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Newton's First Law: Text, Translations, Interpretations and Physics Education

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Abstract. The translation from Latin of Newton's First Law (NFL) was considered in a historical perspective. The study showed that Newton's original yields two versions of complementary meanings, one temporal and the other quantitative. The latter is especially important in presenting the idea of inertia of massive bodies, and a new paradigm of understanding motion. The presentation of NFL in physics textbooks was reviewed and a decline in the status of NFL in the physics curriculum was noted. As a rule, if quoted at all, NFL is presented in its temporal form, while the quantitative form does not appear. Normally, NFL is interpreted as a special case: a trivial deduction from Newton's Second Law. Some advanced textbooks replace NFL by a modernized claim, which abandons its original meaning. We advocate the importance and nontrivial meaning of NFL, and call for its 'rehabilitation' in physics instruction within the discourse mode of education.

1. Introduction

Newton's laws, which constitute the foundation of classical physics, normally comprise the core of introductory physics curricula. Newton's First Law (NFL), the law of inertia, presents a topic of special interest. More than others, it manifests the break with the tenets of medieval physics, and the establishment of a new understanding of motion that, to a great extent, survived in contemporary physics and remains fundamental in terrestrial and space engineering.

Newton presented his new theory in the 'Mathematical Principles of Natural Philosophy' (the *Principia*) published in 1687, which immediately became a classic ('the greatest scientific work ever produced by the human intellect' – Jeans 1947). Rich in meaning, it is an example of a text of 'productive semantics' for his contemporaries, and remained such for generations of learners henceforth, who need to rediscover and reinterpret it, given their own perspective of validity and meaning. When, about a century ago, the frontier of physics surpassed Newton's laws, it was primarily educators and historians of science who continued to consider the Newtonian legacy in the changing context of physics education.

This study presents a new attempt in this direction in regard to NFL or, as it is known in physics, the Law of Inertia. The implication of such efforts could influence the way Newtonian mechanics is taught to the new generation of scientists, engineers and educated individuals. Being central in the paradigm of classical physics, the interpretations and reinterpretations of NFL are especially important in physics education, surpassing simple pragmatic goals of physics training.

In the framework of the contemporary perception of text, as possessing non-unique meaning and validity, we returned to the original wording of this law, and reviewed its several translations from Latin. The new translations made in the twentieth century reveal the richness of NFL, which we discuss and compare with the views of Newton's great competitors in their pursuit of the meaning of inertia. We then reviewed the status of NFL in contemporary physics textbooks, to facilitate possible implementations of the results of this study in modern physics instruction.

2. The Difficulty of Analyzing text

NFL is unique in many aspects. Perhaps its most striking feature, in the perception of a scientist, is that it exists solely in textual form. This itself presents a special problem, uncommon in physics, making it difficult for us to reveal the meaning of NFL. There are several reasons:

2.1. LANGUAGE OF PHYSICS

'Language of physics' is a term designating certain modifications of a regular language, developed by scientists to address each other and not the public at large. This claim seems obvious with regard to mathematics, operating with abstract symbols and imaginary objects. However, a theoretical description of physical knowledge, by means of a text, might be not less difficult to comprehend, as it presumes conceptual knowledge normally not self-evident. Physics redefines words in everyday use, providing them with a specific meaning, which usually deprives them of their usual flexibility, and often makes them far less obvious to the reader.

2.2. NEW TERMS AND NEW MEANINGS

Every conceptual change in science is accompanied by a radical semiotic change, i.e., the appearance of a new vocabulary. This often presents a problem for contemporary scientists, a fortifiori so for learners, who try to perceive the new knowledge by means of old scientific terms and by using words in their everyday meaning. The situation becomes even more complex when a new meaning cannot be conveyed by an old term. Lacking necessary precedent, the pioneers themselves experienced difficulties with the transfigurations of the terms designating the concepts of time, space, mass, force, and energy, which are just a few examples. As some of the redefined concepts are especially important, being regulative for the new scientific paradigm, one should look for the required explanations in the originals, at the time when the new theories were under consolidation. In time, the new terms assimilate into experts' knowledge and drop their conceptual scaffoldings. As a result, their original meaning often becomes unclear. Therefore, addressing the original writings may allow us to reveal the genesis of meaning, and increase our understanding of the subject. This was seemingly why Wittgenstein regarded a child's articulation of a subject as 'better' than any adult's, and similarly a young science, as 'better' than the mature one.[1]

