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Everyday Language and Technical Terminology: Reflective Abstractions in the Long-term History of Spatial Terms

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Abstract: This paper[1] discusses the origin of technical terminology in everyday language by outlining stages in a long-term history of technical terminology marked by increasing degrees of reflexivity. It uses the examples of spatial terminology in an ancient Chinese theoretical text, in Newtonian mechanics, and in relativity theory, and attempts to explain the increasing distance of the meanings of technical terms from their everyday counterparts by relating it to historical processes of knowledge integration.

1. A paradox and a question

Let me start with a paradox. We usually think that, in technical language, terminology holds a key role. We usually think that it is primarily the technical terms that make the language technical. Let me contrast this view with an alleged quote of the turn-of-the-century mathematician David Hilbert (1862–1943):

> One must be able to say each time—instead of 'points', 'straight lines', and 'planes'—'tables', 'chairs', and 'beer mugs'.[2]

Hilbert supposedly said this in the context of a discussion about the foundations of geometry, about which he would later write a groundbreaking work, *Die Grundlagen der Geometrie*, first published in 1899.[3] In that work, Hilbert reformulated Euclidean

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[1] This paper is based on a presentation given at the workshop *Terminology in (ancient) science* organized by Markus Asper in the context of the *TOPOI* project cluster and held May 5–6, 2014 at the Humboldt University of Berlin.

[2] "Man muß jederzeit an Stelle von 'Punkte, Geraden, Ebenen' 'Tische, Stühle, Bierseidel' sagen können" (Hilbert 1970, 403). The statement is found in the section *Lebensgeschichte* written by the mathematician Otto Blumenthal (1876–1944).

[3] Hilbert 1899.

geometry in such a way that it became independent from geometrical intuition and the everyday meaning of terms such as 'point', 'straight line', and 'plane'. The meaning of the terms is fixed solely through their use in the axioms, and it therefore becomes arbitrary what words are used. This is what is called *implicit definition*.[4]

Hilbert's quote thus argues that, in axiomatic theories, the meanings of technical terms should be fixed by means of implicit definitions and therefore be completely independent from the meanings of the words of everyday language. Euclid, by contrast, defined many of his terms *explicitly*. A point, for instance, is according to his *Elements*

> that which has no part.[5]

This definition reflects the intuitive idea that a point is so small, it cannot be further divided into parts.

The disparity between Hilbert's and Euclid's cases gives rise to a fundamental question with regard to theoretical terms in the exact sciences: What is the relation between everyday language and intuition on one hand and scientific terminology on the other? As I shall argue in this paper, this relation changes over history and depends on the types of theoretical knowledge considered and their relation to experience. In particular, I shall argue that theoretical terms may have different degrees of reflexivity, i.e., they may embody different, and differently progressed, histories of reflection.

As befits the wider context of this contribution,[6] I shall particularly discuss examples of theoretical terms related to spatial knowledge. My examples relate to the following three historical episodes:

- the origins of theoretical science in antiquity (section 2);
- the emergence of classical mechanics in early modern times (section 3); and

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[4] For an introduction to the concept of implicit definition and its relation to Hilbert's *Foundations of Geometry*, see Schlick 2009, 205–217.

[5] Euclid 1956, 153.

[6] The project cluster *TOPOI*, which provided the framework of the workshop at which this text was first presented, is devoted to the study of *the formation and transformation of space and knowledge in ancient civilizations*.

– the transformation of physics in the early twentieth century (section 4).

These are all well-studied episodes, which are widely considered turning points in the history of the exact sciences. While I do not argue for a linear, let alone predetermined, development connecting the three episodes, we shall see that one may understand them as displaying progressively higher degrees of reflexivity in the theoretical terms they bring about. This overall result will be summarized in the concluding section.

