Transitions to Nominalization in Newton's "Opticks"

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ABSTRACT: The significance of Newton's *Opticks* is not only founded on its epochal discoveries, theorems, and claims, but it is also remarkable for its language. Linguistic means are obviously chosen in order to support the methodological and philosophical conviction, which Newton calls experimental philosophy, as opposed to the axiomatic-deductive school of the Cartesians. Special attention seems to be given to gradual transitions from an expressive and narrative style to a more formalized and rigid professional language which, among other features, can be characterized by the use of nominalization. Following the approach of Functional Grammar, I consider nominalization as a case of grammatical metaphor. For the analysis of processes of further formalization, I introduce the concept of algebraic metaphor.

KEYWORDS: Newton *Opticks*, grammatical metaphor, nominalization, Functional Grammar, Cartesian view

Introduction

Isaac Newton lived from 1642 to 1727. In his early years Newton already occupied himself with the problems of optics, studying, especially, the works of Descartes, Kepler, Boyle, and Hooke. His predecessor at the Lucasian Chair in Cambridge and teacher, Isaac Barrow, held lectures on geometrical optics, and optics was also the subject of Newton's own first lectures (1670-1672), his having already presented results of his observations on questions concerning refraction and color noted by him as early as 1663. Together with *Principia,* published in 1699, which laid the grounds for mechanics, *Opticks*[1] represents a second focal point of Newton's lifework. In 1672, he published a letter, "A New Theory about Light and Colours", in *The New Transaction of the Royal Society*. Being put under pressure by many critical reactions to his work, he delayed publishing

1 I follow the original spelling instead of "optics" as would be correct today; both can be found in the literature.

Opticks until 1704, after the death of Hooke, who was, alongside with Huygens, one of his fiercest critics. The background of these controversies was not only the nature of light, which can only deficiently be implied by the alternative of wave or corpuscle. The debate was much more concerned with philosophical and methodological differences between the axiomatic-deductive mindset of the Cartesian school, represented mainly by Huygens, and the newly introduced experimental philosophy, as promoted by Newton.

Opticks was extremely popular among the scholars of the 18th century, attracting, in contrast to *Principia,* also non-experts because of its content and literary style, which is evident from its reception by Locke and Voltaire.[2] The fact that the book is written in English—and not, like *Principia*, in Latin, as was the academic standard—is another hint at a deliberate composition in accordance with the less rigid and more narrative character of the work. Newton's methodological strictness, which is formulated in *Principia's* motto *Hypotheses non fingo*, is not characteristic for *Opticks*, which contains rather openly speculative elements, especially—but not exclusively—in the chapter *Queries* at the end of the work[3].

Recently, Newton's work on optics has been analyzed according to its linguistic style and use of language. His early lectures are the subject of Ben Chaim's (2004) socio-linguistic analysis, that deems the rhetorical form a consciously-deployed means to propagate Newton's philosophical standpoint as an antagonism between two genuine goals of science: safekeeping the facts and causal explanation.

Aspects of the epoch-making argumentation on basic principles between Newton and the Cartesian school are revealed in a study by Banks (2005), in which he analyzes the considerations of the application of the passive voice, the deployment of the personal pronoun, the nominalization of processes, and ideology[4], by contrasting passages from Newton's *Opticks* with Huygens's *Traité de la Lumière*. In the context of technical language, nominalization, namely, the substitution of a noun for a verb or an adjective, is of particular interest. In the latter study, it is treated like Pulaszewska's (1999) vast investigation of imagery in physics on the

2 As is well-known, the reception by Goethe is to be treated somewhat differently.

3 Nonetheless, Newton proclaims at the beginning of *Opticks,* "My Design in this Book is not to explain the Properties of Light by Hypotheses, but to propose and prove them by Reason and Experiments."

4 In Part IV, I refer to the corpus defined by Banks.

basis of systemic-functional linguistics, as developed by Halliday (Halliday & Matthiessen, 1999). In this approach, the concept of *grammatical metaphor* is introduced with nominalization as an important case. This allocation allows for specific insights into the reciprocal forming of language and cognition in the context of modern metaphor theory and has been widely discussed under the name of conceptional metaphor since the seminal book by Lakoff and Johnson. The reciprocity is not only of interest in the history of science but also in the philosophy of science and, not least, in the didactics of physics.