2.3. TEXT VERSUS SYMBOLIC FORMALISM

In the course of scientific progress, a sort of 'self-purification' takes place, whereby a more succinct and sophisticated meta-language of mathematical, symbolic forms gradually displaces the original less-formal lexical designations. The obvious pragmatic advantages of this process were interpreted by the positivist philosophy as maturation, attaining more rigor and accurate knowledge (Comte's 'positive' science). Mature science seeks laconic codifying, evades textual descriptions, almost reducing their role to the explanation of the symbolic. This tendency, however, changed with the rise of the cultural approach to science. It revived the appreciation of text as an indispensable form of presenting ideas. The absence of unequivocal interpretation characterizing textual form, which was viewed previously as a shortcoming, is now often interpreted as a reflection of the complexity and richness of the subject, and the superiority of the text over symbolic formalism.

3. Cultural Aspect

As mentioned, texts written by the pioneers in science possess a special importance. Distant in time, they represent a different culture. Newton's laws are a cultural phenomenon of the seventeenth century; nevertheless, we study them from our own perspective, as these laws remain an important constituent of the knowledge in the physics we teach.

Newton wrote his laws as metaphors, as vividly and clearly as he could. Addressing his contemporaries, these metaphors constituted the declaration of a new paradigm that described and interpreted the universe in terms of forces and material particles moving in a vacuum of absolute space. This new paradigm established an entirely new conceptual framework for generations to come. Understandably, its novelty for Newton's contemporaries can be scarcely appreciated now, when such ideas are authoritatively taught to every science freshman.

Why should we then bother to return to the past, trying again to understand Newton's original writings? The answer lies in the change of approach to knowledge that has taken place in the cultural-educational doctrine. In the past, any new scientific knowledge replaced some old knowledge deemed wrong and inaccurate. Within the modern perspective, the new knowledge constitutes an ongoing discourse revealing new facets of the particular knowledge, often complementary, and not necessarily contradictory. All together, they are relevant to the present and future, comprising a cultural hypertext. The authors, through their views, beliefs, ideas and values, regardless of the culture they originally belong to, continue to legitimately contribute to this dialogue throughout time. Throughout history, the reader's role thus becomes more complex and interesting, as he himself becomes a participant in this discourse.

4. The Phenomenon of NFL Translation

Although the *Principia* is a gem of the English culture, it was written in Latin, the indisputable form of scientific treatises in the pre-modern European science. Latin, unifying the scientific community, on the one hand, presented a barrier that significantly reduced the number of consumers of scientific texts, on the other.[2] Latin especially affected the understanding of NFL, because of its pure textual form. Words possess multiple and context dependent meanings, which practically exclude the possibility of an exact translation. Thus, since speculative interpretations are almost inevitable, translation presents the construction of a new text rather than simply its conversion by means of the substitution of terms. The translator, especially of a text presenting a new idea, can easily miss or misunderstand the original intention of the author. In light of the above, we now briefly review the history of NFL translations.

The first two Latin editions of the *Principia* in 1687 and 1713 read:[3]

> Corpus omne *perseverare* in statu suo quiescendi vel movendi uniformiter in directum, *nisi quatenus* a viribus impressis cogitur statum illum mutare. (emphasis added) (L)

The first English translation was provided by Motte, a mathematician, who published the *Principia* in 1729, two years after Newton's death (Newton 1729). The translation became well known in the time of classical physics. Motte's text of NFL reads:

> Every body *perseveres* in its state of rest, or of uniform motion in a right line, *unless* it is compelled to change that state by forces impressed thereon. (emphasis added) (E_1)

