

Scientific Concepts in the Engineering Sciences

Epistemic Tools for Creating and Intervening with Phenomena

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1. Introduction

In philosophy of science, phenomena are understood as observable and unobservable objects, events or processes that have two important roles to play in science. They make us curious and thus point at theories, and they serve as evidence for theories (e. g., Hacking 1983; Bogen/Woodward 1988). Similarly, in the engineering sciences, phenomena are understood as both observable and unobservable objects, processes and properties. Yet, while the philosophy of science focuses on their epistemic role—that is, the role phenomena serve in constructing and testing theories—phenomena in the engineering sciences also are important for their own sake. This is because one of the ultimate purposes of these scientific research practices is technologically reproducing, newly creating, preventing, intervening with and detecting phenomena, especially those that could play a productive or obstructive role in the technological functioning of artifacts.

The formation of scientific concepts of phenomena in those domains cannot be understood as merely defining or describing pre-given things, because phenomena of interest usually are not observable in an unproblematic manner. Instead, our conceptualization of such phenomena often is entangled with the development of technological devices that produce, intervene with and/or detect phenomena. Taking this fact as a point of departure, the thesis of this paper is that in the engineering sciences, *scientific concepts of phenomena function as epistemic tools for creating and intervening with phenomena that are of technological relevance*. I will argue for this thesis by providing an account of (a) how phenomena of technological interest are conceptualized; (b) in what manner their conceptualization is entangled with the development of technological

devices that produce them; and (c) how such conceptualizations are entangled with already existing concepts, such that the latter enable epistemic uses with regard to the technological production of phenomena.

Elsewhere, Knuuttila and I have argued that *scientific models* of phenomena enable epistemic uses, not because they are first and foremost correct representations of the phenomenon, but rather because they have been constructed in a specific way, which makes them suitable as epistemic tools (Boon/Knuuttila 2009; Knuuttila/Boon 2011). In a similar fashion, I will propose to consider *scientific concepts* of phenomena as epistemic tools. Similarly, Feest (2010) has analyzed how concepts can figure in the generation of knowledge. She proposes that concepts figure as tools for the investigation of objects. Important in her account is the idea that operational definition of concepts function as tools by providing paradigmatic conditions of application for the concepts in question (also see Feest in this volume). “[Operational definitions] are cast in terms of a description of a typical experimental set-up thought to produce data that are indicative of the phenomenon picked out by the concept” (Feest 2010, 178). As a result, scientific concepts are tools which allow for experimental interventions into the domain of study, thereby generating knowledge about the phenomenon. I will follow Feest in her emphasis on the role of paradigmatic experiments in the formation of concepts. Also, I side with her idea that concepts are tools for the investigation of the phenomenon. Furthermore, I acknowledge that in real scientific practices, scientists may have preliminary scientific concepts that are tentative representations of purported objects, as Feest (2010) suggests. Yet, my account aims to dig a bit deeper into the formation of concepts. Where my account differs from hers is that I am interested in the ways in which phenomena are conceptualized prior to their existence and with the aim of technologically producing them. Metaphorically speaking, I am interested in the *design* phase of a novel phenomenon, and I think of that design phase as one of *conceptualization*. It is for this reason that I will pursue the metaphor of *design* to describe the role of concepts. It will be argued that in scientific practice the successful functioning of scientific concepts has to do with specific features of conceptualizing. Conceptualizing a phenomenon (e. g., phenomena that we wish to create or intervene with for performing technological functions) involves that relevant but heterogeneous content is fitted together similar to how in designing heterogeneous content is fitted together. In this way, *heterogeneous epistemic content* is introduced, which enables further investigation of the phenomena.

The paper is structured as follows: I begin with a brief explanation of how I view the relationship between phenomena and concept formation by comparing my account of the role of phenomena in scientific practice with the way this role is typically understood in philosophy of science (2.1). I will then argue that Bogen and Woodward's (1988) analysis of phenomena, if it is to be useful for an analysis of engineering science, must be supplemented with the idea that phenomena have a *material function* (2.2), and I illustrate this with case study (2.3). In section 3, I draw on these ideas to give a more detailed account of engineering *practice* to elaborate on my thesis that the epistemic role of *concepts* has to do with specific features of *conceptualizing*. Section 4 returns to the question of how concepts can perform the epistemic function my *analysis* attributes to them, highlighting in particular the extent to which heterogeneous concepts are involved throughout the entire process of conceptualizing phenomena, and highlighting the design-character of concepts.

2. What Are Phenomena?

2.1 The Epistemic Roles of Data and Phenomena in Experimental Practices

Traditionally, philosophers of science have held that the word 'phenomenon' denotes observable objects, events, or processes (e.g., Fraassen 1980; Hacking 1983, 220). The primary epistemic role attributed to phenomena is that of making us curious about the world and allowing for the testing of scientific theories. Philosophers have also emphasized the role of phenomena as the *explanandum*, that is, as objects, events or processes that attract our attention, and are explained or predicted by the theory. Bailer-Jones (2009, 167) even suggests "to identify a phenomenon with recognizing that something has the potential to be theoretically explained." Traditional and contemporary empiricists who rejected the idea that science aims at explanations, nevertheless agree on the epistemic role of phenomena in the construction of theories. They assume that theories must be constructed such that they 'save the phenomena', that is, make correct predictions of what has been observed or measured (e.g., Duhem [1906] 1962; Fraassen 1980). Thus, according to most of the philosophy of science, the role of phenomena in scientific practices is epistemic.