2. Technical terminology at the origins of theoretical science

Technical terminology predates the rise of theoretical science. Technical terms may form whenever specialized knowledge is communicated. This may happen in the context of joint action within a group of experts, in the context of teaching to apprentices, or in the context of communicating knowledge to an appropriately informed audience outside the group of experts. The formation of technical terminology may thus occur in fields of various cultural practices such as tool-making, construction, navigation, surveying, administration, or astronomical observation and record-keeping. All these practices have developed prior to the emergence of theoretical science, which is marked by a reflection on the linguistic or otherwise material representations of the more practical forms of knowledge.[7]

The earliest evidence for this type of theoretical knowledge stems from antiquity. Aristotle's *Physics* and Euclid's *Elements* present prominent examples of theoretical reflections on spatial knowledge and are part of an intellectual tradition that reaches back to Pre-Socratic times. Less known is the fact that similar reflections are documented in sources from ancient China. In particular the so-called *Mohist Canon*, a text from around 300 BCE and one of the most formal and most rigorously argued texts from ancient China, contains passages that define and discuss spatial terms.

Thus, parallel to the Euclidean definition of a point we find, in the *Mohist Canon*, a definition of an 'end-point'.

[7] See Schemmel 2016 and further references given therein.

> *duān* 端 'end-point' is the element that, having no magnitude, comes foremost.[8]

The everyday word '*duān*' 端, which denotes an extreme, or an end of an elongate object, is here turned into a technical term. How do we know that it is to be understood as a technical term? Not only is it defined, but, most importantly, it is part of a network of defined terms. Thus, 'element' and 'magnitude' are both defined in other sections of the text. Let us here take a closer look at the definition of 'magnitude'.

> *hòu* 厚 'having magnitude' means that there is something in relation to which it (i.e., the thing that has magnitude) is bigger.
>
> *hòu* 厚 'having magnitude': Only an end-point has nothing in relation to which it is bigger.[9]

Hòu 厚 in everyday language means 'thick' (in the sense of a material, physical dimension). Here it is turned into an abstract term that implies spatial magnitude and can be used in other definitions or explanations. A later section, for instance, reads:

> *yíng* 盈 'being filled out' is nowhere not having something.
>
> *yíng* 盈 'being filled out': Where there is no filling out there is no magnitude (*hòu* 厚). On the measuring rod there is no place to which it extends such that you do not get both (i.e., filling out and magnitude).[10]

Thus we have a pair of terms, *hòu* 厚 'having magnitude' (being extended) and *yíng* 盈 'filling out', that consistently differentiate the material and the spatial aspects of bodies.

Taking into account all the sections on spatial, temporal and material concepts, we obtain a network of terms which is presented in fig. 1.

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[8] This is Canon A 61, following the enumeration by A.C. Graham (Graham 1978). The translations from ancient Chinese have been done in cooperation with William G. Boltz, see Boltz and Schemmel 2016.

[9] Canon and Explanation of section A 55.

[10] Canon and Explanation of section A 65.