In the 1930's, Cajori, a historian of mathematics, revised Motte's old translation (Newton 1934). This new edition of the *Principia* became widely used,[4] and was the quote found in physics textbooks citing NFL.[5] In Cajori's modification, NFL changed as follows:[6]

> Every body *continues* in its state of rest, or of uniform motion in a right line, *unless* it is compelled to change that state by forces impressed upon it. (emphasis added) (E_2)

In fact, both these English translations are somewhat problematic. The Latin premise indicator *nisi* indeed corresponds to *unless*. However, the translation of *nisi quatenus* by *unless* is inappropriate. *Nisi quatenus* has a meaning *so far as not*, or *except inasmuch as*, which addresses the idea of 'to the extent of' while including the negation of some factor.[7] This, in contrast with the simple conditional sense of 'unless.' Worthy of mention is that the same text (the form 'perseverare – nisi quatenus') appeared in two more places in the *Principia* – in the Definition Three and in the examples, immediately following NFL. It also appeared in the preface of Newton's colleague, Cotes. Indicatively, in all four cases the same original language form was translated differently. Thus, the text of Newton's example of NFL, read in Latin (Newton, 1687):

> Projectilia perseverant in motibus suis *nisi quatenus* a resistentia aeris retardantur & vi gravitatis impelluntur deorsum. (Example-L)

in Motte's and Cajori's translations it became:

> Projectiles *preserve* in their motions, *so far as* they are *not* retarded by the resistance of the air, or impelled downwards by the force of gravity. (Example-E)

– the more correct translation. Why the inconsistency between the translations of the same text? In the apparently correct translation of Example-E, one can notice the context of acting forces, e.g. air friction and gravity, which might be perceived as being quite at odds with the usual understanding of the law as regarding a forceless case. The explicit presence of forces in the original could have guided the translators to the Example-E form, either consciously or intuitively, whereas the law itself, being formulated as a context-independent statement, escaped such interpretation by the translators.

Cajori (E_2), in comparison with Motte (E_1), further simplified the text by replacing *perseverare*, directly corresponding to 'preserve,' by *continue*.[8] This translation deprived the text of the meaning of persistence (tenacity, adherence) not necessarily presumed in *continue*. '*Perseverare*' is not among the choices of the reverse translation of 'continue' from English into Latin. Despite the intention of the translators to seemingly seek greater simplicity, the introduced changes ('continue' and 'unless') clearly created a new text of NFL.[9]

We may also mention that the translation of *perseverare* as *continue*, might entail another premise indicator. As 'continue' addresses time span, the indicator 'until', is more logical, and therefore preferred. 'Unless' (or, as also used, 'if ... not') became logically deficient.

Although it is not within the scope of this paper to explore all the translations of NFL into other languages, we mention here two important cases. In 1759 the *Principia* was translated into French (Newton 1759). NFL appeared as:[10]

> Toute corps *persiste* dans l'état de repos ou de mouvement en ligne droite dans lequel il se trouve *á moins que* quelque force *n*'agisse sur lui et ne le contraigne *á* changer d'état. (emphasis added) (F)

In 1873, the first German translation of NFL appeared as following (Newton 1872):

> Jeder Körper *beharrt* in seinem Zustande der Ruhe oder der gleichförmigen geradlinigen Bewegung, *wenn er nicht* durch einwirkende Kräfte gezwungen wird, seinen Zustand zu ändern. (emphasis added) (G)

Both (F) and (G) forms translated *perseverare* as 'persist' (*beharrt* in German), and *nisi quatenus* as *wenn er nicht*, and *à moins que . . . n'* corresponding, in backwards translation, from German to the premise indicator 'if it not' and 'if only not' in French, both equivalent to 'unless'. Thus, one can see that German and French translators followed the form, and hence the interpretation of NFL provided by Motte.

