 1981; O'Hear, 1989; Schindler, 2006, 2009; Suppe, 1972; Van Fraassen, 1976, 1980; Woodward, 1989, 2009) connect the work phenomena do in science to proving the truth of theories, whilst for scientists explaining and structuring of phenomena is much more important (Bailer-Jones, 2009; Bogen, 2009; Hacking, 1983).

I do believe that most scientists are realists about entities, or materialists as Hacking (1983) calls it. If they can manipulate entities scientist have good reasons to believe they are real. I do not believe that scientists necessarily are realists about theories and phenomena. First of all, scientific laws do not exist independent of the world. Phenomenological laws and phenomena can be very specific to experimental setups, the system, and the conditions; they are not independent of the setting where they hold truth (Basu, 2003; Hacking, 1983; Kroes, 1994). Also, as I will show in my case study in Chapter 4, scientists are flexible with applying models and phenomenological laws and will try things that work in another field of study to get results in their own. Engineering scientists might be qualified more as pragmatists than as realists when it comes to phenomena and theory.

3.2 The Need for Phenomena

At he basis of this thesis is the distinction between data and phenomena made by Bogen and Woodward (1988). This might show my predisposition towards the idea that this distinction is relevant and phenomena are needed to give a good account of science. And although most philosophers mentioned in this thesis will agree with me, there are those who do not. In this paragraph I will connect the proposed need for phenomena with the epistemic ideas of the philosophers.

3.2.1 There is No Need for Phenomena

As mentioned in 2.5, one philosopher clearly sees no need for phenomena: Glymour (2000). The reason for this is that Glymour's philosophy of science is a form of probability theory. The idea of probability theory in the philosophy of science is a reaction to the problem of induction. Induction can never give truth, a sample study can only provide a statistical chance. Probability theories try to give mathematical formulas to calculate degrees of belief. For Glymour the distinction between data and phenomena is nothing more that that between sample and population structure.

> The Bogen and Woodward version of the distinction between data and phenomena relies heavily on supposed differences in the epistemic status of data and phenomena. … This supposed difference is illusory: certain entities have both the epistemically foundational status of data and are susceptible of explanation by theory in just the way phenomena are. … So sample statistics have the same epistemic status as the observation reports comprising the data in the sample. But it is precisely this sort of statistical feature of data sets that are explained by scientific theories.
>
> (Glymour, 2000, p. 33)

I agree with Glymour when he argues against Bogen and Woodward's (1988) idea that phenomena are natural kinds, but to banish the idea of phenomena completely leaves him with only statistics. This idea, that there is only statistics, is a very minimal vision of science. It is true that scientists use a lot of statistical analysis to process their data, but it is not true that only statistics can magically give us a theory. Glymour does acknowledged that there is a kind of theory-drivenness in choosing what kind of statistics to pick. I would want to counter Glymours standpoint with McAllister. McAllister (1997, 2009) sees that there is a infinite number of patterns in a data-set and that the outcome of the analysis of that data—which is mostly statistical analysis—depends on what you were looking for in the first place. But the fact that a scientist can choose which pattern is relevant and statistics is used to process it, does not make the outcome—the phenomena—less relevant.

Also Van Fraassen (1976, 1980) sees no relevant epistemic difference between data and phenomena. The empiricists position, or Semantic View, center the activities of scientists around proving theories. Experiments give data, which is interpreted and formed into a data model or data structure. The theory or axiom that has to be proven is modeled into a theoretical model. These two models are compared to see if the data fits the theoretical model, if this is true, the theory is proven. All scientist need to verify—or falsify—their theories is data. In this process there is no room, and no need, for phenomena. Phenomena are only there to be saved, once the theory has been proven.

Like Glymour, Van Fraassen also has a quite minimal vision of what science is and what science does. He only goes into the proving of theories. As will be made clear in the case study in chapter 4, proving theories is not the main activity of engineering science. Engineering science is much more concerned with improving materials, construction and machines. This search for better, stronger, lighter, more flexible ways of engineering makes that it has a great focus on harnessing phenomena—both the desired and the undesired.

3.2.2 There is a Need for Phenomena

Bogen and Woodward (1988) caused a small revolution in the philosophy of science by giving phenomena center stage. Their argument—mostly against Van Fraassen (1976)—is that science does need phenomena to come from data to theory—phenomena are an indispensable part of the context of discovery. They show that data and phenomena are indeed ontologically different. Data belong to a specific experiment and always have an error margin. Data can be the evidence for a phenomenon, this phenomenon in turn can be evidence for a theory. Theories and hypotheses predict phenomena and not data. Data are idiosyncratic to a specific experimental context, phenomena are not. Therefore Van Fraasses idea that there can be a direct step from a data structure to a model of a physical system is not possible, because this model is not compared to the data, but to the phenomena.

But Bogen and Woodward were not the first to give credit to phenomena. Hacking (1983) showed that we need phenomena to intervene. The phenomenon is what scientist try to create in their experiments and what they try to manipulate. “Traditionally scientists are said to explain phenomena that they discover in nature. I say that often they create the phenomena which then become the centerpieces of theory” (Hacking, 1983, p. 220). For Hacking phenomena are a starting point in science. They can be predicted, but often they are found incidentally—to Hacking it does not really matter how the idea of the phenomenon arose. This means that “a phenomenon could well be an anomaly rather than any known regularity” (Hacking, 1983, p. 222). Once the idea is there, the phenomenon will be the basis for the research.

Bailer-Jones (2009) shares Hacking's vision. She suggests to identifies phenomena with something that has the potential to be explained theoretically. For Bailer-Jones and Hacking phenomena are relevant in the context of discovery. She also agrees with Bogen and Woodward that there is a critical distinction between data and phenomena. She focuses here on modeling. It is not the data that can be compared to the theoretical model, but the phenomena.

Bogen and Woodward see a need for phenomena in the context of justification and Hacking and Bailer-Jones see a need for phenomena in the context of discovery. They might see a different reason for the need for phenomena, they all—and many other philosophers with them (Basu, 2003; Brown, 1994; Kroes, 1994; Schindler, 2006, 2009)—connect phenomena with theory. Either phenomena are used to prove theories, or they are used to discover theories. As I will show in my case study in Chapter 4, in engineering science phenomena are often the focus of study, but not with such a strong focus on proving or discovering theory. Engineering science is about the understanding, harnessing and manipulating of phenomena to improve upon construction, materials or machines. The study of phenomena is not guided by the wish to prove theories, but by the wish to understand phenomena and the systems they occur in, so they can be used.

Massimi (2007, 2008) shows us that we cannot do science without phenomena, because the moment we observe data our mind makes an interpretation on the basis of our knowledge and experience. From her Kantian perspective there cannot be just data once your mind has perceived it. Our minds create phenomena and when we articulate our ideas about the data, the phenomena are out there. Thus there can never be any kind of science without phenomena.

3.3 *Physical Phenomena or Phenomena in Language*

But then, if we follow Massimi's Kantian epistemology where does the phenomenon reside? Is there a physical phenomenon, or is it just a linguistic expression of a concept of the mind? In this paragraph I will explore whether phenomena are pure linguistic concepts or whether they are part of the external world.

3.3.1 Are there Phenomena Out There?

The question whether phenomena are out there is a question concerning the ontological status of phenomena. As explained in 2.6.2 and 3.1.2, Bogen and Woodward think of phenomena as part of an external world, as being out there and belonging to the natural order itself. Brown (1994), who describes phenomena as natural kinds, shares this idea. This idea that phenomena are out there coincides with scientific realism. But scientific realists are not the only ones who envision phenomena as real existing entities. For the empiricists observable phenomena are also out there in the world. If we can perceive them with our senses they must exist out there and be real. When we cannot directly perceive them—in the case of unobservable phenomena—we must reserve judgement. As said in 3.1.1 and 3.1.4 realists and empiricists share the idea that empirical research of the outside world gives knowledge of that world.

Hacking (1983, 1992) is a realist about entities, but he believes that phenomena are construed[xxxiv]. This means that phenomena are not out there waiting to be discovered, but can be made real. With the right mixture of instruments and under the right conditions, a phenomenon will present itself. As Cartwright (1998) describes it, nature has the capacity to produce phenomena. Phenomena do not exist in nature as entities or natural kinds, but will arise if the preconditions are met. The phenomena are not out there, but their capacities are. But once the phenomena are created, they exist as real ontological entities.

Massimi's (2007, 2008) Kantian perspective says that phenomena are conceptualized in our mind, but this does not mean that there is no connection to the world. Not just anything can be conceptualized, the world offers conditions of possibility and boundaries. These preconditions are out there, they are what we perceive. The phenomena we conceptualize are thus not free form, but directed by the outside world. Cartwright thus says that the physical production of a phenomenon is bound by the way the world is, while Massimi says the same for the conceptualization of a phenomenon in the mind.

3.3.2 Phenomena as Conceptual Articulation

Besides a physical artifact a phenomenon can also be interpreted as a linguistic, or epistemic concept. This means that it is something that is articulated in language and can give knowledge. Rouse (2009) goes into the idea of conceptual articulation by combining philosophy of science with epistemology. He says that "What conceptual articulation enables us to do, is to entertain and express previously unthinkable thoughts, and to understand and talk about previously unarticulated aspects of the world" (Rouse, 2009). According to Rouse we have to articulate a phenomenon first for it to exist. A phenomenon is not just a pattern in nature. "What makes natural and experimental phenomena meaningful, I suggest, is that the pattern they embody is understood to refer beyond itself, in ways that are informative about a broader range of actual or possible occurrences" (Rouse, 2009). To grasp a phenomenon thus means that we have to understand what is happening in more complex or less accommodating settings, without limiting the scope of application of the relevant concepts.