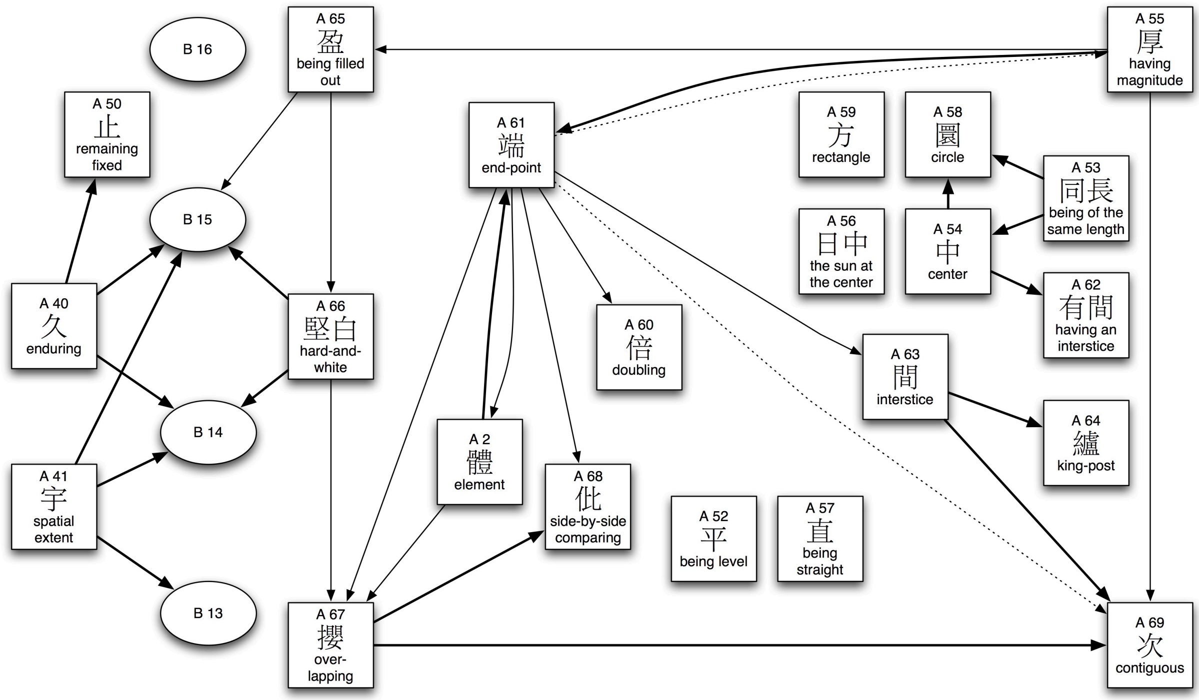

Figure 1: Terminological relations between sections on space, time and matter. Definitions are represented by squares, propositions by ovals. A bold arrow indicates that a defined term is used in the Canon of another section, a thin arrow that it is used in the co-ordinated Explanation. Dotted arrows indicate that the occurrence of the term is only conjectural.

Although the terms form a network, they are not implicitly defined, as in Hilbert's axiomatic geometry. Rather, their meaning is partly derived from their everyday meaning. The everyday language terms reflect everyday structures of cognition. The material and the spatial aspects of bodies, for instance, are aspects of everyday intuitive thinking and form part of what may be termed *anthropomorphic knowledge*.[11] Anthropomorphic knowledge is studied by developmental psychology and its structures are prior to any theory. Furthermore, owing to the similar biological make-up of all humans and the similar experiences they make in a shared environment whose fundamental physical features are the same everywhere, large parts of this anthropomorphic knowledge are universal.

But the universality of anthropomorphic knowledge structures does not generally translate into a universality of their linguistic representations. This is because, in

[11] On the gradual differentiation of the corporeal and spatial aspects of the environment in the process of ontogenesis, see, for instance, Piaget 1959 (in particular 97–101).

language, the universal aspects of cognition may become mixed up with, and modified by, other, culture-specific parts of cognition and with culture-specific aspects of their representation. This holds, in particular, for the linguistic representation of anthropomorphic knowledge structures provided by theoretical terms.

The meaning of theoretical terms is set apart from that of their everyday counterparts by an act of explicit reflection in the medium of representation. This may be a definition or any other use of material means of representation designed to delineate meaning. As a consequence, terms referring to real-world objects and events now become themselves objects of reflection and are considered with respect to their mutual relations. This may be understood as a process of reflective abstraction: The reflection abstracts from the particular contexts of the terms in their everyday use. On the higher level of reflection, new meaning is constructed by concretization, i.e., by explicitly establishing relations to other terms of the theory.[12]

Thus, when 'filling out' is taken out of all practical contexts of filling something out, and considered regardless of such contexts and applied to material objects, attributes, and times and spaces (as happens in the *Mohist Canon*)[13], this is a process of abstraction and generalization. Anthropomorphic knowledge structures remain effective but are modified in their reconstruction on the theoretical level of reflection. The shifts in the meaning of terms may, in particular, bring about what may be called *artifacts of theory*: Owing to their generalization and absolutization, the meaning of terms may now involve typically theoretical properties, like those relating to infinity, which are alien to their everyday counterparts, and which are often at the core of philosophical-mathematical problems. Thus, while a 'point' is intuitively understood as something very small like a dot of very small size, it is now claimed to be infinitely small, thereby forcing the reconsideration of notions such as composition, extension, and motion.