Interestingly, Thorp, a Cambridge Fellow, first made the linguistic justice to NFL in the rarely mentioned translation in 1776 (Newton 1969). It reads:

> That every body *perseveres* in its state of resting, or of moving uniformly in a right line, *as far as* it is *not* compelled to change that state by external forces impressed upon it. (emphasis added) (E_3)

In our century, Whiteside did the same, when translating the Portsmouth collection of Newton's manuscripts (Whiteside 1967–1981). There, in the treatise De Motu Corporum (On the Motion of Bodies), which preceded the *Principia*, we find the First Law of Motion in the form (L), translated as (Whiteside 1981):

> Every body *perseveres* in its state of resting or moving uniformly straight on, *except inasmuch as* it is compelled by impressed forces to change that state. (emphasis added) (E_4)

Finally, Cohen and Whitman (1999) seemingly closed the case by providing the public with an accurate translation of the *Principia*, free of the above-mentioned discrepancies.

Here we have to mention another cultural event, the translation of the *Principia* made in the thirties into Russian because its vision of NFL presents an entirely new phenomenon. Krilov, a member of the Russian Academy of Science, an intellectual and a first class expert in mechanics, thoroughly scrutinized the *Principia* beginning with its Latin original (Newton 1936/1989). His outstanding effort provided profound insights into the meaning of the Newtonian text in the form of numerous comments, detailed commentaries and performed calculations (often omitted in the original).

With respect to NFL, a new feature appeared – a dual translation. Within one perspective, NFL designates persistence resulting in preserving some entity at any point in time (active perception), whereas the other, points at continuity of something, a sort of neutral status (passive perception). In light of the perceived dichotomy, Krilov suggested two versions of translations, as equally legitimate. They correspond to the two interpretations of *perseverare*:

- 'to preserve' [the state] (1)
- 'to continue' [to be in the state] (2)

Krilov mentioned that although the first meaning apparently would more adequately represent the original, in some cases the second version could be also perceived in the original. In Krilov's view, Newton played with both meanings, in this way making full use of the equivocalness[11] of Latin. This claim implies that neither of the two versions alone would be sufficient, and cannot 'truly' represent

Table I. Versions of the translation of Newton's First Law

Form of NFL	Translation of 'perserverare'	Translation of 'nisi quatenus'
quantitative	to preserve	so far as [it is] not
temporal	to continue	until

the meaning of NFL. Our understanding of the case should draw on the fact that Newton invested a special effort to be accurate in every word chosen in the formulations of his laws and definitions. There is a good reason to believe in such pedantry. L. S. Polak, a historian and editor of the Russian edition of the *Principia* wrote (Polak 1989):

> From the huge number of currently published manuscripts and letters produced by Newton, we know him as a highly scrupulous person, a first grade scrutiner who could thoroughly rewrite the same piece five-six times until the product satisfied him completely.

Seemingly committed to produce a single and better definition, Krilov suggested a compromise, amounting to hybrid of the two translations:

- 'continue to preserve' (1) + (2)

Furthermore, from his new perception of the text, Krilov saw the duality of translation of 'perseverare' as implying the same regarding 'nisi quatenus'. Namely, the translation of *perseverare* prescribes the translation for *nisi quatenus* (Table I). In version (1) *nisi quatenus* should be translated as *so far as not* (or, *except inasmuch as*), whereas in version (2), apparently addressing time duration, *nisi quatenus* requires *until* as the translation.

Summarizing, Krilov stated two NFL translations, 'quantitative'[12] and 'temporal'. Quantitative form:

> Every body *preserves* its state of rest or uniform motion in a right line, *so far as* it is *not* compelled to change that state by forces impressed upon it. (emphasis added) (Q)

Temporal form:

> Every body *continues* in its state of rest or uniform motion in a right line, *until* it has been compelled to change that state by forces impressed upon it. (emphasis added) (T)

Finally, seeking the widest meaning, Krilov adopted an excessive combination. Translated into English, it reads:

> Every body *continues to preserve* its state of rest or uniform motion in a right line, *until it is* and *so far as* it is *not* compelled to change that state by forces impressed upon it. (emphasis added) (E_5)