Of the aforementioned linguistic means this article mainly examines nominalisation, by means of examples and with a didactic interest. in Newton's *Opticks*. First, a closer look is taken at the overall structure of the work. Then, some stylistic elements are identified in the second part. This is followed by the presentation of the linguistic basics of the approach used, which are illustrated with several exemplary text passages in the fourth part. The fifth part outlines the concept of the algebraic metaphor describing formalizing processes, which are not used in *Opticks,* deliberately. Finally, references to the didactics of physics are given in the sixth part.

Structural Elements of the Work

Opticks is divided into three books. Book I deals exclusively with the dispersion of light, and, in correlation with that, a theory of color. It offers an explanation of the rainbow that enhances the interpretation presented by Descartes. Book II presents Newton's concept of reflection and the question concerning the transparency of objects, an account of the thereafter-so-called Newton's rings, the colors of small plates, and, based upon this, the theory of surface colors. It contains the concept of "fits," aiming at describing an alternating tendency of light to be reflected or refracted. Book III contains observations and measurements concerning phenomena of diffraction and, finally, a collection of miscellaneous thoughts on and outlines of optics and other subjects of the sciences and natural philosophy, including theological reflections. These *Queries* or *Questions* are interrogative from a grammatical viewpoint, but they let Newton's theses or hypotheses shine through.

The combination of inductive and deductive movements reveals itself in the categories of Definition-Axiom-Theorem-Proposition, on the one hand, and Observation-Question-Consideration of Probability, on the other hand, which gain validity by means of a systematic interplay. The methodological assault on the Cartesian view becomes strikingly obvious when one considers the importance of the

experiment The Proof by Experiments. Newton views the set of axioms as the compendium of the existing standard of knowledge.

The descriptions of the numbered experiments are not entirely uninspiring protocols; they are written in the first person and have high narrative qualities. At one point (15th experiment in Book I, Part II), for example, the visit of an old friend is mentioned, effectively serving as a reagent and witness for the comparison of two "whites".

The aforementioned categories and characterizations[5] are evident in the text and can readily be illustrated by examples, as demonstrated below.

1. *DEFIN. I: By the Rays of Light I understand its least Parts and those as well Successive in the same Lines as Contemporary in several Lines. (1)*

This definition obviously already presupposes a statement about the "nature" of light. The status of the term "Ray" is not at all consistent in Newton's work; it appears as a mathematical construct, as well as an ontological concept.

2. Definition IV exists only in a pre-definition of an abbreviation:

The Sines of Incidence, Reflexion, and Refraction are the Sines of the Angles of Incidence, Reflexion, and Refraction. (9)

3. Even today, the same is found in textbooks.

AX. I: The Angles of Reflexion and Refraction lie in one and the same Plane with the Angle of Incidence. (5)

4. In the statement below, the plural of "lights" is striking. With "Degrees of Refrangibility," a physical parameter is already implicitly mentioned, namely, the refractive index. I will return to physical parameters in the fifth paragraph.

PROP I. Theor. I: Lights which differ in Colour, differ also in Degrees of Refrangibility. (20)

5. The symptomatic title "The Proof by Experiments" is followed by the first of many detailed and vivid depictions that sum up the idealizations of the actually-conducted experiments:

Exper. 1: I took a black oblong stiff Paper terminated by Parallel Sides, and with a Perpendicular Line drawn cross from one Side to the other, distinguished it into two equal Parts. One of these parts I painted with a red color and the other with a blue. The Paper was very black and the Colours intense and thickly laid on, that the Phenomenon might be more conspicuous. The paper I view'd through a Prism of solid Glass, whose two sides through which the Light passed to the Eye were plane and well polished, and contained an Angle of about sixty degrees. (20)

5 The page numbers indicated after quotations refer to Newton 1979.

6. The very first question of the "Queries" or "Questions", whose number had grown to 31 in the fourth issue (1730), is, especially from today's point of view, of a highly speculative or prophetical character:

> *Query 1: Do not Bodies act upon Light at a distance, and by their action bend its Rays; and is not this action (caeteris paribus) strongest at the least distance? (339)*

7. Building on the aforementioned discussion of color perception, one finds an explicit reflection in Prop. II, Theor. II (Book I, Part II) on the generation of technical language, as well as on the liberal use of the language in the communicative handling.

> *The homogeneal Light and Rays which appear red, or rather make Objects appear so, I call Rubrifick or Red-making; those which make Objects appear yellow, green, blue, and violet, I call Yellow-making, Green-making, Blue-making, Violet-making, and so of the rest. And if at any time, I speak of Light and Rays of coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame. For the Rays to speak properly are not coloured. (124)*

8. The manner in which mathematical calculus is avoided may be illustrated in different passages, where, for example, not more than the application of Pythagoras is dealt with:

> *The Demonstration Mathematicians will easily find out, and therefore I will not trouble the reader with it. (80)*

One can speculate that Newton avoided the inclusion of mathematical formulae in order to retain his readership.