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[12] The concept of reflective abstraction is taken over from the work of Piaget (Piaget 1985), but we follow here the enhancement of the concept of reflection proposed by Damerow (1996, 1–27), according to which the object of reflection consists not only of the actions of the reflecting subject but crucially includes the material means of action.

[13] Sections A 65 (see above), A 66, and B 15; see Boltz and Schemmel 2016.

That the results of such abstractions are not universally the same is already indicated by this example. While in the Greek context the abstract term is the point (σημεῖον), in the Chinese case it is the end-point (*duān* 端).[14]

Besides the sections on spatial terms, there are sections of the *Mohist Canon* that reflect on knowledge structures related to mechanical and optical phenomena. The following section, for instance, documents the occupation with unexpected effects when mechanical devices are involved:

> The beam (*héng* 衡): If you add a weight (*zhòng* 重) to one of its sides [that side] will necessarily drop down. This is due to the effectiveness (*quán* 權) and the weight matching each other. If they are made level with each other, then the base is short and the tip is long. Add equal weights to both sides, then the tip will necessarily go down. This is due to the tip having gained effectiveness.[15]

The section deals with a situation in which a lever is involved, so that equal weights may have different effects on its two ends. The puzzle is theoretically resolved by complementing the term *zhòng* 重 'weight' with a term *quán* 權 'effectiveness', to account for the different behavior of weights in different distances from the fulcrum. This differentiation of the term 'weight' may be understood as a theoretical response to instrumental knowledge, namely knowledge obtained in the handling of cultural artifacts, in this case instruments involving a lever.[16]

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[14] Note, however, that there are alternative definitions of a point in ancient Greek texts, in particular one defining the point as the extremity of a line; see Euclid 1956, 155–158 . This similarity between the Greek and Chinese cases (which have to be considered independent with regard to the theoretical layer of knowledge) may be taken as indicative of the shaping force of materiality even on the choice of our theoretical abstractions.

[15] Explanation of section B 25b. The translation resulted from joint work in the context of a working group on the history of mechanics at the Max Planck Institute for the History of science, which included William Boltz, Jürgen Renn, and the author.

[16] This interpretation has first been given in Renn and Schemmel 2006.

We may thus distinguish between anthropomorphic and instrumental knowledge, the first obtained through experiences with respect to universal features of the physical environment, the latter obtained through experiences in handling culture-specific artifacts. Theoretical knowledge emerges from the systematic reflection on these more elementary types of knowledge. While there are marked differences in the specific theoretical terms that form in the case of ancient Greek and ancient Chinese theoretical sciences, the phenomenon itself turns out to be a cross-cultural one. Let us formulate general characteristics of the formation of technical terminology at the origins of theoretical science.

Origin: The technical terms at the origins of theoretical science are taken from everyday language, possibly including the specialized language of practitioners.

Knowledge structures: Their meaning reflects structures of anthropomorphic and instrumental knowledge. At the same time, their meaning is distinguished from that in everyday language by the decontextualization from concrete action and the recontextualization within theory. Theoretical demands such as consistency, comprehensiveness, and the resolution of paradoxes give rise to differentiations and fixations of the terms that are alien to their everyday counterparts.

External representation: The system of theoretical terms is transmitted and stabilized through external representation in texts. The theoretical texts may be handed down orally, but most often a written component plays a crucial role. This written component entails the possibility of communicating theoretical knowledge to later generations even after the oral tradition in the context of which it emerged has ceased.

The last point brings us to the question of the fate of Mohist science. The *Mohist Canon* originated in the Warring States period when China was politically fragmented into many smaller states, often at war with each other. At the time, a variety of aristocratic thinkers strove for an appointment to high office and offered their services as advisors to the various rulers and governments. A vivid culture of disputation flourished and we even see the emergence of a type of sophists, the *bianzhe*, who disputed for the sake of disputation and became famous for framing paradoxes. In this environment, it seems, the later Mohists strove to show that consistent reasoning is possible and that paradoxes could be avoided or resolved by reflecting on language and delineating the meaning of terms. In this context, they dealt with a variety of subjects ranging from matters of conduct, government and ethics to subjects that we would today classify as geometry, mechanics and optics, as is documented in the *Mohist Canon*.