In the mentioned accounts, phenomena are observable regularities, events or processes, but also measured data-patterns. Bogen and Woodward (1988) agree with the epistemic role of phenomena, but object to the idea that phenomena must be observable. They propose making a conceptual distinction between data and phenomena. According to them, data are observable but idiosyncratic to the experimental set-up. Phenomena, in most cases, are not observable in any interesting sense of that term, but are detected through the use of data. Concerning the epistemic role of phenomena, they characterize phenomena as stable, repeatable effects or processes that are potential objects of prediction and systematic explanation by general theories and which can serve as evidence for such theories. Empirical data play a different epistemic role. They are *manifestations* of phenomena and *evidence for their existence* (see also Woodward 2000, 163; Woodward 2011). In this manner, Bogen and Woodward reinterpret phenomena against a 'thinner' notion typical of the empirical tradition according to which phenomena are observed regularities (see also Massimi 2011).

My position is that in doing scientific research, scientists need phenomena in the broader sense that Bogen and Woodward (1988) have suggested. Also, they need conceptions of them in order to investigate them, as Feest (2010) puts forward. However, considering the question *how* concepts of phenomena are formed in experimental practices, my difficulty with these accounts concerns the suggestion that phenomena are pre-given, ontologically independent entities. In this paper, I will not elaborate on why this view is problematic in general, but instead focus on the fact that a distinguishing feature of the *engineering sciences* is that in those areas of research *genuinely novel phenomena are produced*, thereby suggesting that the above-mentioned accounts of phenomena and concept formation about phenomena fail to illuminate the ways in which phenomena figure in the engineering sciences.

My point is not to deny the existence of *a world out there*. Surely, scientists more or less think this way, but this cannot be appealed to as an explanation of how concepts are formed in scientific practice and why they enable the generation of knowledge. Let me put things straight: On my analysis, data can be manifestations of phenomena, but they are also idiosyncratic to experimental set-up for two reasons. Firstly, scientists acquire data of an unobservable phenomenon by means of the contingent measuring instruments and techniques they have at their disposal. This allows for the idea that other (e.g., past or future) instruments may produce a different set of data of the experimental set-up.

Secondly, stable, repeatable patterns of data are produced by stably and reproducibly functioning experimental set-ups, that is, nomological machines, as Cartwright (1983; 1989) put it. Conceptualization of phenomena draws on patterns of data, and, as Feest (2010) proposes, on the paradigmatic experimental set up that produce those data. Consequently, conceptualizations of phenomena also are idiosyncratic to the instruments and measuring apparatuses and procedures that generate the data, and to the specific experimental set-ups.

Following this line of reasoning, I argue that when we ask how concepts are formed (that is, when we inquire about the processes whereby phenomena are conceptualized), the primary question ought not to be whether concepts line up with independently existing, mind independent, pre-given phenomena. The question rather is how conceptualizations arise in relation to manifestations of phenomena that are produced under the highly idiosyncratic circumstances of particular experimental conditions and instruments. My point is that conceptualizing phenomena, as well as the generation of knowledge about them, is inescapably entangled with their technological production and measurement. In other words, concept formation goes hand in hand with the construction of a theory of the domain of the phenomenon, as Feest (this volume) suggests, but also with producing an experimental set-up for investigating it (see also Nersessian in this volume).

2.2 The Material Roles of Phenomena in the Engineering Sciences

In the engineering sciences, *what we want to know* about the world is closely related with wanting to *know how* to intervene with the world.¹ Therefore, our interest in phenomena does not only concern their role as objects, events and processes that guide in the production of scientific knowledge about the world, but also as the objects, etc. that we *create* and *intervene with*.² By intervening with phenomena we

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- 1 Engineering sciences are scientific practices, which must be distinguished from engineering practices. In Boon 2011a, I explain the character of the engineering sciences, and the epistemic relationship between these scientific practices and practices of engineering.
 - 2 The idea that phenomena sometimes are created is not new. Hacking (1983, 220) has argued that phenomena often are created by means of technological instruments, “which then become the centerpieces of theory.” He uses the notion of ‘creating phenomena’ to stress that many of the phenomena in physics

create other phenomena. What is more, we purposefully aim at creating phenomena, not only because of their epistemic role, but also because we want these phenomena for specific technological functions. I will call this the *material role* of phenomena. Hence, in these scientific practices, in addition to their epistemic role, phenomena have a material role to play. By ‘material role’ I mean to point to the fact that the phenomena of interest in the engineering sciences literally are productive of physical effects and functions (or malfunctions, as the case may be). Hence, phenomena can play material roles in two ways: (1) as physical processes or regularities that are manifestations of technological functions, and (2) as objects, processes or properties by means of which the proper and/or improper functioning of technological artifacts is produced. As a consequence, observable phenomena and data not only are manifestations of the world ‘behind’ them in an epistemic sense (i. e., ‘data’ in the sense of Bogen/Woodward 1988). They are also manifestations in a material sense, for instance, of technological (mal)functions.

It should be clear, then, that while I adopt some aspects of Bogen and Woodward’s distinction between the epistemic roles of data and phenomena. I argue that to understand the role of data and phenomena in the engineering sciences, the analysis must be differentiated somewhat further. I will illustrate this in section 2.3 below. On my account, scientific research involves two kinds of entangled activities (also see Hacking 1992). One is the development of *scientific knowledge* that enables thinking about the creation of and/or intervention with phenomena. The other is the development of *technological devices* that *produces* the phenomena under study and/or *allows for interventions with* those phenomena. In scientific research, the development of these technological devices also involves the (qualitative or quantitative) detection of data (in the sense of Bogen and Woodward), both of the phenomena that are manifestation of the technological function (as mentioned in 1) and/or those that are manifestations of the ‘underlying’ phenomena (as mentioned in 2).

do not exist outside of certain kinds of apparatus. Hacking suggests that they emerge by mere chance in experiments, or that they are predicted by the theory, after which they are experimentally produced. My paper points at yet another possibility. New phenomena are *conceptualized* by means of theories or otherwise, rather than *deduced* from them. Subsequently, the conception of a new phenomenon functions as an epistemic tool in the production of scientific knowledge about it to such an extent that this tool enables their (technological) creation.

