"How Science is applied in Technology: Explaining Basic Sciences in the Engineering Sciences"

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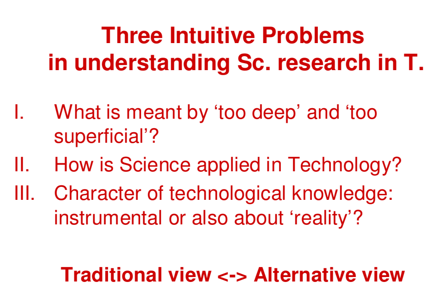
Abstract

The issue of this oral presentation is "How Science is applied in Technology"; more specifically, how science is used in developing knowledge of phenomena and processes that occur in technological devices. Firstly, a traditional picture of applying science in technology is sketched. This picture is inappropriate for understanding how science is used in the engineering science. Next, and alternative picture is proposed. In this alternative view, engineering sciences aim at models of physical phenomena in technological artifacts. A distinction is made between three types of models: diagrammatic models, nomo-mathematical models and experimental models. These models are mutually related,involve different types of already existing scientific knowledge, and involve distinct epistemological claims.

Oral Presentation

The issue of my presentation is "How Science is applied in Technology"; more specifically, how science is used in developing knowledge of phenomena and processes that occur in technological artifacts. Therefore, I will present a picture of how scientific research in technology can be understood.



I will start with three problems, not from the perspective of a philosopher, but from the perspective of an engineer doing scientific research that is dedicated to technological design. These are in fact three intuitively formulated problems that I encountered in my research as a chemical engineer.

1) The first problem of a researcher is to find a middle-way between being too deep and too superficial. This is an intuitive distinction, and it is vague what is exactly meant here. Better understanding of this distinction is important to research methodology.

2) The second problem a researcher may have is: "How to understand the application of scientific knowledge in developing technological knowledge?" This, also is important to the development of research methodology.

3) The third problem is: What is actually the character of technological knowledge. Does it only provide us with instrumental knowledge or is it telling us something about reality also? This problem is relevant to judgment of the reliability and generality of knowledge produced.

These intuitive problems of engineers in scientific research are usually dealt with in terms of an - often implicit - traditional view on the epistemic relation between science and technology. I will shortly explicate this traditional view, which appears also to be held by many philosophers of technology. Next, I will criticize this traditional view and propose an alternative that is more appropriate to existing practices.

Three Problems
of understanding Sc. research in T.

I. What is meant by 'too deep' and 'too superficial'?
II. How is Science applied in Technology?
III. How to unite a realist and instrumentalist interpretation of knowledge?

Traditional view <-> Alternative view

ad 1)

I will start with the first problem. In the traditional view science and technology are ontologically distinguished. An example of this idea is found in the following quote of a philosopher of technology:

Henryk Skolimowski: *The Structure of Thinking in Technology.* (1966)

"There is a fundamental difference between the ontological character of scientific and technological knowledge … this difference can be best grasped by examining the *idea* of scientific progress and the *idea* of technological progress."

"Science aims at enlarging our knowledge through devising better and better theories; technology aims at creating new artifacts through devising means of increasing effectiveness. Thus the aims and the means are different in each case."

Another example is a quote of the mathematician and engineer, Vannevar Bush, who wrote an influential report on the relation between science and technology.

Vannevar Bush: *Science – The Endless Frontier (1946)*

"'Basic' or 'pure' research is being performed without thought of practical ends, leading to general knowledge and understanding of nature and its laws".

"Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science".

Thus, scientific and technological knowledge are regarded as fundamentally distinct types of knowledge:

Ontological distinction Sc-T

Scientific knowledge	***Technological knowledge***
Laws about **physical phenomena** in 'Nature'	Practical knowledge about **technological artifacts**

Problem: **physical phenomena** in **technological artifacts**.