For Rouse conceptual articulation is the real achievement of science, it is what it is all about. "The question, that is, concerns how we articulate and understand relevant conceptual content rather than how we justify specific judgments that employ it" (Rouse, 2009). Science as focusing on cognitive achievements for him is something dynamic. He focuses on how phenomena get their meaning and how this is connected to their use and context, his vision of conceptualization is one of evolution (M. Boon in a comment on Rouse).

Conceptual articulation is thus not a 'point and name'-game as McAllister's (1997, 2003, 2004, 2009) pattern choosing or van Fraasses (1976, 1980) idea of saving phenomena might suggest. Conceptual understanding as Rouse suggests it is much closer to Massimi's (2007, 2008) Kantian idea of conceptualization: conceptualization is giving meaning to something. Conceptual articulation of a phenomenon means that it receives meaning and context. The language used to express a phenomenon is connected to its theoretical context (Basu, 2003). Because a concept has meaning, it goes beyond just a name; it involves more information—a concept incorporates hypotheses. To go back to the solar neutrino example, to suggest that the blobs on the graph are solar neutrinos means that it is made part of something bigger. The conceptual articulation as 'solar neutrino' connects the phenomenon to a bigger picture which involves all kind of knowledge and hypotheses about the sun and about neutrinos. A lot of other information can be deduced and induced from a concept. This also means that a concept can fail, like a theory can (Rouse, 2009).

The empirical idea of phenomena as being out there as objects has limitations when it comes to meaning. Bogen and Woodward (Bogen, 2009; Bogen & Woodward, 1988; Woodward, 1989, 2009) and Van Fraasses (1976, 1980) adhere to this empirical idea and tell us that phenomena should not be seen as mini theories. As a result conceptualization becomes a problem. Phenomena have no conceptual content nor context. This makes the critique of Glymour (2000) and McAllister (1997, 2009)—that all that remains then is data—possible. Bogen and Woodward (Bogen, 2009; Bogen & Woodward, 1988; Woodward, 1989, 2009), Hacking (1983, 1992) and Bailer-Jones (2009) see this problem and try to get content en context back in via the back door which makes them run into some problems in this area. Massimi (2007, 2008) and Rouse (2009) suggest that you do indeed have much more than just data. With phenomena as conceptual articulations you incorporate much more information. But this information is not static since it is a hypothesis, which means that it is not certain and can fail.

3.3.3 Creating Phenomena

The risk you run if phenomena are seen only as conceptual articulations is that you get too far away from the laboratories. I agree with Rouse that conceptual articulation is needed to give meaning to phenomena, but I also think that articulating a phenomenon alone is not enough to 'create' a phenomenon; the ontological understanding is missing. I suggest a marriage between the conceptual articulation of Rouse (2009) and the experimental construction of physical phenomena Hacking (1983, 1992) advocates.

I follow Hacking in that phenomena are physically constructed in a particular experimental context. This experimental construction is based on intervening[xxxv], there is work involved. But I do think that Hacking's view in isolation is too narrow. He gets stuck in the empirical name-giving idea, which makes it hard for him to give epistemic context to phenomena. I also adhere to Rouse's idea that phenomena need to be conceptually articulated to receive meaning. Calling something a specific phenomenon is more that just giving it a name; it is connecting it to a broader context—conceptualizing is making a hypothesis. But his idea too is to narrow on its own, for he misses out on the experimental context.

I believe that phenomena are created along two sides: the side of the experimental construction and the side of conceptual articulation. This two sided vision incorporates both the epistemic and experimental context. Phenomena are constructed experimentally by intervening and conceptualized by hypothesizing and modeling at the same time. This hypothesizing and intervening is done in interaction, see Illustration 2: Combining Rouse and Hacking. Phenomena are not found by observation and then named. Phenomena are created in an interaction between intervening and hypothesizing, between experimentally constructing and conceptually articulating. As Boon and Knuuttila (Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming) point out, this is done in modeling.

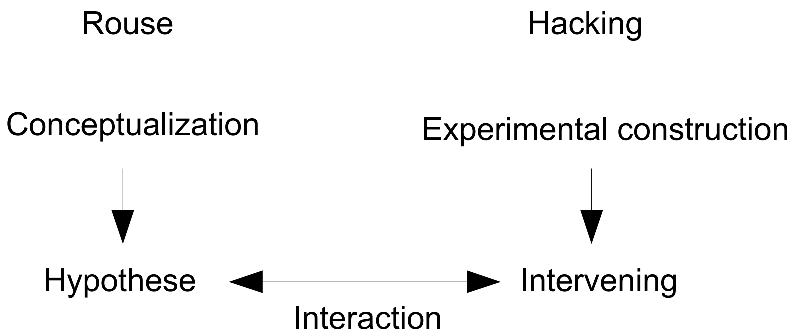

Illustration 2: Combining Rouse and Hacking

Phenomena are not out there in the world, but their preconditions are. Phenomena are created in an interaction between conceptual articulation en experimental construction, but not without restrictions. It is not done in free form. The outside world restricts the conceptualization of a phenomenon as well as the experimental creation.

3.4 The Function of a Phenomenon

In this chapter I have connected the way philosophers of science see phenomena to their philosophical conviction. I have discussed phenomena in the light of the realism discussion and explored whether phenomena are part of the outside world or not. Now I will discuss the function of a phenomenon. If we leave Glymour (2000) out of the discussion, the consensus is that there is a need for phenomena. The fact that phenomena are needed means that they have a function. If they would have no function, there would be no need for them—as is Glymour's argument. What I call theory in this section can also mean axiom, hypotheses, theoretical law or phenomenological law, depending on the context.

3.4.1 Phenomena as Theory-Provers

As has become clear from what I have written above, almost all philosophers of science connect phenomena to theory. Most do this explicitly (Basu, 2003; Bogen, 2009; Bogen & Woodward, 1988; Brown, 1994; Cartwright, 1983, 1998; Friedman, 1974; Hacking, 1983, 1992; Kroes, 1994; McAllister, 1997, 2003, 2004, 2009; Schindler, 2006, 2009; Suppe, 1972; Van Fraassen, 1976, 1980; Woodward, 1989, 2009), some do this more implicitly (Bailer-Jones, 2009; Falkenburg, 2009; Massimi, 2007, 2008; Rouse, 2009). The most common functions given to phenomena in connection to theory are: phenomena as proof for theories and phenomena as manifestations of theories. These two functions are connected. If you agree that a phenomenon is a manifestation of a theory, then finding the phenomenon will prove the theory.

A more indirect way to connect phenomena with theories is saying that the function of a phenomenon is to be explained or to arouse curiosity (Bailer-Jones, 2009; Hacking, 1983). Saying that a phenomenon can be explained, means that it can be explained by something. It is about answering the 'how'-question. This something a phenomenon can be explained by, is most commonly a theory. We see that a phenomenon occurs and we want to know how this happens, thus we come up with an explanation; this explanation we call a theory. A next step can then be, to find more phenomena—or the same phenomena again—to prove this theory. Causing inquisitiveness as a function of a phenomenon also points to theories. Curiosity is about answering the 'why'-question—why does a phenomenon occur. As with the 'how'-question, the answer lies with theories. Phenomena can cause questions—both 'how' and 'why'-questions—and the answers to these questions are given by theories.

3.4.2 Phenomena as Tools

This theory-centered vision of phenomena will indeed be correct in certain parts of science—the more theory centered parts of science, like fundamental physics. For the part of science I focus on in this thesis—engineering science—it is only a partial truth. Theories play an important role in engineering science, but phenomena play an even bigger role. The function of a phenomenon in engineering science can be connected to theory as described in 3.4.1, but as I will show in my case study in the next chapter, the function of a phenomenon can also be something else.

Phenomena in engineering science can also arouse curiosity, not so much to the theory behind it, but to the uses it can have. It is not about the simple ‘how’ or the ‘why’-questions, it is about the more elaborate ‘how can I use this,’ ‘how can I improve this,’ or ‘why doesn't this work’-questions. It is not about answering theoretical questions, but answering functional questions. It is about ‘what we can do with it?’ The function phenomena have in engineering science is use and functionality. Engineering scientists try to to harness the wanted phenomena and eliminate the unwanted phenomena to improve upon their constructions, materials, or machines.

An important aspect here is that phenomena do not need to have a theoretical base to be used. The powers of steam where used long before they where theoretically understood. The case study in the next chapter will also show that engineering sciences are about using phenomena to make advancements instead of proving theories. The subject of the case study is the work engineers do in the field of heat distribution in fiber-reinforced composites. The engineering scientists explore phenomena which are based in fundamental theory, but also new and complex phenomena, which are not fully understood or have no theoretical basis.

The fact that engineering scientists conceptually articulate and experimentally create phenomena makes them go beyond just trial and error. For a phenomenon to be used in engineering science it has to be physically and epistemologically created to have a function. Phenomena can thus be seen as functional entities. By means of modeling these functional entities one can understand them and make calculations about them. Data can be collected about a system—this can be both measurements and causal characteristic. In these data, phenomena can be discerned—like McAllister (2009) says, the choice is up to the scientist. Then these phenomena are modeled. The ‘choosing’ and modeling of the phenomena coincide with the process of conceptualizing—the phenomena is placed in a bigger context. These models can be used to think about intervene with the systems governed by the phenomenon that is inverstigated. Conceptualizing and modeling go hand in hand. Models of phenomena are epistemic tools (Boon & Knuuttila, 2009).