2.3 The Case of Paint

The above-mentioned roles of phenomena can be made somewhat more concrete by means of a very simple example, such as scientific research and development of paint. The technological function(s) of paint include qualities such as protecting a surface, workability in its application, durability and esthetic qualities. The manifestations of these technological functions involve perceivable and/or quantifiable properties of paint such as its color, its viscosity, and its fastness of drying, its adherence to a surface, its smoothness, its shininess, its hardness, and the stability of these properties. Hence, these are the phenomena that manifest (or display) the technological function. Examples of manifestations of technological dysfunctions of paint are properties (i. e., phenomena as mentioned in section 1) such as the tendency to maintain ripples, the increase of viscosity when applied at higher temperatures, the tendency to capture air-bubbles, the toxicity of the solvent, its poor scratch-resistance, formation of cracks in hardened paint, loss of color and the tendency to turn yellowish under the influence of sun-light. Hence, for a technological artifact to perform its technological function(s), we aim at producing the phenomena that are manifestations of its proper functioning, and prevent or change the occurrence of those that are manifestations of its improper functioning.

A common sense kind of approach to the improvement of the technological functioning would be trial-and-error interventions with the *technological artifact* at hand, for instance, by systematically testing the effects of different kinds of solvents or pigments or filling materials in the case of paint. Sometimes this is considered as a typical *engineering* approach. In addition to the trial and error approach, the engineering *sciences* focus on creating and intervening with the *phenomena* that supposedly produce the proper and/or improper functioning of technological artifacts (i. e., the material phenomena as mentioned in section 2). Examples of such phenomena are evaporation of solvent, molecules responsible for the color of paint, degradation of color-molecules under the influence of heat or light, chemical or physical properties of pigments, and properties such as viscosity, diffusivity, hydrophobicity and surface-tension of the substance.

Hence, the engineering sciences aim at creating or intervening with the phenomena that are manifestations of technological (mal)functioning. That is, they aim to produce, change, control, or prevent these observable or measurable phenomena. Also, they aim at creating or inter-

vening with ‘underlying’ phenomena that are held responsible for those just mentioned—that is, the phenomena that supposedly produce the proper or improper functioning of an artifact.

Nevertheless, these scientific practices usually investigate phenomena of interest in ways that are very much similar to the approaches of experimental practices in the natural sciences (e. g., Hacking 1983, 1992; Franklin 1986, 2009)—yet, with the difference that the ‘ultimate’ purpose of these research practices are the phenomena and their technological production, rather than theories.

3. How Are Phenomena Conceptualized in the Engineering Sciences?

As already explained, scientific researchers in the engineering sciences, in aiming at contributions to the improvement of technological functions, usually think in terms of interventions with phenomena held responsible for the (mal)functioning of a technological device. Technological functions are physically embodied and exerted through technological artifacts such as (assemblies of) materials, processes, apparatus and instruments, which supposedly contain or generate the phenomena responsible for the functioning of these devices. Examples of improving the functioning of existing technological artifacts are: enhancing the energy efficiency of engines, preventing the production of side-products of chemical processes, reducing the degeneration of paint by sunlight, and improving the mechanical properties of biodegradable fibers used in medicine. These are examples of ways in which technological (mal)functioning manifests itself. Scientific research aims at discovering and explaining the causes or contributing factors of, e. g.: the limitation of the efficiency, the formation of side-products, the degeneration of compounds, and physical or chemical relationships between mechanical strength and biodegradability. These causes or contributing factors are what we call ‘phenomena’. Through firstly discovering or determining, and then explaining and/or modeling these causes or contributing factors, scientists and engineers generate knowledge by means of which they may find ways of intervening to the improvement of the technological artifact.

Additionally, the engineering sciences often aim at creating new ways of performing existing technological functions and, even, at creat-

ing newly imagined technological functions. This is done by aiming at the technological creation of phenomena that may not exist as yet, but which have been conceptualized in concert with imagining new technological possibilities. An example of the conceptualization of a new phenomenon is 'artificial photosynthesis'. Scientific researchers imagine that artificial photosynthesis could make possible new ways of generating specific technological functions such as 'producing electrical energy from sunlight' and 'producing fuels from carbon dioxide containing flue gasses and sunlight'. Other examples of technological functions that at some point have been imagined in concert with conceptualizing a phenomenon by means of which these functions could be produced, are: measuring toxic levels of compound X in air (the technological function) by means of utilizing components of the biochemical pathways in lichen L sensitive to X (the phenomenon), separation of pollutant P from waste-water Z (the technological function) by means of a membrane that selectively carries P through its surface (the phenomenon), conversion of sunlight to electrical energy (technological function) by means of a 'light-harvesting molecule' (phenomenon), super-conductivity at relatively high temperatures (technological function) by means of a ceramic material that is super-conductive at high temperatures (phenomenon), and a chemical process that produces exclusively one of the isomeric forms of a drug that has chemical composition M (technological function) by means of a catalyst that converts compounds A and B exclusively to the desired isomeric form of M (phenomenon). In these examples, scientists have developed a (preliminary) conception of a phenomenon in view of its role in performing a technological function.