Connections to Metaphor

In general, a metaphor is understood as a transfer[6] of a word from a source that is a field alien to the given context which, in turn, is the target. In the sentence "Light is refracted", the verb "to refract" stems from a context of experience concerning the fracturing of fragile, usually oblong objects, such as branches or sticks[7]. This import, on the one hand, cannot but appear as extrinsic; on the other, it is supposed to have a helpful effect for the sake of style. It can also enhance the understanding of factual circumstances. In this respect, one speaks of a *conceptual* metaphor. A metaphor requires the differentiation of two separate fields of experience and the corresponding linguistic register, which concerns the word choice,

6 Metaphor literally means transfer.

7 By the use of the passive the identification of an "agent" or "participant, refracting the light is avoided

especially. In case the subject matter of the source tends to be familiar or concrete and the target tends to be extrinsic or, perhaps, abstract, the transferred word can stimulate one to view the extrinsic field from an "as if" angle and to utilize its common characteristics or structures for the stylistic or matter-of-content composition. The resulting possible effects on the construction of terms and models are the subject of cognitive linguistics and are increasingly studied in the context of learning processes. Of the many metaphors in physics, the clockwork metaphor for a mechanistic world view, spatial metaphors for contexts regarding time, and material metaphors for extensive magnitudes are significant. Certain metaphors are used to bridge different physical theories, as, for instance, balance (cf. Gerstberger, 2002). These examples of metaphors also show the close relationship between metaphor and model. The metaphorical interaction of different functional registers with the field of common speech has become the subject of research in technical language and didactics.

9. In Alice's Wonderland, the linguistic transformation called nominalization is quite casually broached:

> *"Well! I've often seen a cat without a grin" thought Alice; "but a grin without a cat! It's the most curious thing I ever saw in all my life." (Carroll 1994)*

The activity of the Cheshire cat—it grins—is transformed into an autonomous entity, as if the grin is a thing or person. Grammatically, it shows as a transition from verb to noun—nominalization—which is an example of a grammatical metaphor. In contrast to a transfer in the lexical field, a transformation in the grammatical form takes place. With nominalization, a fact originally expressed in a whole sentence, "The cat grins", is now presented through a grammatical structure of lower order[8], namely, "the grin" of the cat. Such a transformation is typical of administrative and technical linguistic registers and also of the technical language of science.

The grammatical metaphor is often based on a deviance from the "normal" congruency between semantic contents and their respective grammatical realization: quality–adjective, thing–noun, activity–verb. Through compression of the congruent descriptions to simpler phrases, contents of higher complexity can be grammatically represented more easily. As in the previous example, the congruent expression usually requires multiple structural elements of a

8 The technical phrase is noun phrase.

sentence, whereas the metaphorical form only calls for one structure of lower order[9].

One effect of the grammatical metaphor is that some semantic relations turn implicit. If an activity is formulated in a sentence or part of a sentence (subclause), the semantic relations are executed in the configuration of the grammatical elements; if, in contrast, it is constructed as a nominal group, this is not at all, or, only partly, the case. Generally, the higher the degree of grammatical metaphorization, the more the reader has to know in advance to be able to understand the text.

In the case of nominalization, static, and often technical, terms emerge, but they do not lose their semantic character of being properties or activities. By being reconstructed as nouns, however, they can acquire an additional function in the form of being the subject matter or focal point of the information given. For this purpose, they have to be "packed", so to say, and, therefore, a nominal construction is the only possibility; for example, instead of being a process on its own account, in *Light falls on an object*, the according phenomenon is constructed as participant, the *incidence* of light, on an object. Thereby, it can be put into a wider variety of references in the grammatical construction of the discourse.

Even though semantic relations have partly turned implicit, they are not supposed to have changed. In one sense, this is true: one can "unpack" the metaphor, and among experts there will be a general consensus on how to do so; however, in another sense, it is not true. The discourse of the sciences, especially, started with the creation of technical taxonomies and mathematical constructs; they already modulated the semiotic construction of experience by creating a new set of abstract things not having existed before. The transformation, however, is even more fundamental: not only is the set of abstract things enlarged by transforming phenomena that have been constructed as processes and properties into things, but the phenomena were *re*constructed through grammatical metaphor and so afford a new basis for an ongoing creation of abtractions. As mentioned by Halliday, this transformation took place in all the languages that adopted the semiotic functions of Medieval Latin.