3.4.3 Phenomena in Service of the Target System

Boon (personal communication with M. Boon) describes engineering science as being about the ‘target system’. The target system is that which is under study, the material, process, machine or construction; in my case study that would be the fiber reinforced composites, in which the heat transfer occurs. In a target system many different phenomena can be discerned. The study of these phenomena is always in service of better understanding of, or creating better ways to intervene with the target system. The target system is a part of the conceptual reference of a phenomenon.

In engineering science, phenomena do thus indeed cause curiosity, but curiosity with a purpose. This curiosity is about use and function. Research into phenomena is in service of developing the target system (personal communication with M. Boon). Engineering scientists are less interested in proving theories, and more interested in understanding and improving their target system. But this does not mean that for engineering scientists phenomena are objects you can point at, in the Bogen and Woodward (1988) sense. Engineering scientists give epistemological value to phenomena by articulating them in the context of the target system. Phenomena are made by the knowledge and understanding one has about them, without actually seeing them—it is epistemic differentiating.

That both physical phenomena as well as the conceptual articulations of phenomena are valued for their function will also show from the case study in the next chapter. Here it is shown that the marriage between Hacking's (1983) experimental creation and Rouse's (2009) conceptual articulation is every day practice in engineering science. Phenomena are isolated and created as Hacking describes it, but at the same time they are made part of a bigger hypothesis about the target system by conceptually articulating them.

4 Phenomena in Practice

In Chapter 2 and 3 I have presented an overview of ideas about phenomena in the philosophy of science. The philosophers of science focus mostly on fundamental sciences; which in their view are focused on theory-creation. But since this thesis is about phenomena in the *engineering* science, this does not give a complete picture; the viewpoint of the engineering scientist is missing. Engineering scientists do not generally write articles about what they think phenomena are and what the work is phenomena do in their scientific research. A way to investigate what engineering scientists think about phenomena and how they use them, would be to interview them. Another way to explore this is to reconstruct what the work is phenomena do in the engineering sciences.

To do this I will examine five articles in engineering science which study the characteristics and qualities of fiber reinforced composites. The reason I have chosen this particular field and these articles is that I have studied them for my bachelor in Mechanical Engineering. I consider this field quite typical for what is going on in engineering sciences. First I will introduce the field of study so it is clear what the different authors are talking about. Then I will discuss the different articles and filter out what the different phenomena under study are and how they are observed, interpreted, and used. This will lead me to a conclusion about what the work is that phenomena do in engineering science.

I am fully aware that a small case study like this one is not a blessing from the sky. This is a very small observation of one specific field of engineering science; although I picked this field because I think it is typical. It of course is only one example and does not necessarily represent how the whole of engineering science works. Like Bailer-Jones (2009) said: “No matter how good and how representative examples are, they are only examples and not a complete set of cases, rather like the problem of induction” (p. 132). This case study is thus a small insight in how engineering scientists use phenomena, but it is not all encompassing.

4.1 Temperature Distribution in Fiber-reinforced Composites

Throughout this case study I will number the articles and the corresponding phenomenon to make it easier to keep track of them. The titles of the articles studied in this case study are: (1) *Temperature distribution along a fiber embedded in a matrix under steady state conditions*

(Esparragoza, Aziz, & Damle, 2003); (2) *Thermal conductivity and mechanical properties of various cross-section types carbon fiber-reinforced composites* (Shim, Seo, & Park, 2002); (3) *Transverse thermal conductivity of fiber reinforced polymer composites* (Tavman & Akıncı, 2000); (4) *The disturbance of heat flow and thermal stress in composites with partially bounded inclusions* (Lekakis, Kattis, Providas, & Kalamkarov, 1999); and (5) *Dependence of the transverse thermal conductivity of unidirectional composites on fiber shape* (Tai, 1998). As is clear from these titles the subject under study is temperature distribution in fiber reinforced composites. What does that mean?

Composites are materials that are composed of two or more other materials that are still recognizable in the composite; they do not merge, but maintain their individual material properties. A nice example is reinforced concrete; a material in which in iron rods (the filler) are embedded in concrete (the matrix) Carbon fiber reinforced plastic is another example; it this case strands of carbon are the filler, and plastic is the matrix. The reason to create composites is that they combine the qualities of the different materials. In carbon fiber reinforced plastic, for instance, plastic is light weight and flexible, whereas carbon fibers have great tension strength but are brittle; together they produce a material that is light, strong and tough. The filler can be pellets or fibers. Fibers can be configured in a woven structure, longitudinal next to each other or randomly. A problem in constructing composites is creating a good distribution of fibers and matrix, and a good fixation between them. Pockets of air between the fibers and the matrix can occur during fabrication and prevent a good connection between matrix and fiber. This in turn can disrupt a good transfer of tension and heat through the material. An uneven distribution of fibers and matrix can lead to uneven material properties throughout the material. Because a composite consists of two or more materials which are still recognizable, the properties of both materials influence the property of the composite. However, this does not mean that the characteristics of the composite are simply the sum of the different parts.

The articles used in this case study focus on temperature distribution and heat dissipation in composites. For some construction purposes the dissipation of heat can be a serious constraint, for instance in a friction situation. Friction creates heat which must be dissipated in order to prevent fire or melting. Most plastics have very bad heat conduction properties—they melt at low temperatures and their heat conduction and dissipation is bad—while those of carbon fibers are reasonably good—their ignition temperature is very high and it has a good heat conduction coefficient. The possible pockets of air between fibers and plastic have the worst heat conduction of them all; air is a very good heat isolator. Since the heat conductive properties of composites are not the sum of the properties of the different components, they are hard to predict. Because of this, values have to be determined experimentally. With these experimental results models can be made, which in turn can help make predictions. Also experimental outcomes are compared to the predictions of mathematical models and computer models to improve the prediction qualities of these models.

4.2 The Studied Articles

In the analysis of the studied articles I will make use of the following concepts, which I briefly define:

- *Experimental data* are data that have been acquired via an experiment. They can be measurements or causal relations.
- The *target system* is the system in which the phenomena occurs. In this case study the target system is the composite. This material is the context in which the phenomena are studied.
- *Phenomenological laws* are laws of nature which are not derived from fundamental theory, but from experimental findings. They are a description of the phenomenon.
- *Models* are theoretical interpretations of phenomena which make making calculations and thinking about intervening possible (Bailer-Jones, 2009). Models can be based on fundamental theories or on phenomenological laws.
- The *external conditions* are the conditions that bring about and/or affect the phenomena. As Hacking (1983) said, these conditions are a factor in whether or not a phenomenon will occur. They are the external boundaries[xxxvi] provided by the world which will determine the conditions of possibility for the physical phenomena.
- The *phenomena* are the objects of study in these articles.

What I want to show in this case study is how phenomena in engineering science are used in a specific way and with a specific purpose. Phenomena are not studied in isolation, they are studied in the context of the target system. This way of approaching phenomena makes that they are always specific to the target system, which has an influence on the way the phenomenon is experimentally created en conceptually articulated. What phenomena are in engineering science is defined by the work they do. They are not valuable in themselves, their value is represented in the work they do.

The phenomena studied in these articles are: (1) “the temperature distribution along a high thermal conductivity bar (fiber) embedded in a low thermal conductivity half-space (matrix) subjected to a axial differential of temperature” (Esparragoza, et al., 2003, p. 429), (2) the thermal conductivity and mechanical properties “of carbon fiber-reinforced composites with different fiber cross-section types, such as round, C, and hollow-shape” (Shim, et al., 2002, p. 1881), (3) “transverse thermal conductivity of high density polyethylene reinforced with chopped strand glass fiber mat” (Tavman & Akıncı, 2000, p. 253), (4) “the two-dimensional heat conduction and thermoelastostatic problem for a composite material containing a curvilinear inclusion with an interface crack” (Lekakis, et al., 1999), and (5) “composite transversal thermal conductivity for unidirectional elliptical and rectangular cross section fibers” (Tai, 1998, p. 1491).

I will analyze the articles on the basis of nine aspects. Guided by these aspects I will try to extract the relevant information: (i) the phenomena; (ii) the model type used; (iii) the measurable physical variables; (iv) the function or intended epistemic purpose of the model; (v) the relevant physical circumstances and properties; (vi) how the phenomenon is experimentally brought forward; (vii) the idealizations, simplifications, and abstractions made; (viii) the knowledge and principles used in constructing the model; and (ix) the justification of the model (based on Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming; and in personal conversation with, and in handout from M. Boon)[xxxvii]. Not all of these aspects have to be present in every article. For instance, if there are no experiments done, (iii) and (vi) will not be present.

Luckily engineering scientists are much clearer in their titles and abstracts about what they are doing than most philosophers. It is therefore quite interesting to start by looking at the abstracts—their description of what they are going to do. These abstracts show us quite clearly what the author is about to do and how the author intends to do it. It also shows what the studied phenomena are, how they are modeled and what the subject under study, or target system, is. To show this I will quote the abstract and will comment next to it, which of the nine aspects I see in the abstracts. After discussing the abstract I will go into the aspects not mentioned in the abstract.

4.2.1 Temperature Distribution Along a Fiber Embedded in a Matrix Under Steady State Conditions

The following abstract by (1) Esperragoza, Aziz and Damle (2003) clearly states the phenomena under study, the external conditions, the models used, and the error.