Conceptualizing a phenomenon for performing technological functions doesn't start from scratch, but utilizes and combines already existing concepts. When struggling with a technological problem, existing concepts are crucial in structuring and articulating preliminary ideas that come to mind, for instance, ideas concerning the kind of phenomenon by means of which we could possibly produce a new technological function or improve existing ones in ways that solve the problem at hand. Different kinds of concepts play a role. Firstly there are established scientific concepts that guide in finding the kind of phenomenon we might be able to (technologically) utilize or intervene with in producing the desired technological function. Examples of such phenomena are, 'membrane transport', 'bio-toxicity of compounds', 'photosynthesis', 'catalytic reactions', 'energy-loss in electricity transport' and 'electricity-

ty-conduction by ceramics'. Additionally, there are concepts that enable thinking about physical and/or technological interventions with phenomena, often in connection with how a phenomenon may bring about (the manifestation of) a technological function. These latter concepts concern types of *operations*. In other words, they concern specific kinds of physical or technological interventions with phenomena. For instance, phenomena (objects, properties and processes) can be physically or technologically created, produced, reproduced, re-built, (and repeated or re-created at other circumstances), isolated, separated, harvested, singled-out, amplified, enhanced, composed, decomposed (in space, time, or matter), joined together, summed up, added up, transformed, transferred, converted, suppressed, repressed, restrained, and reversed. In brief, conceptualizing technologically producible phenomena involves utilizing scientific concepts of existing phenomena as well as concepts of types of operations.

4. How Do Scientific Concepts Enable Epistemic Uses?

In the previous section I have provided a brief overview of the engineering sciences, and in particular of the importance of what I called 'conceptualizations'. I have argued that the conceptualization of phenomena is crucial for the possibility of thinking about them, in particular about how to determine, quantify, create, reproduce, control or otherwise intervene with them. Moreover, I have indicated how my view about the function of *conceptualizations* fits with the thesis stated in the introduction that scientific *concepts* are epistemic tools. Additionally, I have illustrated that conceptualizing a phenomenon for performing technological functions doesn't start from scratch, but utilizes and combines already existing concepts. This makes room for a position according to which existing concepts play a vital role in an ongoing process of conceptualization, i. e., of conceptual change. I will now elaborate my views on this matter.

4.1 Concepts as Epistemic Tools

It needs to be explained how we get from perceptions (in daily life or experiments) to concepts of observable or unobservable phenomena, and why these concepts function as epistemic tools. I will propose

that the formation of concepts of phenomena involves adding epistemic content such as empirical and theoretical knowledge, analogies, and other concepts (also see Nersessian 2009). It is through this additional content that concepts of phenomena are formed. Moreover, as I will argue next, it is by means of this additional epistemic content that these concepts function as epistemic tools. The notion of concepts as epistemic tools will be explained by starting from common sense ideas about the use of concepts of perceivable objects, processes or properties in ordinary language, such as ‘apple’, ‘auto-mobile’, ‘storm’, ‘tides’, ‘heavy’ and ‘fluidic’.

When a child asks, “What is ‘apple’?” we can explain it by pointing at an apple. We can also explain it by specifying its features: apples can be eaten; they are round, red or green or yellow, sweet and sour, and crisp; they weigh about 200 grams; they are grown on trees; they can become rotten; etc. Additionally, an adult can use abstract concepts—i. e., different kinds of *categories*—for finding out more systematically what the word ‘apple’ means: Is it about an object, property or process? What kind of object (property or process) is it? How can we use an apple? What kinds of functions do apples have? How is the object (etc.) produced, or how does it come about? Is the object (etc.) stable or transient? Is it natural or artificial? Is it organic or inorganic? Which are its perceivable properties? What are its shape, size, weight, color, smell, taste, and texture?

In this way, humans have learned to *recognize* an apple, and to *use the word* ‘apple’, as well as to *think about doing things with* apples. Moreover, we expect that the child has learned to recognize *manifestations* of apples by perceiving only some of their features (e. g., their smell or shape only). Also, we expect that the child will recognize *uses* of apples (e. g., in an apple-pie). Furthermore, when grasping a concept of perceivable things, events or properties, humans are able to recognize *representations* of apples, for instance in texts (e. g., when the author speaks of a juicy, sweet and sour, crispy thing) or in pictures (e. g., on photographs, paintings and drawings). In addition, craftsmen such as the fruit grower or the cook are able to ask sensible questions about apples, and to think of interventions with growing apples that may change specific features. Why do apples get a musty taste? Can we grow apples that are bigger, sweeter, and less sensitive to insect damage, keep longer, and taste of apricots? How should we store apples to keep them? Can we apply apples as a thickener in home-made jam? Clearly, the concept of apples that craftsmen have in mind is epistemically richer than the un-

derstanding of apples that the child has. Or putting it the other way round, by utilizing the concept for asking questions that are relevant in a specific application context, these craftsmen are *enriching* its epistemic content.

These examples aim to illustrate that concepts of things (or more exactly, phenomena) play a role in diverse epistemic activities that concern, for instance, doing something with these things. I will suggest that thinking about things such as apples in the mentioned kinds of ways—which includes asking sensible questions about them—is guided and enabled by the concept of it that humans have in mind.

4.2 How Do Concepts of Perceivable Objects, Processes and Properties Enable Epistemic Use?

Philosophical accounts often have focused on the idea that concepts are definitions, which provide the necessary and sufficient conditions for applying the concept. On this account, the meaning of, say, ‘apple’, is given by specifying a conjunction of properties. If P_1, P_2, \dots, P_n are all the properties in the conjunction, then anything with all of the properties P_1, \dots, P_n is an apple (also see Putnam 1970). Wittgenstein opposed this view, arguing that we learn the meaning of a concept by its use rather than by presenting its definition. While refraining to take a position in this debate, I wish to emphasize that the ability to use a concept not only concerns its correct application, whether learned by means of a definition or by its use. Grasping a concept also involves the other mentioned kinds of epistemic uses. Putting it this way emphasizes the epistemic function of concepts. It is assumed that concepts enable the mentioned variety of epistemic activities. Therefore they can be called *epistemic tools*. Using a concept as a definition is just one way of being an epistemic tool.