Such a translation was innovative. For the first time, two versions of the law were presented as equally correct. Neither the quantitative nor the temporal form coincided with (E_1), employing the pair 'perseveres – unless', and certainly not with the 'continue – unless' in (E_2). The Thorp, Whiteside and Cohen-Whitman translations coincide with the Q-form, but only very recently the latter became available to the wider public, and still not adopted by the authors of physics textbooks. For quite a long time, nobody questioned the accuracy of (E_1), or (E_2). The new translation of Krilov, as well as of others, failed to attract the attention of physicists or physics educators. We may summarize the aspects of NFL translation as follows:

- Quantitative translation (Q), was originally suggested by Thorp in the eighteenth century, and revived by Krilov, Whiteside, Cohen and Whitman. Physics textbooks never adopted it.
- Krilov's temporal translation (T) was never used by other authors.
- Motte's translation (E_1), as well as the first French (F) and German (G) ones, were close to Q-form, but suffered from a certain deficiency due to the inappropriate premise indicator 'unless' (instead of 'so far as not').
- Cajory's (Ball's[13]) translation (E_2) was close to the T-form, but also suffered from a deficiency due to the inappropriate use of 'unless' (instead of 'until').
- Krilov's innovative dual reading of NFL suggested to combine its temporal (T) and quantitative (Q) forms.

5. Complementarity of Contexts of the Two Versions

As stated, the bifurcation in the translation of the Latin original gave birth to two forms of NFL, quantitative (Q-form) and temporal (T-form). That the latter is closer to the commonly adopted form is the fact deserving interpretation, which is best considered after taking a closer look at both forms.

The T-form describes a scenario extended in time. It claims that when forces do not act on the body it, by itself, does not change its state of rest or uniform rectilinear motion. This claim dismisses, besides the trivial case of the absence of forces, a more complex possibility of retardation, a sort of a delayed reaction, when forces are *already* applied, but the body is *still* at the state of rest or uniform movement. The latter would contradict Newton's Rule I of Reasoning (Newton 1978), because the external force (*vis impressa*) is defined solely by its effect of leaving the state of rest, or uniform movement (Definition IV). Thus, T-form addresses the *extended in time* (diachronic) situation, with *no* external forces acting on the body.

The Q-form of NFL addresses a situation at a certain instant. This is implicit in the text, which discusses a body that *persists* to remain in its state (of rest or uniform rectilinear motion). The term 'persistence' here indicates a sort of activity. If there are no forces applied, why should the body persist? It would simply *continue* to move (as takes place in Descartes' theory). On the other hand, if forces do act on the body, an immediate non- delayed result follows (in accord with the T-form). Thus given a change of the state, the body cannot remain in its initial state. These two statements (regarding persistence and change of state) adequately describe the situation, only if one assumes that Q-form addresses an *instant of time* (synchronic situation) when forces are applied but the body is in the state that will be left in the very next instant. And indeed we read in Newton (1999, p. 404):

> . . . inherent force [*vis insita*] may be also called by the very significant name of *force of inertia*. Moreover, *a body exerts this force only during a change of its state, caused by another force impressed upon it* . . . (emphasis added)

We may infer here that in Definition III, defining inertia, Newton keeps in mind *only* Q-form of NFL, which will be elaborated later. In this scenario, although the body intends to preserve its state (of rest or uniform movement), it does not succeed. How could we know the state of the body at each moment? If the force ceases to act, we observe that very state in which the body was at the last moment of force activity. Q-form of NFL requires a special faculty of the body (*vis insita*) to persist in preserving something, and specifies what is this something to be preserved – the state of rest or uniform rectilinear motion.

Indicatively, to illustrate the first law, Newton, immediately after provided three examples, all addressing curvilinear non-uniform motion in the presence of forces impressed upon, or acting inside, the moving body, quite at odds with the usual understanding of the law as regarding a forceless case, and consistent with the discussed meaning of the Q-form. Newton addressed movements of projectiles and planets, both cases *with* forces applied on the bodies moving along a curvilinear trajectory, whereas Galileo addressed motion of bodies on the horizontal plane without friction. In the third example to illustrate the first law Newton, although free of Galileo's 'rotational inertia', suggested a spinning top.