The temperature distribution along a high thermal conductivity bar (fiber) embedded in a low thermal conductivity half-space (matrix) subjected to an axial differential of temperature is studied.	The phenomenon (i)
It is assumed that the fiber and matrix are perfectly bounded along the entire interface between them. The system is assumed to be in steady state condition and no heat is generated internally.	The idealizations (vii) of the physical circumstances (v)
An approximated analytical solution to the problem based on the heat conduction equation, the principle of conservation of energy and the idea of boundary layer is presented.	Knowledge an principles(viii) An analytic model (ii)
The problem is also solved numerical by means of the finite element method using commercial software.	A numerical model (ii)
The results obtained by both approaches, analytical and numerical, are compared. The discrepancy between the two approaches appears very small in most of the cases although substantial relative error can be found at specific points in specific cases.	The justification of the models (ix)

(1) (Esparragoza, et al., 2003, p. 429)

(1) Esparragoza et al. model their system in two ways: with an analytic—or mathematical—model and a numerical—or computer—model and compare these two models (ii). Both of these models are based on fundamental theories and phenomenological laws, not on experimental data. These models are constructed by means thermodynamical laws applied to an idealized hypothetical system (viii). The analytical model is a based on mathematical derivations of the energy balance for an ideally shaped fiber, and of the thermal conductivity in the perfectly bounded boundary layer. The numerical model is based on the Finite Element

Method in only one plane since the ideal system is assumed to be axisymmetric. The models are justified by comparing them to each other (ix). There is no experiment done, and therefore there is no comparison with experimental data. They do however advise to check their models against experimental data.

Their goal is to make better models to predict the heat distribution in composites. The models in this article are used as epistemic tool; with them (1) Esparragoza et al. hope to pave the way to solve a host of other problems. "This problem provides the foundations to understanding other problems such as the heat dissipation in a fibrous composite, and it is also a necessary prelude to thermal stresses in the fiber and matrix due to the mismatch in the thermal expansion coefficient between the constituent materials" (1) (Esparragoza, et al., 2003, p. 430) (iv). This shows that the focus is not on theory proving or theory finding, but on understanding the phenomena that determine or deteriorate the functioning of the target system; in this case the composite material. And this understanding is given by models.

4.2.2 Thermal Conductivity and Mechanical Properties of Various Cross-Section Types Carbon Fiber-Reinforced Composites

Also the abstract by (2) Shim, Seo and Park (2002) is very clear. It states the phenomenon that will be compared, the experiment, and the outcome.

In this work, to study the characteristics of carbon fiber-reinforced composites with different fiber cross-section types, such as round, C, and hollow-	The phenomenon (i)
shape, the thermal conductivity and mechanical properties were investigated and compared. The	The measured physical variables (iii)
thermal conductivity was measured by means of steady-state method to the parallel and perpendicular direction of reinforced fibers The mechanical properties were evaluated by a variety of test methods i.e. flexural, interlaminar shear	How the phenomena was experimentally brought forward (vi), the physical circumstances (v), and the measured physical variables (iii)
strength, and impact strength. As a result, it was found that the thermal conductivity was greatly depended on the cross-section type of reinforcing	The physical circumstances (v)

fibers, as well as, the reinforcing orientation. Especially, the anisotropy factor ($k_{//}/k_{\perp}$) and the thermal diffusivity factor ($\alpha_{//}/\alpha_{\perp}$) of C and hollow-type carbon fiber-reinforced composites showed	The measured physical variables (iii)
about two times higher values than those of round-type one. Also, the mechanical results showed that C and hollow-type carbon fibers-reinforced composites had higher values than those of round-	The physical circumstances (v)
type one in all mechanical tested[xxxviii]. These results were probably due to the basic properties of non-circular (C and hollow-type) carbon fiber which can improve interfacial binding forces and widen interfacial contact area between reinforcement and matrix, resulting in effectively transferring the applied stress. (2) (Shim, et al., 2002, p. 1881)	The knowledge and principles used (viii)

The goal of (2) Shim et al. is to extract the data from the different phenomena occurring in carbon fiber reinforced composites with different cross-sections. For their experiments they use Epotoho YD-128 epoxy resin reinforced with carbon fibers. The specimens where made especially for the experiments. As a knowledge base for the making of these measurements phenomenological laws and the understanding of the working of the lab equipment is used. For instance, “for the measurement of the heat conductivity, the principle of the measurement was based on the heat transfer of Fourier's law. … For the investigation of mechanical properties, Instron Model 1125 Tester was used to measure flexural properties of the composite according to the ASTM D-790” (Shim, et al., 2002, p. 1882) (viii).

In this article the phenomena are not explicitly modeled (ii), but the phenomena here are directly conceptualized in language by connecting them to hypotheses about the structure of the material. This article can be interpreted as an experimental verification of models and hypotheses about the phenomena existing in this field of study (iv). “The thermal conductivity, as well as, the mechanical properties of the fiber-reinforced composites greatly depends on the micro-molecular orientation controlled by precursors and cross-sectional geometry or cross structures of the reinforcement” (2) (Shim, et al., 2002, p. 1881). It can thus be said that they justify previously made models (ix).

(2) Shim et al. acquire these data, justify these models, and confirm the hypotheses to provide material information for construction.

> The growing needs for materials dedicated to thermal management applications leads to the design of new composite materials. Indeed, with appropriate combination of selected matrices and reinforcement, it is now possible to tailor composite materials with almost the desired thermal conductivity as to the fiber direction and shape.
>
> (2) (Shim, et al., 2002, p. 1882)

Again the focus is thus not on theory, but on acquiring data to confirm constructed epistemic tools that enables thinking about the phenomenon (e.g., predicting its behavior at specific circumstances), or about possible interventions to improve the material.

4.2.3 Transverse Thermal Conductivity of Fiber Reinforced Polymer Composites

(3) Tavman and Akıncı (2000) compare experimental outcomes with predictions from different models.

Transverse thermal conductivity of high density	
polyethylene reinforced with chopped strand glass fiber	The phenomenon (i)
mat is investigated experimentally for temperatures	The physical circumstances (v)
ranging from 10°C to 85°C. Models predicting the	The model type used (ii)
transverse thermal conductivity of composites filled	The epistemic purpose of the
with long fibers are stated and compared with each	models (iv) and the justification
other and with experimental results.	of the models (ix)
(3) (Tavman & Akıncı, 2000, p. 253)	

In this article (3) Tavman and Akıncı compare several models with experimental data.

> The determination of the effective properties of composite material is of great importance in effective design and application of composite materials. There are numerous theoretical, ampirical[xxxix], as well as numerical methods to predict effective thermal conductivity of

composites, each of these methods have certain assumptions, therefore they may be applicable for certain specific cases and ranges. It is therefore necessary to have experimental data on each type of composite materials.

(3) (Tavman & Akıncı, 2000, p. 253)

They start with two very simple mathematical models (ii). “The simplest models are the series and parallel models where different components of the composite are arranged in layers series or parallel to heat flow. These two models give the lower and upper bounds of the effective thermal conductivity” (3) (Tavman & Akıncı, 2000, p. 254) (vii) (viii). Other models that are compared are a semi-theoretical model by Springer and Tsai, a model that analyzed the influence of obstacles by Rayleigh, a model that assumes parabolic distribution by Chang and Vachon, and a model by Halpin-Tsai that uses “the analogy between in-plane field equation and boundary conditions to the transverse transport coefficient” (3) (Tavman & Akıncı, 2000, p. 256) (ii).

The material used for the experimental testing is made especially for the experiment. They are rectangular shaped samples composed of HDPE[xl] and a glass fiber mat. Experiments are done with 14% and 27% glass mat by volume (v). The thermal conductivity (iii) of these two samples as well as of pure HDPE is measured with a Shotherm QTM thermal conductivity meter (vi). The outcomes of these experiments are compared to the predictions based on the models. This comparison is needed to check the accuracy of these predictions made on the basis of the models, so they can responsibly be used in design (iv).

The fact that Tavman and Akıncı focus their work on testing the accuracy of models, again shows that the focus of the engineering scientists is not the phenomena themselves, but the target system: the fiber-reinforced polymer composite material. An accurate model is not in the interest of the phenomenon; the phenomenon is itself will not change because of the accuracy of the model. An accurate model is important for acquire knowledge about the phenomenon and for using it to make thinking about intervening with the target system possible. It is the target system that benefits from more accurate models.

4.2.4 The Disturbance of Heat Flow and Thermal Stress in Composites with Partially Bounded Inclusions

(4) Lekakis, Kattis, Providas and Kalamkarov (1999) make a model to predict failure of

composite material and to predict behavior of flawed composite materials. A simplification of reality is practiced to make predicting possible.

A general solution to the thermoelastic and heat conduction problems for composite materials with curvilinear partially bounded inclusions is obtained. The solution to these problems is based on the complex potential method, conformal mapping and analytic continuation techniques.	The knowledge principles used (viii)
The obtained general solution is applied to the special case of an elliptical inclusion with the uniform heat flux applied to the matrix at infinity.	Relevant physical circumstances (v)
As in the case of mechanical loading, the crack-tip stress field possesses the square-root singularity with the logarithmic oscillation. In the special case of a line rigid inclusion, the order of singularity changes as the crack tip approaches the end of the inclusion.	The knowledge principles used (viii)
The thermal stress intensity factor at the crack tip is determined and numerical results are obtained for the case of an elliptical rigid inclusion.	The model type used (ii)

(4) (Lekakis, et al., 1999)

The focus here is on creating useful models for thinking about failure; these models are simplifications reality (vii), but simplifications with a purpose.

> This mode of failure is usually modelled by an inclusion within an elastic matrix having an interface crack. For modelling purposes, idealizations are usually made with respect to the geometry and the thermomechanical properties of the constructed materials. Thus for fiber-reinforced composites with large values for elastic modulus and thermal conductivity, the fiber can be assumed to be rigid and isolated.
>
> (4) (Lekakis, et al., 1999)

The inclusion in the material is modeled mathematical (ii) based on its geometry and thermodynamic laws and principles (viii) to give a solution for both heat conduction and thermoelastic problems. The phenomena—"the two-dimensional heat conduction and thermoelastostatic problem for a composite material containing a curvilinear inclusion with an interface crack" (4) (Lekakis, et al., 1999) (i)—is modeled in two parts. First a solution for the elliptic inclusion is obtained, this is then used to study the asymptotic behavior of the thermal stresses at the crack tip. The author represents this model numerically in graphs where they vary the different parameters to compare the outcomes—this is how they justify their model (ix). There are no experiments done in this study and there is no comparison with experimental data—there is also no mention of any experiments that should be done.