The question remains, *why* concepts enable the different kinds of epistemic uses just mentioned. I propose that this has to do with several characteristics of conceptualizing perceivable objects, properties and processes. In what follows, I will present a *systematic* account of the formation of concepts that aims at explaining how concepts enable and guide epistemic uses. Saying that it is ‘systematic’ means to emphasize that it is a philosophical account, rather than a historical or empirical description of how concepts are formed, nor is it a scientific theory, such

as a theory that describes the psychological mechanism of the formation or learning of concepts.

Above, it has been suggested that explaining or learning a concept involves two cognitive activities, namely, perceiving the object and conceptualizing it. I assume that explaining or learning the use of a concept is similar to how new concepts of perceivable objects are formed, and also, how already existing concepts are enriched or improved. This is why the given example of learning, explaining and enriching a concept is used for developing a systematic account of the formation of concepts that explains in what manner these concepts enable and guide different kinds of epistemic activities.

The example of how ‘apple’ is explained, illustrates that explaining a concept involves using *categories*—that is, more abstract concepts are used that enable, for example, to articulate that ‘apple’ refers to an object (rather than to an event or a property, etc.), and that it is a fruit (rather than an animal, etc.). Categories are more abstract concepts, which are ‘applied to’ perceptions of things (objects or properties or processes). Another way of putting this is to say that perceptions are subsumed under specific kinds of concepts, which are applied because these categories suit the perceived thing and general kinds of epistemic uses of the resulting concept.³ In this way, more abstract concepts (such as ‘object’ or ‘fruit’) become part of the concept that is being formed (e.g., ‘apple’)—they are, so to speak, *built into* the concept.

For the sake of simplicity, suppose that we would start off by forming a concept of what we perceive, by means of only the two kinds of abstract concepts (object and fruit) just mentioned. The idea defended here is that the use of these abstract concepts *introduces conceptual and epistemic content that goes beyond what is perceived*. This additional content enables epistemic uses, both in the further development of the concept, and in thinking about, say, apples. Saying that A is an object informs us about properties that *objects* typically have, without actually having seen that A has them. For this reason, calling something an object introduces knowledge about it, such as that it is solid; that it has a size, shape,

3 My account of concepts heavily leans on Kant’s ideas. My interpretation lines up with Allison’s (2004) interpretation of Kant’s transcendental idealism. Furthermore, my understanding and application of Kant’s ideas is deeply indebted to Neiman’s (1994) explanation of Kant’s philosophy of science, which she interprets in terms of his third critique. Also see Massimi (2008; 2011), Rouse (2011) and Boon (2009).

weight, etc.; that it can be transported from one location to another; and that it has specific properties. Calling something a fruit tells us that it is organic, edible, tender, etc. The conception thus formed enables diverse epistemic activities. It directs in asking specific kinds of questions about the object under study, such as what is its size, shape, weight and taste, by means of which the content of the concept is developed further. In sum, conceptualization involves the use of categories by means of which we introduce conceptual and epistemic content that enable creative thinking and asking empirically testable questions about the object, because these categories *articulate* significant distinctions (e.g., a specific kind of entity or property), contrasts and dissimilarities, or analogies and similarities, which thus adds to what is merely empirically given when perceiving something.

This is not to say that the abstract concepts applied in the formation of a concept are automatically adequate. It may very well turn out that we come to agree that the object is more like a kind of vegetable than a fruit, or that these things are apples albeit they are pear-shaped, or that apples tasting of apricots must be classified as a different kind of fruit. Nevertheless, the idea of concepts as epistemic tools accounts much better for the situation that a concept may turn out to be inadequate than the idea that concepts are first and foremost definitions that provide the sufficient and necessary conditions for its correct application. When considered as epistemic tools, concepts typically entail empirical knowledge characteristic of the object, as well as abstract conceptual content, and (hypothetical) epistemic content. The abstract conceptual content is introduced by means of categories of which we expect that they suit to our perceptions. The epistemic content is derived from the conceptual content and concerns aspects that can be empirically tested or determined.

Imagine, for instance, that we call this object a fruit. Through applying this category, we are enabled to infer that this object must be sweet and sour. But this inference may be proven empirically wrong. The latter observation may either lead to a revision of the category 'fruit' (e.g., not all fruits are sweet and sour), or to a new category (e.g., veggie-fruit), or to revising the conception of this object (e.g., it is not a fruit), etc. Hence, there is no warrant that the epistemic content that has been added to the concept by applying certain categories is true about the object. Instead, conceptual content, and the hypothetical epistemic content derived from it, enable investigation of the object—that is, this content enables articulating hypotheses and asking questions, by

means of which new things are learned about it, for instance, whether the epistemic content is correct about the object, and whether the concept sufficiently suits the object.

The idea of concepts as epistemic tools is meant to be an alternative to the idea that concepts of objects, events and properties are first and foremost definitions. This is not to say that I reject the idea that definitions can serve a purpose. Once a concept has been firmly established, important functions in ordinary language-use are made possible—for instance, to facilitate economy of words and refinement of meaning, to recognize an object or occurrence as of a particular kind, and to enable adequate descriptions and explanations of a situation. These kinds of uses require that language-users agree on the proper uses of concepts, which implies that concepts must have a definitional character as well. Accordingly, their use as a definition is one of the ways in which concepts function as epistemic tools.