We have arrived at an understanding in which T- and Q-forms describe different kinds of physical situations, complementary to each other. On the surface, 'complementarity' here does not reflect the meaning introduced by Niels Bohr to interpret the quantum world. It is applied in a general sense, implying the addition of areas and modes of application of NFL. This feature of NFL may demonstrate to the learner that people can conceive of Nature in a way that is not reducible to a univocal description. To stimulate further possible thinking on the subject, we can call attention to the fact that the two forms in English correspond to one text in Latin, and both meanings are present within the same Latin original. Keeping in mind this complementarity, we proceed toward a closer examination of the subject.

6. The New Paradigm of Movement: Elimination of the Rest-Motion Opposition

Koyré, the eminent twentieth century scholar, made the contemporary reader aware of the importance of the notion of 'state' in NFL (Koyré 1968). Following his lead, we mention that besides NFL, the term 'state' (status) appears only in the Definitions III and IV, closely related to NFL. There, Newton defined the major actors of the science of dynamics – the faculty of inertia (*vis insita*) and the concept of applied force (*vis impressa*). Koyré argued that despite Newton's extremely rare use of the term 'state,' the change of its meaning should be considered one of his most fundamental conceptual innovations. The concept of *state* was first introduced in science by Aristotle, in the form of 'natural state,' to designate the state of *rest* which all bodies spontaneously seek. Aristotle conceived of the physical reality of terrestrial mechanics as having two modes of existence: the *state* of rest and a *process* of motion ('locomotion,' in his terms). Any movement of an object was conceived as a process in which the body leaves its initial state of rest (state_{in}) and, through a process (of motion) arrives at another state of rest ($\text{state}_{\text{fin}}$). We may represent Aristotle's view on motion by a scheme:

$$\text{state}_{\text{in}}\text{ (rest)} \Rightarrow \text{process (movement)} \Rightarrow \text{state}_{\text{fin}}\text{ (rest)} \qquad \text{(MA)}$$

Newton fundamentally revised this view. In his first law of motion, he redefined the concept of state, incorporating in it both the 'rest' *and* the 'rectilinear uniform motion'. Thus 'state' integrated two very different concepts, in the view of old science (and today's popular conception).[14] Newton thoroughly sought, and finally achieved, a revolutionary new understanding of actual (real, non-uniform) motion. Within his new paradigm, actual movement of a body under applied forces emerged as a sequence of interchanging states:

$$\text{motion} = \text{state}_{\text{in}} \Rightarrow \text{state}_2 \Rightarrow \text{state}_3 \Rightarrow \cdots \Rightarrow \text{state}_{\text{fin}} \qquad \text{(MN)}$$

At any instant, a body occupies a state and changes it yielding to a force causing non-uniform motion. This was a strong paradigmatic shift, which dismissed the binary opposition considered to be indisputable for two thousand years (also deeply entrenched in the laymen's perception), of rest and motion. Thus the opposition:

$$\{\text{rest vs. motion}\} \qquad \text{(OA)}$$

was replaced by Newton (and approximated by Galileo) with:

$$\{\text{rest-or-rectilinear-uniform-motion}\}\ \text{vs.}\ \{\text{non-uniform-motion}\} \qquad \text{(ON)}$$

Comparing MA with OA, we can express Aristotle's paradigm of motion (matching the common-sense perception of reality) by a schematic relationship:

$$\frac{\{\text{state}\}}{\{\text{process-of-change}\}} = \frac{\{\text{rest}\}}{\{\text{motion}\}} \qquad \text{(PA)}$$

Similarly, basing on MN with ON, we get for Newtonian paradigm of motion (embedded in Q-form of NFL) the scheme:

$$\frac{\{\text{state}\}}{\{\text{process-of-change}\}} = \frac{\{\text{rest + rectilinear uniform motion}\}}{\{\text{non-uniform motion}\}} \qquad \text{(PN)}$$