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9 In this example, a simple subject-verb structure is replaced by a group of nouns. In general, Halliday (Halliday & Matthiessen 1999, ch.6) differentiates among structural types of clauses—complex, clause, and element—which belong, respectively and congruently, to the semantic categories of sequence, figure, and element.

Nominalization

A verb is the natural choice to describe processes and activities, whereas the noun is used to represent things and persons. Nominalization means that the process assumes the syntactical properties of a noun and can function grammatically as subject or prepositional complement. It receives the semantic qualities of an entity, as opposed to a process, by being reified to a certain degree. In addition to the nominalization of processes, one of the properties can be observed, as well. The congruent part of speech in this case is the adjective.

Banks introduces four kinds of processes, which can be demonstrated in Newton's *Opticks*.

10. The first kind is the material process, concerning physical activities or events, such as

... in the Shut of a Window I placed a Glass Prism.... (26)

11. The second type is the mental process, concerning cerebral activity (cognition, perception, or affection), illustrated in

... I have chosen to define Rays and Refractions in such general terms (2)

12. The relational process creates a relation without an activity or an event being present, for example,

... I was curious as I could be ... (29)

13. The final process is the verbal process (not explained)

... I have here set down an account of them. (194)

Newton nominalizes mostly experimental processes or the examined physical phenomena. Both belong in the category of material processes.

Nominalization now offers the opportunity of a multistage procedure to show the relationship among the object-like, process-like and property-like elements: (a) nominalization of processes, (b) disjunction of two nominalized processes, and (c) nominalization of the disjunction.

A progression of nominalization, in this sense, up to the third stage is observable, especially, in scientific texts. This can occur either in an external form, in the case of one nominalization appearing to be the *cause* of a second nominalization, or in an internal form, in the case of one nominalization appearing as *proof* of a second nominalization. In *Opticks* the second stage is well represented in the five examples that follow.

14. *...[D]ifferent inclinations of the Prism to the Horizon, made no sensible changes in the length of the image. (30)*

In this external case two nominalizations of material processes are linked: inclination and change of length. The experimenter adjusts the prism according to the horizon. This process and its result, the relation of the prism to the horizon, are nominalized by the word *inclination*. Accordingly, the measurement processes are represented in the variety of the results (length).

15. *... [T]he variety of Colors depends upon the composition of Light ... (54)*

In place of descriptions of manifold experience with colored apparitions, "the variety of colors" is mentioned as the subject of science and related to results of further processes or activities.

16. *PROP III. Prob. I: To define the Refrangibility of the several sorts of homogeneal Light answering to the several Colors.(64)*

This example presents, through a mental and verbal process, the conception of a physical parameter: Light acquires the status of an agent through the anthropomorphic depiction of *answering*.

17. *... [T]he permanent whiteness argues that ... (134)*

A nominalized property (*whiteness*) acquires the status of a quasi-personalized subject through the verb (*argues*).

18. *Those colors argue a diverging and separation of the heterogeneous Rays from one another by means of their unequal refractions (79).*

The gerund *diverging* and the forms marked with the endings *ion*, like *refraction*, are morphological means of achieving the nominalization of processes.

An advantage that nominalization can provide can be seen in the focusing on the participant of the processes or the owner of properties (not on a process or property) gaining relevance on textual grounds. It affords the potential growth of information by experience through the involvement of the participant in the compact, linguistic accounts of complex structures and conceptual taxonomies.

This is contrasted by the loss of relevance of experience because the more concrete relations of the configurations are not explicit. Halliday describes this as a loss of dimensions of experience and calls it *construction of unreality* (Halliday & Matthiessen 1999, 70f.).

From Nominalization to Algebraic Metaphor[10]