This also results in defining distinct epistemological aims: Science aims at theoretical knowledge of natural phenomena, whereas technology aims at practical knowledge of man-made technological artifacts. Philosophers of technology summarized this idea by the slogan "Science aims at truth, technology aims at use."

A problem of this ontological distinction between science and technology is that theoretical knowledge of physical phenomena in technological artifacts is excluded.

An example is knowledge of thermodynamic cycles in heat engines. In the traditional view is not clear whether this is scientific or practical knowledge?

Concepts 'Alternative' View

1. Engineering Sciences aim at explaining and describing physical phenomena that occur in technological artifacts.
2. 'Engineering Sciences' mediate between 'Basic Sciences' and 'Technological Design'

'Too deep': only physical phenomenon
'Too superficial': only technological apparatus

In my 'alternative' view the notion 'Engineering Sciences' is introduced. I will propose a pragmatic definition - as opposed to the ontological distinction:

1. Engineering Sciences aim at explaining and describing physical phenomena in technological artifacts. This also involves knowledge about how to manipulate these phenomena in technological devices.
2. Engineering Sciences use existing scientific knowledge in producing knowledge that can be used in technological design. This requires replacing the traditional ontological distinction between 'science' and 'technology', by three alternative concepts: 'Basic Sciences', 'Engineering Sciences', and 'Technological Design'. Those concepts are commonly used in existing practices. In this triad 'Engineering Sciences' mediate between 'Basic Sciences' and 'Technological Design'.

This revision of concepts is the first step in developing an alternative view for better understanding how scientific knowledge is used in technology.

With regard to the researcher in the engineering sciences, the first intuitive problem can now be elucidated:

'Too deep' means: developing knowledge of physical phenomena detached of relevant circumstances in the technological artifact.

'Too superficial' means: developing knowledge of the technological artifact without understanding physical phenomena involved.

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Traditional view <-> Alternative view

ad 2).

The second problem for a scientific researcher in technology is how to understand the application of science? This involves certain epistemological problems.

In a traditional view of the relation between science and technology, science provides technology with scientific laws that can be 'filled out' at proper boundary conditions. This is illustrated with the following quote of a professor in chemical engineering:

H.F. Rase: *The Philosophy and Logic of Chemical Engineering.* (1961)

"The basic laws commonly used in chemical engineering are laws of chemistry and physics and, therefore, chemical engineering has no basic laws per se. .... Chemical engineering is an applied science; and its genius lies in its ability to apply these laws of science, not only those listed but laws from any science that are needed to solve a process problem. Competent chemical engineers have always succeeded in creating useful things for society by applying the laws of science."

According to this view, in order to apply science in technology one has to subsume a phenomenon occurring in a technological artifact under a general law. This model of scientific explanation is called the deductive-nomological model.

D-N model of explanation and prediction

L1, L2, ..., Lr	Explanans sentences
C1, C2, ..., Ck	Special conditions
E	Explanandum sentence

Epistemological Problems:

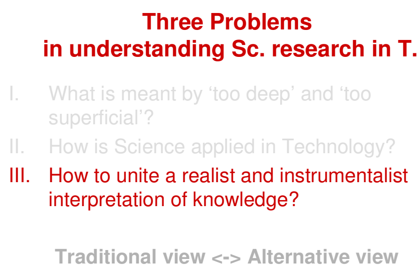
1. Laws are not true of phenomena. Application of laws requires approximation etc.
2. Scientific theories do not give rules how to approximate, etc.

As we know from philosophy of science, the deductive-nomological model of explanation, involves certain epistemological problems, which are also very relevant to the Engineering Sciences.

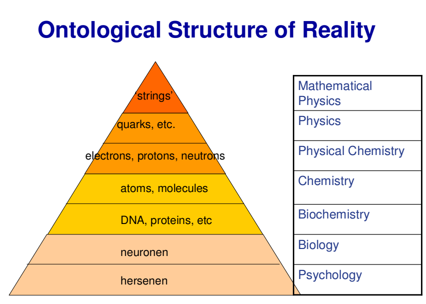
(1) As has been explained by Nancy Cartwright, applying basic scientific laws for describing concrete phenomena usually requires idealizations, de-idealizations, approximations, simplifications and ad-hoc extensions. (2) Scientific theories, however, do not give rules how to idealize, de-idealize, approximate, simplify and extend a scientific law in order to make the law fit for concrete phenomena.