It is interesting to see that this article is about an unwanted phenomenon in the target system.

> In the thermally conducting composite solids the heat flow is affected by the presence of geometrical or material discontinuities. This causes local increases in temperature distribution, which in turn results in increase of local thermal stress, and may often lead to the structural failure of the material.
>
> (4) (Lekakis, et al., 1999)

The conceptualization of the phenomenon is in a negative purview—the phenomenon of inclusions is unwanted and therefore models are made to take this negative factor into account (iv). These models give an understanding of the processes of failure. "The analysis of this type of failure mechanism is of major importance for the understanding of the failure process of the composites" (4) (Lekakis, et al., 1999).

4.2.5 Dependence of the Transverse Thermal Conductivity of Unidirectional Composites on Fiber Shape

The article by (5) Tai (1998) is an application and generalization of an existing model.

The model for transversal thermal conductivity of unidirectional composite materials published by Springer and Tsai, which yields good results when compared to experimental results, is generalized to	Knowledge and principles used (viii)
include fibers having elliptical cross sections. It is shown that thermal conductivity of the	The phenomenon (i)

> unidirectional composite normal to the filaments
> depends strongly on fiber shape.
>
> (5) (Tai, 1998, p. 1485)

The model that is used, is based on analogy (viii). It was first developed for shear loading problems, but has been shown to do well in thermal conductivity problems. It "essentially is a finite difference numerical approach" (5) (Tai, 1998, p. 1485) (ii). (5) Tai does not develop this model, but applies this already existing model to different fiber shapes (v). This article shows that the model not only works for fibers with a square cross-section, but also for fibers with an elliptical cross-section (ix). The model is thus expanded to be applicable to more target systems, and therefore to more phenomena.

The goal of (5) Tai in expanding this model is to be able to see what the influence of fiber shape is on heat conduction. If one model can predict the outcome for different fiber shapes, then this factor (the fiber shape) can be manipulated to accommodate ideal heat transfer (iv). As was the original model, the expanded model is an idealization. "Of course, in reality, there are no truly elliptical fibers in existence, and even if they were to exist, controlling the fiber orientation would be a major processing challenge" (5) (Tai, 1998, p. 1491) (vii). In this article the model is not tested against experimental data, but the original model was.

> When they compared their theoretical predictions with the experimental results, … they found that for a high thermal conductivity ratio, … the data agree reasonably well with the results of the sheer loading analogy model, but are higher than the values predicted by the thermal model
>
> (5) (Tai, 1998, p. 1486)

4.3 The Interpretation and Use of the Phenomenon

The field of research into the thermal properties of composites is a field in which both fundamental laws and phenomenological laws play a role in the research; but the outcome of this research is never a fundamental law, but always a phenomenological law. These phenomenological laws do not have to be formulas like fundamental laws, but can be characteristic and causal properties of phenomena. The behavior of the composite material—the target system—is what these engineering scientists are after. The phenomena that determine the functioning of the target system are described in models which combine the different phenomenological laws.

4.3.1 Experiments, Target System, Data and Phenomena

This case study clearly agrees with Bogen and Woodward (1988) that a distinction between data and phenomena is epistemologically relevant. The two articles that present experiments (2,3) (Shim, et al., 2002; Tavman & Akıncı, 2000) show this. In both cases there is no actual experimental data presented. (2) Shim et al. (2002) present averages with an error margin of the experimental data in tables and in graphs, (3) Tavman & Akıncı (2000) do the same. “The thermal conductivity is measured with an accuracy of ±5% and reproducibility of ±2%. For each specimen the thermal conductivity is measured five times and the mean values are reported” (3) (Tavman & Akıncı, 2000, p. 258). These averages with error margins are the values that are presented and compared. This means that the idiosyncratic data are not at all presented or mentioned in these articles. This coincides very well with how Bogen and Woodward describe the measuring of the melting point of lead.

> One does not determine the melting point of lead by observing the result of a single thermometer reading. To determine the melting point one must make a series of measurements. Even when the equipment is in good working order, and sources of systematic error have been eliminated, the readings from repeated applications of the same thermometer to the same sample of lead will differ slightly from one another, providing a scatter of results. These constitute data. Given the absence of systematic error, a standard assumption is that the scatter of observed thermometer readings not only reflects the true melting point (the phenomenon in which we are interested), but also the operation of numerous other small causes of variation or "error," causes which cannot be controlled for and the details of which remain unknown. If one can make certain general assumptions about the character of these causes of variation (for example, that they operate independently, are roughly equal in magnitude, are as likely to be positive as negative, and have a cumulative effect which is additive), then it will follow that the distribution of measurement results will be roughly normal and that the mean of this distribution will be a good estimate of the

> true melting point. Standard scientific practice is to report this estimate along with the associated standard error, which is directly calculable from the variance of the distribution of measurement results.
>
> (Bogen & Woodward, 1988, p. 308)

What is presented in these articles is thus not the experimental data, which proves the point Bogen and Woodward make. The only problem with their account is that they do not describe how one comes from data to a full phenomenon. McAllister (1997, 2003, 2004, 2009) addresses this point by saying that what counts as a phenomenon is a matter of stipulation by the scientist. This is not something I find in this case study. It is not the case that scientists take some target system, probe it to get data, and then pick random pattern in the data-set to play the role of phenomenon. They are explicitly looking for a specific phenomenon. In both the articles in this case study that do experiments (2,3) (Shim, et al., 2002; Tavman & Akıncı, 2000) the phenomena that are explored are known before the experiments are done. It is as Hacking (1983) describes it: the whole experiment is constructed to bring forward a specific phenomenon. The test subjects—the samples of composite material—are made especially for the experiments. The only difference with Hacking's account is that these phenomena are not sought after to prove theories, but to validate models and to produce knowledge—represented in the model—on how to intervene with the phenomenon under study such that the functioning of the target system may be improved.

What can be seen in the articles in this case study—both the ones doing experiments and the ones not doing experiments—is that the phenomena are approximately known. The phenomena are an integral part of the target system, which makes them known and modelable before actual experiments have been done to acquire data. This is also connected to the fact that the phenomena in this case study are very specific. This makes that the phenomena can be articulated before the experiments are done, just by describing the target system. How one comes from data to phenomena is via the target system. The target system prescribes which physical phenomena can occur and which phenomena can be conceptually articulated it its context. In a system with round-shaped fibers there can never be heat distribution of C-shaped fibers. The target system gives the conceptual, as well as the physical constrains for the phenomena. These two ingredients make the creation of a phenomenon in the Hacking-Rouse sense—experimental creation and conceptual articulation—possible.

Almost all philosophers of science mentioned in this thesis say that experimental data are acquired to serve as proof for theories—either direct (Suppe, 1972; Van Fraassen, 1976, 1980), or via phenomena (Bailer-Jones, 2009; Basu, 2003; Bogen, 2009; Bogen & Woodward, 1988; Hacking, 1983, 1992; Kroes, 1994; McAllister, 1997, 2003, 2004, 2009; Schindler, 2006, 2009; Woodward, 1989, 2009). What I see in this case study is that experimental data are used to validate models of phenomena. Phenomena are modeled to make thinking about intervening possible. To access whether these models are accurate, experiments are done; and the experimental data are compared to the predictions made by the models.

The authors of the studied articles do not have the tendency to attribute the label of ‘phenomenon’ to the subject of their study. Only (2) Shim et al (2002) actually uses the word ‘phenomena’. Other words that are used are ‘effect’ (2) (Shim, et al., 2002), ‘problem’ (1,4,5) (Esparragoza, et al., 2003; Lekakis, et al., 1999; Tai, 1998), and ‘case’ (4,5) (Esparragoza, et al., 2003; Tai, 1998). (3) Tavman and Akıncı (2000) use no label at all. The label ‘problem’ suggests that a solution has to be found. The label ‘case’ may in fact point more to the target system than to the phenomenon. The fact that phenomena are not named as such may, again, suggest that phenomena primarily are considered in their function for the target system. Understanding and modeling of phenomena make that the target systems can be understood and intervened with.

As Brown (1994) and Hacking (1983) stated, phenomena as presented in scientific articles are always represented. A phenomenon can be presented as a phenomenological law, in which case it is a physical description of the phenomenon. A phenomenological law represents a phenomenon as its causal relations. Phenomena can also be represented in a mathematical way. In this case the phenomenon is presented as a set of mathematical formulas. An other form of representations are graphs and tables. Then a phenomenon is represented as the mean of its experimental data acquired by measurements or as predicted data derived from models. All these forms of representation are present in the five articles in this case study.

4.3.2 Specific Phenomena

This case study clearly shows that the phenomena investigated in these articles are very specific. Phenomena like “the temperature distribution along a high thermal conductivity bar (fiber) embedded in a low thermal conductivity half-space (matrix) subjected to an axial differential of temperature” (1) (Esparragoza, et al., 2003, p. 429) can be seen as a phenomenon in very specific conditions. Or “the two-dimensional heat conduction and thermoelastostatic problem for a composite material containing a curvilinear inclusion with an interface crack” (4) (Lekakis, et al., 1999) can be read as a phenomenological law with a specific external condition, and thus describes a very specific phenomenon. This specificity is contrary to the idea of the philosophers of science (Bogen & Woodward, 1988; BonJour, 2005; Friedman, 1974; Suppe, 1972; Van Fraassen, 1976, 1980) who think that phenomena are actually very general and should point us to universal laws.