Yet, disagreement between the traditional idea that the meanings of concepts are provided by definitions versus the idea proposed here that definitions also function as epistemic tools concerns suppositions about the epistemic function of concepts. Philosophers may have specific assumptions on how definitions are or should be established. Significant to the idea of concepts as epistemic tools is that concepts entail conceptual and epistemic content transcending the mere empirical information given through perception. Conversely, the empirical tradition has been striving at an account of concepts as definitions that are strictly faithful to what is empirically given. In that account, a concept is a description or representation of, say, properties that every apple has. In other words, in traditional views the correctness of a concept involves that it correctly describes or represents perceivable characteristics of the thing it defines.

However, the idea that the content of a concept is restricted to empirically correct descriptions or representations—e.g., descriptions of the characteristic perceivable features of the thing it is a concept of—cannot account for several of the epistemic uses of concepts. Most importantly, it cannot account for epistemic uses that are made possible by means of the conceptual content added when subsuming a perception under a category such as discussed above. Another important epistemic use of concepts is that they enable us to recognize that something is a *representation* of something else. Someone may object that it doesn't require the concept of an apple to recognize that this drawing is a representation of it. Kant's famous saying that "perceptions without concepts are blind, whereas concepts without perceptions are empty," may help

in explaining my point. Consider, for instance, how humans are able to recognize a one-line drawing of an apple or a rabbit or a duck, say, in a Picasso. Imagine that we present a fox with such a drawing of a duck. Although the fox may be very hungry and would love to eat a duck, we can be pretty certain that the fox won't recognize a duck on this paper. Kant's insight applies as follows: Concepts of perceivable objects enable humans to recognize the object when looking at a 'representation' of it. More precise, "when looking at a 'representation' of it," means "when humans look at what *they* are able to recognize as a representation of an object." The point is that concepts are the tools by means of which the ability of such recognition is exercised. Without concepts humans would respond similar to other animals—they would not recognize the represented object. Hence, the concept of a duck or a rabbit enables recognizing descriptions or representations of them.

So far, I have aimed to make plausible that the formation of concepts of perceivable objects, properties or processes involves the *interplay between existing concepts and perception*. In this way, *heterogeneous content* is put together, which is the content of the concept. The formation of a concept is described more systematically as follows: (a) Conceptual content is added through the application of relevant categories. These categories can be very abstract, such as 'object' or 'property' or process, or more concrete, such as 'fruit'. (b) Epistemic content is added empirically, that is, by means of perception. Yet, the epistemic content added to the concept of 'apple' as characteristic of apples by means of perception is selected by means of the mentioned categories; for instance, calling something a fruit brings more specific categories with it (e.g., taste and shape) that guide which empirical information we gather through perception (e.g., that its taste is sweet and sour, and that its shape is round), and thus become part of the concept. What is more, these specific categories also guide which information possibly given in our perceptions of apples we ignore when forming a concept.

It is proposed that concepts can function as epistemic tools because of this heterogeneous conceptual and epistemic content, which must be fitted together, thereby drawing coherent, consistent and relevant relationships by means of which the concept is developed to a whole. In order to clarify somewhat further why concepts thus understood enable epistemic uses, the notion of *epistemic tools as designs* will be proposed as a metaphor of how concepts are formed and why they enable epistemic uses.

4.3 Conceptualization of Properties in Experimental Practice: The Case of Elasticity

I side with Feest's idea of concepts of phenomena as epistemic tools (or 'research tools', as she calls them) for examining them in experimental set-ups. Her emphasis is on the interrelated activity of experimentation and concept formation. Yet, it needs to be explained how scientists get from an operational definition—which on her account is a description of significant aspects of a paradigmatic experiment—to a (preliminary) concept. Feest's (2010) account seems to suggest that preliminary concepts coincide with operational definitions. I will propose that the formation of concepts of unobservable or 'underlying' phenomena involves descriptions of significant aspects of paradigmatic experiments, as Feest (2010) suggests, but also involves adding epistemic content similar to how the concept of 'apple' is formed. Again, it is through this additional epistemic content that these concepts function as epistemic tools.

Examples of phenomena in the engineering sciences that have been conceptualized by means of paradigmatic experiments are material properties such as 'elasticity', 'specific weight', 'viscosity', 'specific heat-content', 'melting-point', 'electrical resistance', 'thermal conductivity', 'magnetic permeability', 'physical hysteresis', 'crystallinity', 'refractivity', 'chemical affinity', 'wave-length', 'chemical diffusivity', 'solubility', 'electrical field strength', 'super-conductivity', and 'atomic force'. Each of these properties is related to paradigmatic experiments by means of which they were initially defined.

Hooke's experimental set-up, for instance, in which he measured the extension of a spring as a function of the weight, can be regarded as a paradigmatic experiment by which 'elasticity' was operationally defined. The description of the paradigmatic experiment is something like, 'the reversible (and proportional) extension of a spring by a weight', which is the observable phenomenon. The preliminary operational definition of elasticity derived from it is roughly: 'the qualitative and quantitative *property* of a spring to reverse its stretch when extended by a weight'. This definition enables proposing a more abstract definition of elasticity as: 'the measurable property of an object to reverse a deformation imposed by a force'. Hence, by means of the description of a paradigmatic experiment researchers infer to an operational definition of a phenomenon. In turn, this definition can be applied to situations different from the paradigmatic experimental set-up: In any case

where reversible deformation of an object occurs, we attribute the property ‘elasticity’ to the object and assume that it is quantifiable, independent of the kind of object, the kind of matter and the kind of force involved. In this way, such concepts acquire a definitional character, which enables their epistemic uses in new situations.