Cartwright’s solution to this problem, in my understanding, is an alternative metaphysical position. I will explain this position in view of my third problem.

ad 3).



In engineering practice and in philosophy of technology so-called ‘basic’ scientific knowledge is often interpreted realistically, whereas technological knowledge is seen as purely instrumental. This is also expressed in the already mentioned slogan 'science aims at truth, technology aims at use’.

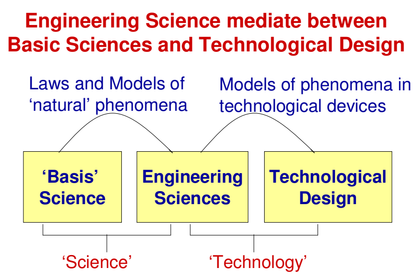


This traditional view involves an ontology that is summarized in this scheme. In this ontology scientific knowledge is about these hierarchically ordered basic constituents of the universe.

My alternative view for explaining the engineering sciences involves Cartwright’s ontology of causes and capacities. That ontology rejects the traditional reductionistic picture, represented in this scheme. Instead, the primary aim of science is discovering capacities and causal structures, and how these are affected by concrete physical conditions, and by other capacities and causes.

In Cartwright's view capacities and causal mechanisms are represented in models, - not in scientific laws. So, in my alternative view, the construction of models is also central to the engineering sciences.

Having sketched my alternative view for understanding scientific research that is dedicated to technology, I will now explain how in my understanding models are constructed in the engineering sciences.



The idea that the engineering sciences mediate between basic sciences and technological design, involves the idea that laws and models developed in the basic sciences are somehow applied in the engineering science, and that the engineering sciences produce knowledge that can be applied in technological design. The knowledge produced in the engineering sciences are models of physical phenomena in technological devices. It will now been explained how these models are constructed.

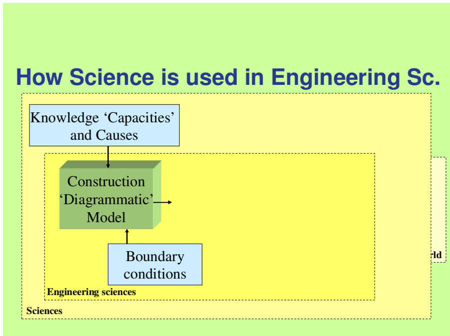
Construction of Models in Eng.Sc.

- Types of models:
  1. Diagrammatic models
  2. Nomo-mathematical models
  3. Experimental models

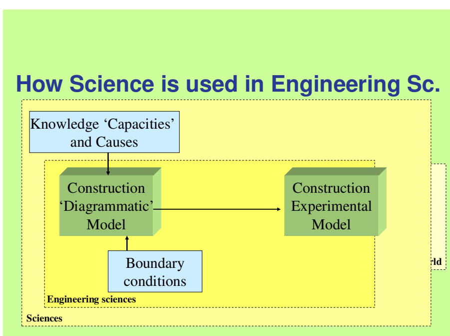
Three different types of models are involved in the understanding and describing of physical phenomena that occur in technological devices. I have called them:

1. Diagrammatic models
2. Nomo-mathematical models
3. Experimental models

Diagrammatic models



(1) A diagrammatic model aims **at representing the causal behavior of the physical phenomenon** under examination.[1] It is therefore, representing the causal or physical mechanism. Constructing this model requires causal understanding of how the phenomenon – represented in terms of relevant physical parameters - is affected by other physical phenomena in the technological device. This involves scientific knowledge of capacities and causes.