The theoretical tradition of the later Mohists did not last long, however. It probably ceased under the changed socio-political conditions of the unified empire and centralized administration of the Qin dynasty in the third century BCE. The text was garbled in its transmission, and although it was handed down to the present, it did not become effective in Chinese intellectual history for a long time. When it was commented on again starting at the end of the eighteenth century, it had become an object of historical and philological interest rather than a source informing an actual tradition of theoretical thinking.

Greek theoretical texts on geometry, mechanics, and optics, by contrast, did have an impact on later European and Near Eastern knowledge traditions and served as models for representing theoretical knowledge well into modern times.

3. Technical terminology in the emergence of classical mechanics

Turning to early modern Europe, one may ask what the main difference is between the ancient theoretical reflections discussed in the previous section and their early modern counterparts. Concerning the science of mechanics, one major difference is clearly the challenge to integrate a vast body of systematically expanded experiential knowledge.

The modern science of classical mechanics resulted from the integration of the cumulated astronomical knowledge embodied in Kepler's laws of planetary motion and the cumulated mechanical knowledge embodied in Galileo's laws of free fall and projectile motion. The integrative reflection on these bodies of knowledge brought about a fundamental change of the concept of force which lies at the heart of classical mechanics.

There is an anthropomorphic knowledge structure that we may refer to as the motion-implies-force model.[17] Whenever we want to set something in motion, we have to exert a force. And the more force we exert, the quicker moves the mobile. This intuitive relation

[17] Renn and Damerow 2007.

was, in medieval science, mathematically quantified by the statement that the moving force is proportional to the velocity of the mobile.

The aspect of mathematization is important in this context. It provides an additional way of relating terms in a network: the relations may not only be semantical, as in the case of the Mohists, but also mathematical. Now, classical mechanics is distinguished from pre-classical mechanics by a reconceptualization of force which only made possible the integration of terrestrial and celestial mechanics: In classical mechanics, force is conceived proportional to acceleration, rather than velocity. Inertial motion, i.e. uniform motion in a straight line, is not in need of a causal explanation in terms of forces, and only change of velocity (acceleration) is. The deep-structure of the anthropomorphic relation between motion and force is preserved, but the modified structure relates acceleration to force, while uniform motion in a straight line is equivalent to rest.

Let us take a look at the terminology in Newton's *Philosophiae naturalis principia mathematica*, first published in 1687. The book is usually considered the first consistent exposition of the conceptual framework of classical mechanics. In analogy to Euclid's *Elements*, Newton begins with a series of definitions of technical terms such as 'quantity of matter', 'quantity of motion', 'inherent force', 'impressed force' etc. Definition 3, for instance, reads:

> Inherent force of matter is the power of resisting by which every body, so far as it is able, perseveres in its state either of resting or of moving uniformly straight forward.[18]

Newton thus introduces an *inherent force* (*vis insita*) to explain inertia. He does exactly what we have just stated is wrong in classical mechanics! To introduce a force for maintaining a motion is compatible with the medieval conception of force and motion, not with the classical one, which Newton pioneers in this book. This means that, despite the new mathematical-conceptual structure of classical mechanics, Newton, in choosing his technical terms, is influenced by a theoretical tradition that directly relates to our intuitions and their reflection in everyday language.

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[18] Newton 1999, 404.

Similar reminiscences of earlier cognitive structures are found in Newton's understanding of *space*, a term he does not define, because it is "familiar to everyone"[19], but discusses in a long *Scholium*. Space, according to Newton, is in a state of absolute rest and does not move. But in classical mechanics absolute rest is indistinguishable from uniform motion in a straight line!

But Newton's understanding of *force* and *space*, which is at odds with the mathematical structure of the science he pioneers, is not his individual blunder. Rather, it is indicative of how conceptual development proceeds in the exact sciences. Newton's integration was possible only on the basis of available conceptual frameworks, which informed the meaning of the technical terms. At the same time, the knowledge integration employed mathematical means, and the reorganization of the mathematical-conceptual structure led to changes in the meanings of the terms. This created the tensions within the conceptual framework that we witness in Newton's writings.