What makes the phenomena in these articles so very specific is that in the description of the phenomenon the conditions it is subjected to are given. The phenomena in these articles are conceptually articulated in terms of a phenomenological law that entails specific conditions or interactions. The phenomenon described by the law is not just thermal conductivity, but, for instance, thermal conductivity in carbon fiber-reinforced plastic, with fibers with a C-shaped cross-section woven in a mat. The material and the specific form of appearance are thus not external conditions, but an integral part of the phenomenon. Hence, it can be said that for engineering science, or for this case study at the very least, that phenomena are articulated as phenomenological laws entailing specific conditions. These conditions are not random, these are the conditions prescribed by the target system. This means that also the physical phenomenon is specific to its target system. This comes closest to the representation of phenomena that Hacking (1983, 1992) gives.

However Hacking (1983, 1992), as do Bogen and Woodward (1988), states that phenomena are not idiosyncratic and hence are not specific to experimental setup as data are. This may seem conflicting; therefore I want to bring some nuance to this statement. On the one hand a phenomenon is not specific to an experiment; in the sense that if I rebuild an experimental setup the data produced will indicate the same phenomena as the data produced by a previous experiment, although the date was different. The data produced in both experimental setups may be different, but the phenomenon is assumed to be the same. On the other hand, a phenomenon is specific to an experimental setup in the sense that it is bound to its target system. Phenomena are articulated in the context of their target system, which makes them so specific; and the physical phenomena is dependent on the experimental setup. If I do a experiment with C-shaped fibers I will have a different phenomenon than if I do the experiment with round-shaped fibers. If a material with C-shaped fibers is the target system, it can never host a phenomenon like the heat distribution in round-shaped fibers. This connection to experimental setup or target system is only visible in these very specific phenomena, and not in the global phenomena as almost always described in the philosophy of science.

Because these phenomena are very specific, they all seem to be part of a family of phenomena. They are all a more specific instantiation of the more general phenomenon of heat conductivity in composites[xli]. This global family can be divided into subfamilies like heat conductivity in composites of different materials, or heat conductivity in composites with different fiber shapes or structures. These subfamilies can be divided even further until the very specific phenomena observed in this case study are reached. It thus appears that the amount of possible phenomena is infinite, since a general phenomena plus a set of external conditions gives a more specific phenomena. This is against the idea of Bogen and Woodward (1988) and Brown (1994) that phenomena are natural kinds.

A target system can hold a host of phenomena, but all the phenomena it contains are made specific by its characteristics. If the target system is a composite with chopped, round shaped carbon fibers, then the heat distribution phenomena will become: the thermal conductivity of chopped, round shaped carbon fibers. These specific phenomena are specific because they are experimentally isolated in a specific system. Hacking (1983, 1992) said that phenomena will only occur in their specific experimental setup. Rouse (2009) said that in the conceptual articulation of phenomena, the phenomena are related to their world. In this case their world is their target system. Phenomena are conceptually articulated as very specific processes, because their world is specific. The conceptualization of the phenomena incorporates the context—the target system (personal communication with M. Boon). In a specific target system only phenomena specific to that system will be found; this is true for both the physical phenomenon, as for the articulation of the phenomenon.

4.3.3 Modeling Phenomena

Because fundamental laws play only a small role in describing the behavior of composites, engineering scientists need another way to predict behavior; and that is by models. As has been made clear from the application of the nine concepts to the articles studied, all the authors produce or use models to describe the phenomenon. These models are based on data—measurements and causal relations—required from the target system combined with fundamental and phenomenological laws. (1) Esparragoza et al (2003) compare an mathematical model with a numerical model; (3) Tavman and Akıncı (2000) compare theoretical models with experimental outcome; (4) Lekakis et al (1999) try to apply a general model to a specific problem; and (5) Tai (1998) tries to generalize a model.

All the research seems to revolve around models for prediction and description. And especially around acquiring reliable, applicable models. This is because

> many difficulties arising in the design and use of composites are caused by the complexity and poor understanding of the interactions between the composite components. There is no generally recognized theory for the transfer between fibers and matrix, nor its effects on the macro-mechanics response of the composite.
>
> (1) (Esparragoza, et al., 2003, p. 249)

To overcome this, good models have to be made to make any prediction possible. To make thinking about intervening with the target system possible, the phenomena described in models have to be simplified by excluding relevant physical factors and assumptions have to be made.

> To ensure no contact between crack surfaces, except that due to the logarithmic oscillation, the assumption of an open crack is adopted. According to this assumption, the thermal stress in the matrix is added to an already existing stress field due to applied mechanical loadings so that the contact zone is infinitesimally small.
>
> (4) (Lekakis, p2)

This is what modeling is all about—models are a simplified representation of reality.

However, not any simplification will do to make a usable model. The modeling done in these articles is not just making accurate representations as some of the more conservative philosophers of science would have it. In modeling, phenomena are simplified and represented with a purpose—they are used to think about intervene with the target system and to acquire knowledge of the target system—which makes models epistemic tools (Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming). This also means that a phenomenon can be modeled in multiple ways, depending on the purpose. (4) Lekakis et al. (1999), for instance, vary the parameters of their models to get different outcomes, which they then compare on desirability. The model is the articulation of the phenomenon; in the model the physical phenomena is conceptually articulated for a specific purpose.

Because of this focus on getting workable material properties without a solid theoretical basis much of the work is done via induction. The existence of phenomena is mostly not predicted by fundamental theories and models are mostly not deduced from fundamental theories. Information is acquired via experiments and predictions based on models. “More measurements with different percentages of reinforcing material and with different materials, especially with materials with higher k_f/k_p ratios, have to be performed in order to be able to generalize with[xlii] model is best suited for predicting transverse thermal conductivity” (3) (Tavman & Akıncı, 2000, p. 260). They need to collect more data about their target system to make reliable models.

In the articles studied here the Hacking-Rouse way of creating phenomena, as developed in 3.3.3, clearly comes to light. This is especially clear for the way the phenomena are modeled. Like the physical phenomena, the conceptually articulated phenomena expressed by the models are bound to their target system. The phenomena that are created here come into existence by both experimentally isolating them and conceptually articulating them. This isolating and articulating is done by making the phenomena a very specific instance of the target system. Models are the epistemic tools in creating the phenomena as conceptual articulations (Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming). Phenomena are not the endpoint, they are not created in and of themselves; the aim of experimentally creating and modeling phenomena is understanding and manipulating the target system. Hence, the purpose of scientific research in engineering science is creating (Hacking, 1983, 1992) and articulating (Bailer-Jones, 2009; Rouse, 2009) phenomena, and constructing models of them (Bailer-Jones, 2009) that function as create epistemic tools (Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming) which enables thinking about, e.g. intervening with the target system.

In her description of the working of models, Bailer-Jones (2009) spoke about a class of phenomena as the subject of a model. She said that the subject of a model is not any odd phenomena, but a prototype representing a class of phenomena. This would agree with my idea of specific phenomena and a family of phenomena. In the cases of (2) Shim et al. (2002) and (5) Tai (1998), whom use the same models and principles for different phenomena, the models that is used is a conceptualization of a more general phenomena than the specific phenomena it is applied to. I agree with Bailer-Jones that what is modeled is not always the very specific phenomenon, but can also be a more general version of that phenomenon. This would suggest that, as with phenomena, models can be more and less specific[xliii].

4.3.4 'Same Conditions – Same Effect' and Conceptual Articulation and Experimental Creation

This case study also indicates that engineering scientists strongly lean on the regulatory principle of 'same conditions – same effect' as described by Boon (forthcoming). They rely heavily on the causal characteristic. Modeling is also done on the basis of causal expectations. The basis of all these studies is that the same conditions will have the same effect; the innovative part is to see what will happen if the conditions are slightly altered[xliv]. (2) Shim et al. (2002) for instance want to see what the effect is if one aspect is varied in an otherwise identical configurations. The only change is the cross section of the fiber, the rest of the configurations is left the same; therefore no other aspects should cause a different outcome. The only thing that is held responsible for the different outcome is the aspect altered.

This 'same conditions – same effect' thinking of the engineering scientists is also linked to the specificity of the phenomena. These phenomena are conceptually articulated in a very specific way to make a clear distinction between what is the same, and what is not the same. This shows that, as Rouse (2009) mentioned, articulation is about conceptualization; about making the world thinkable. With this conceptualization the phenomenon is placed in a bigger context of knowledge and hypotheses about the target system. If you adhere to the 'same conditions – same effect', then expressing the conditions makes that you have expectations about the effect. The specific articulation of these phenomena will thus, implicitly, carry a hypothesis with it. Descriptions of phenomena are thus conceptualizations, they are much more than Van Fraassen (1976, 1980) and the empiricists would allow them to be.

Or as Massimi said it: "phenomena are neither ready-made in nature nor mere images of real objects, but they are instead objects of experience, that is, the only objects we have epistemic access to and scientific knowledge of" (2007, p. 240). This image of what phenomena are does coincide with what is shown in this case study. Phenomena are not ready made in nature waiting to be discovered, nor are they just descriptions of real objects. In a physical sense phenomena are experimentally created and in a linguistic sense phenomena are conceptual articulations, these two aspects together are what makes a phenomenon. With the experimental creation and the principles of conceptualization like comparison, analogy and same condition, same effect, these engineering scientists try to harness the properties of their objects of study, their phenomena. “Instead of depicting an already existing world, the engineering sciences aim at theories and models that provide understanding of artificially created phenomena” (Boon & Knuuttila, 2009, p. 688).