Based on the diagrammatic model an experimental model is constructed that aims at examining the postulated capacities and causal structures. Diagrammatic and experimental models are related by using physical parameters that can be measured or manipulated in the experiment.

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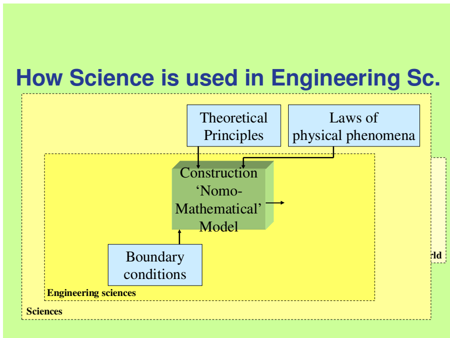
[1] This model is called a 'diagrammatic' model since it often involves diagram or graph-like schema's. It intends to explain the behavior of physical parameters, not physical phenomena for which the notion 'iconic model' is used.

Nomo-mathematical model

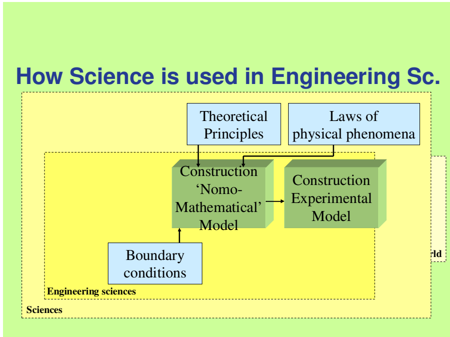


An approach that can also be found in the engineering sciences is the construction of - what I will call - a nomo-mathematical model.[2] This model aims at a mathematical description of the behavior - or dynamics - of the physical phenomenon, which – again - is represented in terms of certain relevant physical parameters. The nomo-mathematical model consists of a set of mathematically formulated physical laws. These laws relate physical parameters by means of mathematical formula.

In the construction of a nomo-mathematical model two types of scientific knowledge play different roles:

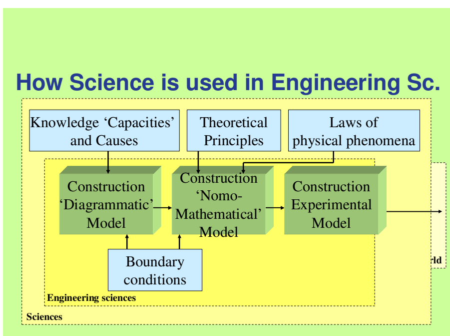
1. Firstly, theoretical principles. These principles determine physical constraints about what is allowed in the model construction. For instance, in chemical engineering, the laws of conservation of mass, momentum, heat and chemical compound set physical constraints to the nomo-mathematical model.
2. The second type of scientific knowledge is existing scientific laws that mathematically describe the behavior of physical parameters as a function of other parameters. Such laws may have been developed in 'Basic Sciences', but also in the engineering sciences An example is the Navier-Stokes equation, or Fick's law for diffusion.

[2] I have introduced the term nomo-mathematical model since the term mathematical model is very confusing. Mathematical models are used in mathematics and do not have a physical meaning. The term is an analogy after Hempel's nomo-logical model. In a nomo-mathematical model laws are mathematically related instead of logically.



The nomo-mathematical model claims to provide an adequate mathematical description of the behavior of physical parameters relevant to the intended application of the knowledge produced, and is interpreted instrumentally.

Like in the case of diagrammatic models, also for nomo-mathematical models, an experimental model can be constructed. This experimental model aims at examining the adequateness of the set of mathematical equations, to which it is related by means of physical parameters that can be measured or manipulated in the experiments.



A more sophisticated possibility in the engineering sciences is to integrate the two approaches of model construction. In this integrated approach, the three types of models represent three phases of model construction. The nomo-mathematical model is now constructed on the basis of the diagrammatic model. The experimental model may now involve experiments that examine the causal behavior, as well as experiments that aim to test the mathematical description.