Let us summarize the characteristics of theoretical terms in the emergence of classical mechanics:

Origin: The technical terms are part of a theoretical tradition, which itself relates back to everyday language. A disciplinarily fixed system of technical terminology is only emerging and controversies over the meaning of terms show that terminology is to a certain extent still a matter of individual system-building.[20]

Knowledge Structures: The meanings of the theoretical terms reflect the cognitive structures of previous theories (which themselves incorporate anthropomorphic and instrumental knowledge structures), modified as to integrate systematically accumulated empirical knowledge. But tensions between established meanings and new mathematical-conceptual structures exist.

External Representation: The system of terms is transmitted and stabilized through external representation mostly by means of written text, diagrams, and symbolic formalisms. The mathematical formalism plays a crucial role in integrating new

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[19] Newton 1999, 408.

[20] As examples consider the terminological discussions in the Leibniz-Clarke correspondence (Alexander 1970), or the *vis viva* controversy.

empirical knowledge and serves as a medium between experience and conceptual structure. It is a means by which new experiences are translated into concepts that create tensions within the existing conceptual structures.

In the case of classical mechanics, it was only in the context of later reflections on a mathematical-conceptual framework that had, not least owing to its empirical success, become firmly established, that the tension between the traditional meanings of terms anchored in intuitions and everyday use and the new mathematical structure could be resolved. Thus, it was only with the development of the concept of 'inertial frames' in the late 19th century that the mathematical-conceptual structure of space in classical mechanics found an adequate terminological expression. At around the same time, however, the distinguished status of mechanics as a fundamental theory for all of physics became increasingly disputed.

4. Technical terminology in the transformation of early-twentieth-century physics

In the late 19th century, fields of physics other than mechanics, in particular thermodynamics and electrodynamics, had developed their own mathematical-conceptual structures and technical terminologies, partly overlapping with mechanics, but partly independent of it. The conceptual revolutions of early twentieth-century physics occurred at the borderlines between these subfields of physics.[21] The theory of special relativity, for instance, resulted from considerations about electromagnetic phenomena in relative mechanical motion and can thus be viewed as having emerged at the borderline between electrodynamics and mechanics.

The conceptual revolutions of early twentieth-century physics are notorious for having rendered that science more 'abstract', to have removed it even further from everyday intuition and everyday language as had previously been the case. And in fact, central terms of modern physics, such as 'energy-stress tensor' or 'quantum state' seem hardly relatable to everyday knowledge. Are then the terms of modern physics to be implicitly defined without reference to everyday meanings, as Hilbert's axiomatic method suggests?

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[21] See Renn 2006, in particular 87–127.

Hilbert himself attempted an axiomatization of physics.[22] To this end he combined Einstein's nascent theory of general relativity with a theory of matter, which is nowadays only known to historians of science.[23] But besides the transient character of the ingredients of Hilbert's axiomatic program for physics, Einstein had some more fundamental reservations concerning the idea of an axiomatic foundation of modern physics. In his essay *Geometry and Experience* of 1921, he says with respect to the application of Hilbert's axiomatic geometry to physics:

> It is clear that the system of concepts of axiomatic geometry alone cannot make any assertions as to the behavior of real objects […]. To be able to make such assertions, geometry must be stripped of its merely logical-formal character by the coordination of real objects of experience with the empty conceptual schemata of axiomatic geometry.[24]

In fact, in order to re-interpret central terms of classical physics related to space and time, Einstein had to disentangle the different layers of knowledge that contributed to their meaning. On the one hand there was the layer of the operations of measurement. This layer is clearly rooted in practical knowledge and involves concepts such as measuring rods and clocks. In order to apply this knowledge, Einstein had to make basic assumptions concerning the existence of rigid bodies and the possibility to synchronize clocks, all rooted in anthropomorphic and instrumental knowledge structures and all in accord with classical physics. On the other hand, there is the layer of theoretical assumptions about the comparison of space and time measures in systems in relative motion, which implies general statements about the structure of space and time. While these assumptions may appear intuitively obvious, Einstein noticed that they are not implied by the assumptions about measurement operations. Giving up the ideas of the independence of length, duration, and simultaneity from the state of motion, Einstein arrived at a new geometrical framework for physics, later described with technical terms such as 'space-time' and 'chronogeometry'.