This example of conceptualizing properties such as ‘elasticity’ illustrates that concepts of phenomena expand on the operational definitions by means of which they were originally formed. Similar to the case of ‘apple’, conceptualizing ‘elasticity’ involves subsuming descriptions of observations under a more abstract concept. As a result, the concept ‘elasticity’ refers to a qualitative and quantifiable *property* (rather than an object or process).

4.4 Scientific Concepts as Epistemic Tools in the Sense of a Design

The question at hand is how scientific concepts of (novel or unobservable) phenomena are formed, ~~how~~ it is possible that these concepts guide in the generation of knowledge about phenomena that cannot be perceived in any interesting sense of that word and which often concerns (aspects of) phenomena that do not even exist as yet. So far, it has been proposed to understand the functioning of scientific concepts of phenomena as *epistemic tools*. Accordingly, *conceptualization* must be considered in terms of *making* epistemic tools. Scientific concepts of phenomena are epistemic tools because they enable thinking about determining, creating, reproducing and intervening with the phenomenon under study. In addition to that, they point at research questions relevant to the ongoing production of knowledge about the phenomenon. In other words, scientific concepts are epistemic tools because they enable the mentioned kinds of *epistemic activities*.

Here, it is proposed to consider these epistemic tools similar to how we understand a *design*. Accordingly, the formation of a concept is considered as *making a design*. The metaphor of epistemic tools as a design will be utilized in developing an account of how we acquire knowledge of phenomena that cannot be observed in any direct manner, and of phenomena that may not even exist. A design firstly is an epistemic tool *for* an object, rather than a definition or a representation *of* it. A design is not produced by means of representing an object that is observed or has been discovered somewhere. If, for instance, someone would draw the Deposition Church of the Moscow Kremlin, we do not con-

sider this representation a design.⁴ Instead, a design is made by constructing a representation, either of an object that does not exist as yet, or of what an existing object will look like when it undergoes certain structural interventions. A design must be constructed such that it can function as an epistemic tool in the sense that it enables thinking about how to build a non-existing object or how to intervene with an existing object in order to change it. Additionally, the design of an object functions as an epistemic tool because it enables to ask significant questions about the designed object, thus guiding to the refinement of our knowledge and understanding of it. Scientific concepts of phenomena function in a similar fashion. As will be explained in more depth, the (partly hypothetical) epistemic content introduced through their conceptualization enables to ask research questions which guide the refinement of our knowledge and understanding of the phenomenon.

Another important characteristic of a design is that it puts together heterogeneous aspects. In fact, the ultimate challenge of designing is not a correct representation of the designed object, but an adequate fit of *heterogeneous epistemic content* concerning ‘real world aspects’ of the object, such as its structure, the materials used, the construction techniques needed, the measures taken for its safety and robustness, etc. In designing an object, these different kinds of aspects must be chosen and molded such that they fit together. They must both make up for the epistemic functions of the design and agree to the requested practical functions of the designed object.⁵ As a result of both its heterogeneous epistemic content, and the relationships drawn between heterogeneous parts of the design, as well the relationships drawn between the epistemic content and ‘real world aspects’, the design can be used as an epistemic tool. It enables thinking about how to actually build (= create) and intervene with the designed object. Also, it may point at aspects that need to be investigated or elaborated in more depth. As a result of this latter role, a design is not only an epistemic tool for thinking about the designed object—it also is an epistemic tool of its own making.⁶

4 Nevertheless, as has been argued, concepts—such as the concept of a cathedral—enable humans to recognize a drawing of it as a representation of a cathedral.

5 When the idea of ‘matching heterogeneous content in designing an object’ is applied to how concepts of phenomena are formed, it resembles Hacking’s (1992) idea of the self-vindication of scientific practices.

6 The same point has been made about scientific modeling of a phenomenon: “... models function also as epistemic tools of their own making. Scientists de-

The notion of scientific concepts as epistemic tools in the sense of a design also suits for explaining why a scientific concept is accepted, and why at some point scientific practices may discard of it. The adequacy of a design does not first and foremost consist in how well it depicts the resulting object, but in its capacity to facilitate the desired epistemic functions. Similarly, a scientific concept of a phenomenon is adopted because it enables thinking about the phenomenon and facilitates investigating it. At the same time, using a scientific concept does not necessarily involve that it is about an existing phenomenon. Rather, *a scientific concept makes the phenomenon thinkable in ways that agree with relevant empirical, technological and scientific knowledge of the world* (see also Rouse 2011). Conversely, we discard a scientific concept when it appears to disagree too much or when it has become redundant.

Similar to how a design enables thinking about aspects of the world that are unthinkable without it, scientific concepts enable thinking about phenomena that may not exist, and that cannot be thought of without them. What is more, they enable thinking about phenomena that cannot be perceived directly. Through scientific concepts we get an epistemic handle for investigating and intervening with the world. In this account, we avoid the idea that the successful epistemic functioning of scientific concepts can only be explained by the apparent miraculous fact that concepts correctly depict phenomena. Instead, scientific practices have the capacity to make scientific concepts that function as epistemic tools, not because scientific concepts correctly depict phenomena, but because their functioning is more like the functioning of a design.