4.4 Phenomena in Engineering Science

After investigating the articles in this case study it may be concluded that understanding and modeling of phenomena is needed to think about intervene with the target system; it is needed for design and construction. The fact that the authors in this case study do not appoint any value to phenomena as such is telling. The phenomena are described as problems or cases for which the properties must be mapped. The interest in phenomena that the engineering scientists show, stems not from the urge to prove theories. They want both to use the physical phenomena to intervene with the functioning of the target system, as well as the knowledge about the conceptualized phenomena to be able to think about improvements or the (dis)functioning of the target system. How this knowledge about phenomena is used in engineering science shows from the article by (2) Shim et al..

> Carbon materials … have been known to posses an excellent thermal conductivity. … One of the carbon materials is quasi-crystalline pyrolytic carbon that show very high anisotropy factor. … But it is difficult to use as thermal structural aerials due to process problems. Among the carbon materials with easy preparation process, it is carbon fiber that has good thermal properties and can be made easily structural materials. … Generally, the round-type is used as a reinforcement fiber in fiber-reinforced composites. In structural mechanics, as the optimization of the stress distributions of materials, some design engineers proved that hollow or noncircular-type is better than round one in mechanical properties. … Especially, C-type carbon fiber has a curved area in the surface contacting with matrices that can improve interfacial bounding force. The phenomena result may solve a delaminiation, playing a great part in mechanical properties of carbon fiber-reinforced composites.

(2) (2002, p. 1881)

The work that phenomena do in engineering science is that they function as the subject of study to acquire knowledge about them, which in turn is knowledge about the target system. Phenomena are also responsible for the functioning of the target system; phenomena make intervening with the target system possible. Because of this, phenomena are the experimental handles of the target system. Everything the engineering scientist does with phenomena is in service of improving design and construction—in service of the target system. A better understanding of the material properties makes designing easier, faster and more reliable. At the same time phenomena provide a way to experimentally work with the target system. The phenomena are used to improve knowledge about the target system and to make intervening with the target system possible. Phenomena can be used in the context of justification to prove theories, or in the context of discovery to initiate theories, but only if the target system demands this; however in engineering science phenomena will always be used in the context of construction. Again, for phenomena to give us knowledge, e.g. to regulate intervening with the target system, they have to be conceptualized in models—the epistemic tools. In engineering science a phenomenon is almost never used unmodeled. The work phenomena do in engineering science, they do represented in models[xlv]. It can be concluded that the work phenomena do in engineering science is making intervening with the target system possible, which is made possible by the fact that models of the phenomena provide knowledge about the target system.

My conclusion from this case study is that phenomena in engineering science do a different job than what almost all the philosophers of science I discussed in this thesis have claimed. Phenomena are very important in engineering science, but not because they prove or initiate theories. They are important because they make intervening with and understanding of the target system possible. The goal of engineering science is to improve upon these target systems. To do this they reason, model and experiment by means of phenomena; and to make these phenomena workable—to make then accessible as tools—they need phenomena represented[xlvi] in models.

5 Conclusion: Engineering Scientists and Phenomena

In this concluding chapter I will recapitulate what I have discovered in this thesis. I will do this by answering the research questions I have posted in the Introduction. Most of these questions can be answered from two perspectives: the currently common notion in the philosophy of science or my own philosophical ideas based on the in-depth study of the notion of phenomena in the philosophy of science and my case study.

5.1 Use of Phenomena in Engineering Science

In the tradition of the philosophy of science, the phenomenon is seen as being used in either the context of discovery, or in the context of justification. The philosophers of science adhering to the semantic view position (Friedman, 1974; Suppe, 1972; Van Fraassen, 1976, 1980) place phenomena in the context of justification. According to them a theory is empirically adequate if it 'saves' the phenomena. The phenomenon itself does not play any relevant role in the saving process, except for being the damsel in distress. The new experimentalist view (Bailer-Jones, 2009; Cartwright, 1983, 1998; Hacking, 1983, 1992; Schindler, 2006, 2009) places phenomena in the context of discovery. Their idea is that phenomena stand at the basis of theories.

I would like to step out of this dichotomy of justification versus discovery and place phenomena in the context of construction. My case study clearly shows that in engineering science the phenomena conceptually articulated in models are the epistemic tools to make thinking about intervening with the target system possible, while the physical phenomena are the experimental handles to actually intervene with the target system. Phenomena are experimentally created and conceptually articulated in service of the target system. This use can be applied both in the context of discovery and in the context of justification. The most important thing to note is that phenomena are not used to serve theories, they are used to serve the target system. This does not mean that phenomena are not used to prove theories, because they will be used that way, but only if it serves the target system.

5.2 The Work that Phenomena do in Engineering Science

The work that a phenomenon is said to do, depends strongly on the role or use that is attributed to the phenomenon. As said, in the semantic view of theories, the phenomenon does not do any work at all, except for being 'saved.' The new experimentalists state that the most important work a phenomenon does is arouse curiosity, the phenomena perform actual work in the context of justification. Bogen and Woodward (1988) prominently diverted from the semantic view in stating that there is an important difference between data and phenomena in the work they do. Data are evidence for phenomena, while phenomena are evidence for theories.

While I agree with Bogen and Woodward that the distinction between data and phenomena, in which they are evidence for, is very important; my case study shows that phenomena in engineering science do first and foremost work in the context of construction. Phenomena can work as evidence for theories if that is in the interest of the target system. The physical phenomena are experimentally created to provide experimental handles to intervene with the target system and the phenomena in language is conceptually articulated in models to provide knowledge about the target system. This modeling is not just a mere accurate representation of the phenomena; the model is an articulation of the phenomenon focused on the work the phenomenon must do for the target system; the model is an epistemic tool (Boon & Knuuttila, 2009; Knuuttila & Boon, forthcoming).

5.3 The Need for Phenomena in Engineering Science

Bogen and Woodward (1988) pointed out a very real need for phenomena in science, by arguing that one cannot come from data to theory directly; phenomena are needed in between. This need for phenomena is acknowledged by most recent philosophers of science (Bailer-Jones, 2009; Basu, 2003; Bogen, 2009; Boon, forthcoming; Boon & Knuuttila, 2009; Brown, 1994; Falkenburg, 2009; Knuuttila & Boon, forthcoming; Kroes, 1994; Massimi, 2007, 2008; McAllister, 1997, 2003, 2004, 2009; Morgan & Morrison, 1999; Rouse, 2009; Schindler, 2006, 2009; Woodward, 1989, 2009). The only real exception is Glymour (2000) who views everything after experimental data as sample statistics.

I would add to this need—or perhaps expand this need—by saying that phenomena are needed to acquire knowledge about the target system—as conceptual articulations—and to intervene with the target system—as experiment creation. Acquiring knowledge about the target system can be done by proving or initiating theories, but it can also be done by providing workable models. Phenomena are thus not only needed to come from data to theory, but also to come from data to model. In engineering science everything revolves around the target system. Often engineering scientists work in a field that is not fully understood yet, and therefore not completely laid out by fundamental theories. Hence, work on target systems is governed by phenomenological laws and models of phenomena. Consequently, phenomena are very important to, and needed in engineering science; not in and of themselves, but because of the work they do.

5.4 The Characteristics of a Phenomenon in Engineering Science

I agree with Hacking (1983) that a phenomenon in engineering science is noteworthy, discernible, and “an event or process of a certain type that occurs regularly under definite circumstances” (Hacking, 1983, p. 221). The fact that they are noteworthy and discernible is almost self-evident. The second part of Hacking's definition—that they are regular under definite circumstances—I will define as Boon's (forthcoming) concept of ‘same condition – same effect’. This is a very important robustness concept. Engineering science is built on this concept; as is shown in my case study. I also agree with Bailer-Jones (2009) that phenomena have the potential to be theoretically explained.

My case study also provided other characteristics of phenomena. Phenomena are specific to their target system. A certain phenomenon will only occur in a certain system under certain conditions; the target system provides the conditions of possibility for a phenomenon. This implies that phenomena are not natural kinds; they do not exist in nature on their own. The Hacking-Rouse vision on the creation of phenomena I have developed in this thesis, states that phenomena are in the same process experimentally created, and conceptually articulated in the context of their target system. Experimenting on the target system will bring the phenomenon forward, and in articulating the phenomenon in a model it will be conceptually linked with the target system in knowledge and hypotheses. Descriptions and models of phenomena in engineering science are thus mini theories. A phenomenon in engineering science is integrally connected with its target system. All characteristics can be traced back to the fact that a phenomenon is always a part of a target system and is used in service of that target system.

5.5 What then is a Phenomenon?

As can be concluded from the characteristics I appoint to phenomena, I do not see phenomena as natural kinds, as Brown (1994) and Bogen and Woodward (1988) do. In their vision phenomena are out there, literally waiting to be discovered. Ontologically I say that phenomena are creations; they are physically created in experiments and conceptually created in articulation and models. Epistemologically I follow Massimi (2007, 2008) in her Kantian vision on phenomena as conceptualizations. When we conceptualize a phenomenon we incorporate it into a bigger picture, which includes our knowledge and ideas about the world and the target system. This Kantian idea of phenomena as conceptualizations also overcomes the realists-empiricists discussion in the philosophy of science. Viewing phenomena as conceptualizations makes the discussion between realists and empiricists superfluous.

Besides answering the question of what phenomena are in an ontological and epistemological sense, we can also answer this question in a more practical sense. This more pragmatic definition of phenomena also follows clearly from the characteristics I have assigned to them: a phenomenon in engineering science is something that is used in service of the target system. A phenomenon is an instrument to which can provide knowledge about a target system and which can be used to intervene with a target system.