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[22] Hilbert, *Die Grundlagen der Physik*, first published as Hilbert 1915 and Hilbert 1916.

[23] This is Gustav Mie's unifying theory. For discussions of Mie's and Hilbert's theories, and for translations into English of their original writings, see the corresponding sections in Renn and Schemmel 2007.

[24] Einstein 1921. The translation is taken from Einstein 1982, 234–235.

Accordingly, Einstein further explains:

> The idea of the measuring-rod and the idea of the clock coordinated with it in the theory of relativity do not find their exact correspondence in the real world. […] But it is my conviction that in the present stage of development of theoretical physics these concepts must still be employed as independent concepts; for we are still far from possessing such certain knowledge of the theoretical principles […] as to be able to construct solid bodies and clocks theoretically from elementary concepts.[25]

This means, the theory of (general) relativity still relies on everyday concepts such as a measuring rod (which we encountered with the Mohists!), although from the viewpoint of modern physics these objects are idealizations. The crucial point here is that, in order to identify the corresponding mathematical structures within a new theory as physical space (or space-time), they must be connected to former theoretical or pre-theoretical knowledge, from which they derive their spatial (or spatio-temporal) meaning.[26]

Let us again summarize some of the characteristics of theoretical terminology in the transformation of early-twentieth-century physics.

Origin: Technical terms are part of various expert traditions organized in a disciplinary hierarchy.

Knowledge Structures: Their meaning is partly fixed by the mathematical structure of a particular theory, but relations to knowledge outside this structure and even to pre-theoretical knowledge are needed to provide physical meaning. This multiple relation constituting meaning also explains how the same term may have different but overlapping meanings in different theories and (sub-)disciplines.

External Representation: The system of terms is transmitted through external representation mostly by means of written text, diagrams, and symbolic formalisms. These representations stabilize the system of terms within a field, but tensions may occur at the borderlines where fundamental changes take their start when the meaning of terms has to be re-negotiated.

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[25] Einstein 1921. The translation is taken from Einstein 1982, 236–237.

[26] See Blum, Renn, and Schemmel 2016.

5. Reflective abstractions in the long-term history of spatial terms

In this paper we have discussed the relation between everyday language and the technical terminology in theoretical texts related to spatial knowledge. In this context we conceived of everyday language as externally representing anthropomorphic and instrumental knowledge structures, i.e. knowledge structures built up in the mind of any individual in the process of ontogenesis, which comprise universal aspects of sensori-motor intelligence as well as knowledge related to culture-specific practices such as the handling of instruments and other cultural artifacts.

We have described the spatial terminology that arose at the origin of theoretical science in antiquity as resulting from a process of reflective abstraction. In this context, the medium of reflection is linguistic expressions, in particular spatial terminology. In theoretical texts from antiquity, the meanings of terms are explicitly reflected in the medium of written language, bringing forth a reconstruction of anthropomorphic and instrumental knowledge structures on a theoretical level. At the same time, this reconstruction modifies these knowledge structures, since it abstracts from the concrete contexts of action from which they derive their original meaning and re-contextualizes them within a network of theoretical terms, which aims at fulfilling theoretical demands such as generality and consistency. While it is this network that makes the terms theoretical, the network is not closed in the sense that the meaning of terms would be sufficiently fixed without reference to knowledge outside it, as would be the case in a completely axiomatized theory of the kind of Hilbert's foundations of geometry.