10 The concept of the algebraic metaphor is introduced in a somewhat different context in Gerstberger 2006a.

While the second stage of nominalization, namely, the disjunction of two nominalized processes, is well represented in *Opticks*, Newton is very reluctant to enter the third stage, as well as the processes of formalization and mathematization. Grammatical metaphor offers a strong potential for describing these latter steps, lending itself as a link to the physical calculation of magnitudes, as mentioned earlier, in the case of refraction and the refractive index. A verb-like description of a process is nominalized in the first instance. With the help of a defined measurement procedure, the allocation on an ordinal scale (*degree*) or the attribution to a relatively scaled measure is carried out. The nominalized expression is reinterpreted as a physical magnitude represented by a formula-symbol from here on. Semiotically, one notices a successive transition here from everyday language to technical language into an algebraic system of symbols. This is a symbolic part of the register of physics and is isomorphic to a symbolic part of the register of mathematics. These structures are, first, of the syntactical kind. The transformation rules are supposed to apply to formulas of physics in the same way as they do to mathematical ones. This was not always the case in the co-evolution of those two scientific disciplines, but discrepancies could always be solved creatively. In this fashion, new perspectives could be opened up in mathematics, as well as in physics, of which especially Newton's and Leibnitz' infinitesimal calculus is an early example.[11]

The calculation of physical magnitudes offers a reversal of the above-outlined transformation typical of technical language, which can also be understood from the viewpoint of metaphorization. From two magnitudes based on experience, for example, the distance and the duration of a trip, mean speed can be algebraically constructed by a formation of quotients. It is then possible to refer to them linguistically and in cognitive patterns as thing-like circumstances, which is starkly apparent in expressions of everyday language. The theoretical framework, as well as the world of imagination, is enriched through reified terms that neither correspond directly to the basis of experience nor to the already theory-based physical objects. They stand out, however, due to their concreteness on a symbolic level, insofar as they can utilized in formal operations. Categorically, as well as genetically, we have an enhancement of the concept of

11 In the above quoted Def. VI from *Opticks*, a weak form of the algebraic metaphor resulting from an "elliptical" reduction is presented: only the term Angle is left out, and this way the term Incident is being treated algebraically, so that it can become the argument of the sine function.

grammatical metaphor at hand. This "algebraic metaphorization" requires a transgression of the grammatical space of common language and technical language; it requires nominalization as an intermediate step for the semantic construction of physical magnitudes, as well as for their reverse "unpacking", that is, their interpretation and application.

Didactic Remarks

Linguistic examinations and considerations of metaphorical phenomena are not ends in themselves. They offer a substantial access to cognitive processes and developments, including learning. Respective approaches in mathematical didactics have been pointed out above; they include a didactically oriented, interdisciplinary reprocessing of the foundations, as well as the work in teaching and learning processes.

As the works of Ben-Chaim and Banks show, linguistic examinations can also aid understanding of historical movements and controversies in the sciences or even more general ones that are paradigmatical for the epoch, and this is a dimension of interpretation also relevant in the didactic context. Concerning nominalization, Halliday sharpens such interpretations and in that way offers a useful hint at possible causes of the resistance to physical sciences. In the world of classical physics, the flow of experience is put under control. Reality has to be hindered to slip away, while being observed and made accessible to the experiment. Control over experience is partly a physical matter, but it is also semiotic, and semiotic control of experience is gained through grammar's power of nominalization. Because it is grammar that constructs experience in the first place, it is also grammar that can transform it by reconstructing it in different terms. Grammatical metaphorization played an important role in shaping our humane world, but it shaped it in a way soon to be considered decidedly inhumane. Already in the late 18th century, not even a hundred years after Newton's *Opticks*, there was resistance to the rigidity of the world of physics. The ideological limitations of the discourse of natural sciences, in the grammar of which any experience was constructed in reified terms, seemed to be unacceptable.

The implied romantic counter movement against a technocratic, degenerated rationalism could also comply with an at least temporary attitude of youth culture. Could it be that the lack of popularity of physics as a school subject, which is chronic, despite huge efforts, contains components of culture criticism because it does not include

individual and social aspects sufficiently? If applied to the pedagogic concerns of the physics teacher, the above quoted thesis corresponds with several currents in the pedagogy and didactics of the sciences, of which only a few are mentioned here exemplarily and in note form: enabling the learners to create an experience basis of their own activities, careful transition to technical language, teachings on the nature of science, semantic work through formalization processes, and communicative and argumentative competencies.

Summary

Newton's *Opticks* is rightly being treated as an epoch-making opus, and that not only because of the historical discoveries, theorems, and theses described therein, but also because of its linguistic composition. The latter supports a methodological and philosophical basic concept, which Newton calls experimental philosophy, and puts it against the axiomatic-deductive concept of the Cartesian school. In this work, the transition to technical language can be examined as a linguistic phenomenon of importance in the philosophy of science, in the analysis of technical language, and, especially, in its relationship to didactics, particularly, nominalization. Here, it is placed into the framework of the concept of the grammatical metaphor, which, in turn, is enhanced by the use of the algebraic metaphor to analyze the processes of formalization.

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