An example of this type of model construction is how Prandtl developed a model for liquid flows around spherical objects, as was analyzed by Margaret Morrison in *Models as Mediators*. Distinguishing between two liquid phases with different types of behavior - a boundary layer at the surface of the sphere, and turbulent flow farther away – is what is modeled in the diagrammatic model. In the nomo-mathematical model the liquid behavior need to be mathematically described. The Navier-Stokes equation is existing scientific knowledge that is used for constructing a mathematical description of the boundary-layer behavior; the Euler equation is used for constructing a mathematical description of the turbulent phase. Theoretical principles such as conservation of mass and momentum are used to merge it into a set of mathematical equations for the whole system.

What may be new in my account – as compared with existing literature on the role of models in scientific research – is that a distinction is proposed between model construction that involves knowledge of physical behavior in terms of capacities and causes that produce the phenomenon, and model construction that involves knowledge of mathematically formulated laws. It is important to recognize that the models are related via the physical parameters that represent the physical phenomenon in the context of an intended application of knowledge produced.
Both diagrammatic and nomo-mathematical models aim to represent the physical phenomenon in a technological device. However, the two model types involve two distinct epistemological criteria: the diagrammatic model aims to be true about the capacities and causes that produce the behavior of the phenomenon, whereas the nomo-mathematical model aims at an appropriate mathematical description of the behavior of physical parameters that represent the behavior of the phenomenon.

The assumption is that the nomo-mathematical model is more reliable in physical domains beyond the physical conditions in the measurements when it is based on a diagrammatic model.
In sum, my alternative view aims at explaining how engineering sciences produce knowledge that is relevant to technological design. I will now summarize my understanding of the engineering sciences:

Summary 'Alternative View' of Eng. Sc.

1. Pragmatic definition: 'Engineering Sciences' aim at understanding and predicting physical phenomena in technological artefacts.
2. 'Engineering Sciences' mediate between 'Basic Sciences' and 'Technological Design'.

3. Central in Engineering Sciences are three types of models:
   a. Diagrammatic models
   b. Nomo-mathematical models
   c. Experimental models

Summary 'Alternative View'

4. Basic scientific knowledge plays different roles:
   a. Knowledge of causal behavior of phenomenon (in diagrammatic and experimental models)
   b. Theoretical principles that set fundamental constraints (in nomo-mathematical model)
   c. Existing laws for describing physical phenomena (in nomo-mathematical model)

Summary 'Alternative View'

5. Models are tested in experiments:
   a. Models predict behavior of physical parameters; experiments measure dynamics of physical parameters.
   b. Diagrammatic model aims to be true about causal explanation. [**Realism**]
   c. Nomo-mathematical model aims to be appropriate with respect to intended application. [**Instrumentalism**]

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Philosophy of Science Association Meetings, 2004
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Radisson Hotel in Austin, Texas, from November 18-20, 2004

Thursday, November 18, 4:00-6:30 pm
Concurrent sessions A

A5 Applying Science (Workshop): THE SKYLINE

Proposers: Rens Bod (Institute for Logic, Language and Computation, University of Amsterdam), Mieke Boon (University of Twente) and Marcel Boumans (Economics, University of Amsterdam)

Chair: Marcel Boumans (Economics University of Amsterdam)
Introduction: Marcel Boumans (Economics, University of Amsterdam)

- Susan Sterrett (Duke University): "Models of Phenomena and Models of Machines"
- Michael Heidelberger (Tubingen University): "Models in Fluid Mechanics"
- **Mieke Boon (University of Twente): "Explaining Basic Sciences in the Engineering Sciences"**
- Rens Bod (Institute for Logic, Language and Computation, University of Amsterdam): "From Theory to Technology: Rules versus Exemplars"

Discussants:

- Margaret Morrison (University of Toronto) and Hans Radder (Vrije Universiteit Amsterdam)