The theoretical terminology related to space that formed in the emergence of classical mechanics may also be viewed as resulting from a process of reflective abstraction. In addition to the semantic relations between terms encountered in Mohist science, relations expressed by means of mathematical formalisms play a central role in this context. These mathematical relations in particular serve the integration of huge corpora of experiential knowledge on celestial and terrestrial motions, experiential knowledge that was mathematically and conceptually pre-processed, as documented in earlier writings like those of Kepler and Galileo. The reflection on the meaning of terms now takes place in the medium of such mathematical-conceptual writings. The mathematical relations between theoretical terms are re-negotiated as to allow for the integration of the experiential knowledge to be captured. At the same time, the terms inherit their meanings from theoretical traditions, which are themselves, as we have seen, rooted in anthropomorphic and instrumental knowledge. The ensuing tensions within the network of terms were only resolved centuries after the pioneering work of Newton and his contemporaries. The result was a further step of reflective abstraction separating theoretical knowledge structures from the knowledge structures represented in everyday language: a further modification of these structures by rebuilding their relations in the context of a mathematical-semantic structure able to integrate the relevant (pre-processed) experiential knowledge.

In the radical conceptual transformations of early-twentieth-century physics we can identify yet another step of reflective abstraction, removing physical spatial terminology even further from its origins in everyday language, without, however, cutting the connection. The new reordering of knowledge that brings about the changes in the meanings of terms (and the creation of new terms) is again imposed by knowledge integration. But this time the knowledge under question is knowledge pre-processed in developed sub-disciplines. Its integration again demands abstraction: aspects of the existing representations that do not correspond to structures of experiential knowledge but are relics of the cognitive history of theory are up for re-negotiation. An example is the constancy of lengths, durations and simultaneity under transformations between inertial frames in relative uniform motion, which is assumed within classical mechanics, but not implied by the operations of space and time measurements. By abstracting from such aspects, generalizations are possible that enable the integration of knowledge from different disciplines. The new concretization is guided by the properties of borderline objects, whose treatment demands knowledge structures from more than one discipline to be taken into account.

From the above it becomes clear that historical processes of reflective abstraction build one upon the other. Not in a linear or a predetermined way: the example of Mohist science and its fate clearly shows that the occurrence of reflective abstractions does not imply the progression to further ones. But the external knowledge representations resulting from instances of collective reflection serve as the preconditions for later reflective abstractions that build on them, since each process of reflective abstraction is the transformative reconstruction of an existing knowledge structure. The reflection on disciplinarily structured knowledge at the beginning of the twentieth century, for instance, was only possible in the medium of the mathematical-conceptual structures that originated in, and had developed since, early modern times. Our emphasis on the three turning points in antiquity, early modern times, and the early twentieth century does not mean to deny the importance of the developments between these turning points, of course. The mathematization of Aristotelian philosophy in medieval times and the formation and advancement of analytical mechanics in the course of the eighteenth and nineteenth centuries are important examples for such developments. But the turning points are characterized by fundamental conceptual reorganizations of knowledge. These processes of knowledge reorganization are, at the same time, processes of knowledge integration, in which experiential knowledge—be it different parts of anthropomorphic knowledge, be it the knowledge of practitioners, or be it knowledge systematically accumulated in scientific traditions and disciplines—is assimilated to theoretical structures, while these structures are accommodated to the new knowledge. The theoretical terms thereby become increasingly abstract in the sense that their meaning becomes increasingly removed from the meaning of the terms in everyday language.

Will the succession of reflective abstractions eventually remove our spatial concepts so far from their origin in everyday language that they may become implicitly defined within an axiomatic theory such as Hilbert's geometry? Was Einstein referring to such a development when (in the last quote given above) he stated that *at the present state* of the development of theoretical physics we are still in need of concepts establishing a relation to everyday, practical, or operative knowledge? Will theoretical physics eventually become independent from such concepts? In Hilbert's foundation of geometry, the meanings of the central terms are decoupled from all exterior knowledge whereby the theory becomes purely structural. It is no longer a theory of physical space, but one that may be applied to it. From this it becomes clear that a physical theory of space must always retain a relation to knowledge exterior to its mathematical structure by the very demand that it be a theory of *physical* space. On the other hand, there are indications that in future theories of physics, space may no longer play the fundamental role it still does at the present. The role of pre-theoretical knowledge in constituting the meaning of the central terms of a theory may thereby become even more mediated. Physical space may, for instance, turn out to be a phenomenon emerging from more fundamental non-spatial entities. The meanings of the technical terms by which these entities are described would then also stand in an emergence relation to the more traditional concepts and could accordingly have little or nothing in common with the meanings of everyday language terms.

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