There is, however, a conceptual pitfall in the use of ‘design’ as a metaphor to describe scientific concepts as epistemic tools. In case of a design, once built, the real object can be visually compared with the design. At that point, the design is reduced to a picture of the real object—which is not to say that the design has lost entirely its epistemic function, as it may very well be reused in thinking about the real object, such as in making calculations about specific performances, and in thinking about improving its performance. A scientific concept, on the other hand, cannot be directly compared with the phenomenon. Therefore, the comparison falls short in this respect: An established sci-

velop a model step-by-step, building in new aspects by which the content of the model becomes richer and more advanced. As an epistemic tool it ‘affords and limits’ also its own further development ...” (Knuuttila/Boon 2011, 699).

entific concept does not become a representation of the phenomenon similar to how a design ‘finally’ becomes a picture of the real object.

5. Conclusions

I have proposed to consider scientific concepts of phenomena in the engineering sciences as epistemic tools in the sense of a *design* for them, rather than a *definition* or *picture* of them. Accordingly, we can think of *conceptualizing a phenomenon* as the activity of designing an epistemic tool. This activity involves adequately choosing and matching *heterogeneous epistemic content* concerning ‘real world aspects’ of the phenomenon relevant to its determination, behavior and functioning, such as: its empirical manifestation, its matter, its physical properties, and its physical connections with technological devices. This is done by applying more abstract concepts (i. e., categories) to perceptions (or empirical data)—in other words, perceptions (or empirical data) are subsumed under categories. As has been explained, a scientific concept thus produced entails empirical, conceptual and epistemic content relevant to the (imagined) phenomenon. It also entails relationships amongst this content, and between its content and ‘real world aspects’.

The question might be raised, however, how the presented account of scientific concepts of phenomena explains their functioning as epistemic tools. In other words, why does the heterogeneous content drawn together in the concept enable investigating how to actually create and intervene with the conceptualized phenomenon? In particular, how can my analysis of concepts like ‘apple’ ~~be transferred to the formation of scientific concepts of unobservable phenomena that have been formed on the basis of observed phenomena and empirical data?~~

In this paper I have suggested that through the conceptualization of a phenomenon epistemic content is introduced that enables to ask research questions which guide the refinement of our knowledge of the phenomenon, and also our understanding of how to create it or intervene with it. Firstly, abstract conceptual content is added through the application of abstract categories such as ‘object’, ‘process’, or ‘property’. In this way, the unobservable phenomenon is considered as an object, process, or property. The above example of the concept of elasticity illustrates that abstract categories introduce conceptual and epistemic content that is partly hypothetical. Again, calling something an *object* introduces knowledge about the purported phenomenon, such as that it is

solid; that it has a size, shape, weight, etc.; and that it can be transported from one location to another. Conversely, when calling something a *property* we know that it cannot be transported, but that we may be able to produce it in other objects, or that we may change (e.g., improve) it in a quantitative sense. It has been argued that conceptual and epistemic content thus added to the concept enables specific ways of thinking and asking questions about the phenomenon—for instance, on how it is produced, and whether it can be reproduced in other kinds of materials (in case of a property such as ‘elasticity’), or whether it can be transported (in case of an object). Importantly, applying the category ‘object’, ‘process’, or ‘property’ in conceptualizing an observable phenomenon differs from applying these categories for interpreting empirical findings of experiments thus inferring to unobservable phenomena. On the one hand, these abstract conceptual notions guide to the same kind of thinking and asking questions about the phenomenon. At the same time, we may be wrong in thinking that the unobservable phenomenon has all the aspects that we attribute to it due to calling it an *object*, etc. Therefore, by calling it an object, we have introduced *hypothetical* epistemic content to the scientific concept. This hypothetical epistemic content enables epistemic uses, for instance, to the conclusion (e.g., by means of empirical tests), that it doesn’t accord in every respect to the ideas introduced by means of this abstract category (see Knuutti-la/Boon 2011 for an example).

Secondly, less abstract categories can be employed in the formation of concepts of an unobservable phenomenon, such as categories which tell that it behaves like a gas, fluid, or a solid compound; that it is chemical or hydro-dynamical or electrical or biological; etc. In other words, we apply categories which tell that the purported phenomenon is of a certain kind. The addition of this content enables epistemic uses similar to those just mentioned, namely, adding partly hypothetical epistemic content and asking sensible questions that guide in further research.

Finally, another class of concepts that may be used in the conceptualization of concepts of unobservable phenomena concern *types of operations* (such as those mentioned in section 3), which enable creative thinking about intervening with them or creating them. Carnot (1824), for instance, conceived of *reversing* the processes that he had conceptualized when explaining how heat produces motive power (also see Knuutti-la/Boon 2011). Similarly, concepts of phenomena such as ‘photosynthesis’ enable contemporary scientists to creatively think about technological possibilities, such as *artificially producing* useful parts of

this phenomenon for technological applications (e.g., Pandit et. al. 2006; Huskens et. al. 2010); and creating artificial molecules for *harvesting* light in ways that could become technologically applicable (e.g., Savolainen et. al. 2008).

If my account of the formation of scientific concepts of phenomena in the engineering sciences is correct, it implies that scientific concepts of phenomena do not present us *certain* knowledge about what the world is like. I have aimed to make plausible that without adding conceptual content to empirical data in ways such as explained in this paper, we would never be able to get beyond what is empirically given. This idea agrees to Kant's important insight that the capacity to produce knowledge of the world requires the capacity to go beyond experience (also see Neiman 1994, 59). This idea also agrees with Rouse (2011), who challenges the assumption that the aim of science are true or empirically adequate theories. Rouse argues in favor of an image of science that would place conceptual articulation at the heart of the scientific enterprise. According to him, "[c]onceptual articulation enables us to entertain and express previously unthinkable thoughts, and to understand and talk about previously unarticulated aspects of the world." Aiming at strict certainty—that is, avoiding any content that goes beyond what is empirically given—would drastically reduce our ability to develop knowledge that enables us to think about interventions with the world that are unthinkable without this knowledge.

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