5.6 Discussion and Recommendations

During the writing of this thesis some ideas have occurred to me, which are not directly relevant for the content of this study, but which are relevant none the less.

5.6.1 Phenomena in which Science?

As the title of this thesis makes clear, this thesis is about phenomena in engineering science. I believe that the characteristics of phenomena may differ in different fields of science. Bogen and Woodward (1988) have shown examples of phenomena from very different branches of science—for instance social sciences and fundamental natural sciences—and tried to find a common definition of phenomena. I think it is more constructive to look at phenomena in the different branches of science individually first. As this thesis shows, an in-depth study into a specific field of science provides much more information on what phenomena are than just generalities that phenomena are noteworthy and discernible. It might also be the case that the description of science as given by the semantic view (Van Fraassen, 1976, 1980) is much more true for fundamental science than I gave it credit for in the engineering sciences. I think therefor that it is important to define the field of science you study when you mention phenomena, this is something not done very often in the philosophy of science.

5.6.2 Realism Discussion

Something that occurred to me during the research for this thesis is that the discussion about phenomena has been hijacked by discussions about realism. Realists and empiricists try to have a discussion about phenomena, but keep misunderstanding each other. Both parties argue on the basis of their conception of realism. This discussion will never lead anywhere, because they will never come to an agreement, since they started out on the basis of different premisses. This, I think, is one of the reasons that there has been little progress since Hacking (1988; 1983) . The only way of overcoming this problem is leaving the Humean perspective and follow Kant in his Copernican turn like Massimi (2007, 2008) does. Viewing phenomena as conceptualizations makes that we can have a philosophical discussion without having to take a stance in the realism discussion; and equally important, it enriches the idea of phenomena greatly.

5.6.3 Other Problematic Notions

In this thesis I have investigated what phenomena are in engineering science, but as quite prominently shown in this thesis, it is not the only problematic notion. It is also hard to define other notions such as model, theory, law, data, observation, and experiment. The same exercise that I have done in this thesis for phenomena, can and should be done for all these other notions. The third chapter of this thesis clearly shows that the understanding of the notion of phenomena by philosophers depends directly on their metaphysical, epistemological, and ontological stance in the philosophy of science. Philosophers coming from a different background position most probably have a different understanding of these other notions as well. Without a common understanding of the notions mentioned, at least within the different fractions of the philosophy of science, further discussion about them will not lead to much.

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Notes

i Italics in original text.

ii These categories are not mutually exclusive and a field of science based on the subject studied can fall in to more than one category based on how this studying is done.

iii Italics in original text.

iv Italics in original text.

v ‘Given’ is perhaps a bit of a problematic word in this context. What I mean to say is that they do not see that making an observation in an experimental setting requires work. The scientist has to envision an experiment, make a setup, test it, refine and adjust it, retest it, etc. before any observation can be made. Actual observing is only a very small part of doing science.

vi The reasons how and why a scientist thinks up an experiment can be numerous.

vii Italics in original text.

viii How these constant characteristics of a phenomenon show from the data-sets is not uncontroversial. For more on this subject see 2.4.

ix As will be explained in chapter 3 the concept of truth in connection to theories is highly problematic and close to the pinnacle of the discussion between the realists and the empiricists.

x Models can be anything from a wire-model of atoms to mathematical models of the dynamics of flows of liquids.

xi Rouse's point is a useful one, but it can also become very problematic. It hits the core of this thesis, namely: what is a phenomenon? The important question is if there is a difference between ‘data model’ and ‘phenomenon.’ What would a model of a phenomenon as a pattern in a data-set in Bogen and Woodward's sense entail?

xii These methods suggest a form theory-ladenness which Bogen and Woodward deny. Later Woodward (2009) does agree with what he calls theory-drivenness, see also 2.4.3.

xiii This idea will be elaborated in my case study in chapter 4.

xiv Gestalt is German for form or shape. Gestalt psychology is a theory of the mind or brain which says that the mind makes us ‘see’ more that what is received in the brain as sense data. We can for instants see perspective in a simple set of lines. A Gestalt shift or switch is a shift from ‘seeing’ things one way to suddenly ‘seeing’ it the other way. This is often illustrated with well known pictures, like the one which shows either a young woman or an old witch, depending on how you look at it; or the the duck that is also a hare. Philosophers of science like Kuhn and Feyerabend often explained incommensurability of scientific theories on the basis of Gestalt theory (http://plato.stanford.edu/entries/incommensurability/, visited on September 13, 2010).

Notes

xv Their claim that they are ontologically non-committal beyond the fact that they consider phenomena to be natural kinds, does not entail much. Their ontological position is very committing.

xvi I do not agree with Hacking here. According to him planetary phenomena can be discovered with the naked eye. Though it is true that you can spot the position op the planets with the naked eye, it still requires a lot of time and computing before you can conclude their elliptic orbits.

xvii Hacking quotes Bacon having said that we should twist the lion's tail, but gives no reference to Bacon's work. After a small search on the internet I found that more people were looking for the source of this quotation, but could not find it—either there was no reference given or it would refer to Hacking. On http://groups.google.com/group/fa.philos-l/browse_thread/thread/9ef17b3188de74a4?fwc=1 (visited on December 17, 2009) I found information, provided by Professor Steven French of the University of Leeds, that it was most probably Kuhn who made the comment about the lion's tail and that Bacon spoke about climbing onto Prometheus while he twists and turns and changes shape.

xviii The difference between the weak and the strong view does not have to be as clear as Kroes presents it. The phenomenon does not come forward on its own, it has to be 'called out' by manipulating the conditions of the experimental setup. These conditions and the setup determine the specific features of the phenomenon. In my opinion the creation of the proper conditions for a phenomenon to appear and the creation of the specific characteristic of the phenomena are not that different. I think that the difference between the strong and the weak version is bigger for realist than for empiricists.

xix I use the word 'spot' of lack of a better word. Bogen & Woodward do not clearly state how they envision this 'spotting' of a phenomenon in a data-set. This is precisely the point McAllister takes an agitation against, as explained in 2.4.

xx Noise reduction and cleansing of data is also directed by a choice in favor of a specific pattern. You do not know which pattern will be relevant, it is not clear which part of the data is error, this makes noise reduction and cleansing impossible.

xxi Italics in original text.

xxii Here revolution is meant in the Kuhnian.

xxiii This defense to me reads more like a defense against social constructivism than against theory-ladenness.

xxiv In this response he also admits that they where perhaps too eager to claim that all of science worked from their proposed bottom-up way. "Our goal was not to replace "top-down" theory-dominated views of science with an equally monolithic view in which scientific reasoning is always understood as "bottom-up" or purely data-driven. Instead our goal was to advance a more pluralistic understanding of science, in which, depending on goals and contexts, sometimes data-driven reasoning *and* sometimes theory played a more leading role" (Woodward, 2009, italics in original text). This is a direct reply to Schindler (2006).

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xxv Italics in original text.

xxvi Hacking (1992) claims that this is exactly what is the case in modern laboratory sciences and calls it self-vindication.

xxvii Error in original text.

xxviii Boon extents this point to an argument against falsification. If a scientist will not get the expected outcome he or she will not immediately discard the law on which the expectation was based. First the phenomena-producing device will be checked and then all other possible causally relevant conditions. Even if the cause of the unexpected experimental outcome is not found, still the law is not just rejected, because there is still a possibility that there are unknown causally relevant conditions.

xxix In discussions about realism it is important to specify (anti-)realism about 'what' you are discussing. One can be a realist about theories, but an anti-realist about unobservable particles. When the 'what' is not specified I talk about (anti-)realism about phenomena, for all other cases it will specify the subject of the (anti-)realism. This is contrary to most writings in the philosophy of science where an unspecified 'what' will indicate (anti-)realism about scientific theory.

xxx The idea of 'saving the phenomena' has been around in the philosophy of science for a long time. It has been said that 'saving' comes from a mistranslation of solving (Hacking, 1983).

xxxi This is the main argument realist give fore their standpoint. It is the logical explanation why science works.

xxxii Kant was once a follower of Hume himself, until he made what he called his Copernican Turn and presented a radical new vision on perception (Ladyman, 2002).

xxxiii It is actually quite typical that Kant is mostly overlooked in the philosophy of science, since Kant himself was in essence a philosopher of science.

xxxiv Constructed here does not refer to some form of social construction, but to actual physical construction.

xxxv This means that the experimental isolation of a phenomenon can also be seen as a physical construction.

xxxvi Boundary conditions would be a problematic word in this context. Boundary conditions here are meant in the general philosophical and scientific sense, not as specific for this field of science: as the interaction on the boundary surface between different components in a composite.

xxxvii It might look strange that I use these aspects given by Boon and Knuuttila (2009; Knuuttila & Boon, forthcoming), since they use them to foremost look at models, and in this thesis my subject is phenomena. However, I do think that these aspects help to fully grasp what is happening in the articles of my case study. And it may be clear, both from Boon and Knuuttila and from this thesis, that in engineering science phenomena and models are closely linked.

xxxviii Error in original text.

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xxxix Error in original text.

xl High Density Polyethylene

xli Which it itself can be regarded as a more specific instantiation of heat conductivity in general.

xlii Error in original text.

xliii I am aware that this statement, to gain more weight, would need more in-depth investigation. But since models are not the subject of this thesis, this lies outside the scope of my research.

xliv Another way in which this concept can be applied, is in investigating which conditions have changed when finding that the phenomenon shows unexpected behavior. This way of experimenting is not something that is present in the articles studied for this case study.

xlv With 'represented' in models here I do not mean that models are just mere accurate descriptions of phenomena. Models are epistemic tool with a purpose.

xlvi Idem