Both schemes clearly represent the essential difference between the paradigms of the old and new sciences. Remarkably, the old paradigm remained relevant in science education. An individual's naïve and intuitive conception of motion is very often similar to that of Aristotle (Viennot 1979). In the course of mastering physics, one must perform a conceptual change from PA to PN. The Q-form of NFL, visualized as addressing interchanging instant states, may help in supporting such a shift of understanding. The instantaneous occupancy of states provides an insight into the nature of non-uniform motion, thus reduced by Newton to a sequence of states of rectilinear-uniform-motions. Apparently however, the new Newtonian notion of 'state' was so revolutionary, that it hardly took root. It was only in the twentieth century that this powerful concept was rediscovered, and became central to quantum mechanics.

7. Implication Regarding the Temporal Form

The Newtonian perception of motion (MN) may influence our understanding of the T-form of NFL. The T-form describes a body in a theoretical (never exactly realized) situation extended in time, when no external force acts. Moreover, if it were only this context the introduction of the very concept of state, albeit possible, would be clearly superfluous. Thus, if one omits the term 'state' the result will reproduce NFL equally well:

> Every body continues to be at rest or uniform motion in a right line, until it has been compelled to change that state by forces impressed upon it. (T_1)

Today, few physics educators would resist this 'abbreviated' version of NFL, and indeed don't, as is evident in the most commonly used university physics textbooks (e.g., Resnick et al. 1992). However, there is a solid basis to believe that it would meet severe criticism from Newton himself. Since he strictly followed the requirement of parsimony (Rule I of 'Reasoning in Philosophy' (Newton 1978), it is highly improbable that Newton would allow any excess in enunciating the fundamental laws. Newton would have definitely employed the T_1-form (seemingly also without 'perseverare' and 'nisi quatenus'), had he wanted to convey solely the temporal content of NFL. The physics textbooks currently in use, however, are insensitive to his intent and often drop the term 'state', using T_1-form (also often without reproducing the correct pair 'continue – until').

8. The Meaning of the Quantitative Form

Superficially understood, NFL in its Q-version has an unjustifiably complex linguistic connection between the claim in the first part, and its stipulation in the second. The Latin premise indicator 'nisi quatenus' creates a rather complex English form – 'so far as [it is] not'. Earlier, we introduced the understanding that the Q-form addresses a momentary situation, with external forces applied on the body.

Although the body persists to preserve its state, it yields to the force continuously changing the states.

To reveal the meaning Newton may have intended, suppose that we have two bodies with identical forces acting on them. It is natural to assume that the change of states is slower in the one that 'preserves' it more strongly. This means that the power of preservation of state (or persistence of the body) is in inverse proportion with the rapidity with which states replace each other:

$$\text{persistence} \approx \frac{1}{\text{rapidity of states exchange}} \qquad (*)$$

The above regards the first part of NFL. As to its second half, reading '*so far as it [the body] is not compelled to change that state by forces impressed upon it*', one can question this seemingly awkward phrasing. For example, why not say 'so far as no forces act' or even more explicitly, 'so far as no forces act and compel the change of its state'? In fact, we find a variety of similar variations produced by the authors of numerous physics textbooks.

Again, assuming that Newton's choice was intentional, we suggest that he wanted to distinguish between the 'applied force' and its result, 'the body being compelled.' While it is hard to talk about the quantity of the 'applied force' (the cause), we can measure the 'being compelled' (effect). But what is the measure of 'is-not-compelled' actually used by Newton? To get an insight into this aspect of his thinking, let us imagine an infinitely large force applied to a body. It is natural in this case to ascribe zero magnitude to the extent of being 'not-compelled'. Now, as the applied force gradually decreases, the body's 'is-not-compelled' will increase. Therefore, we can express this understanding as following:

$$\text{so far as it [body] is not compelled to change} \ldots \approx \text{so far as} \frac{1}{\text{applied force}} \qquad (**)$$

Returning to the original claim of the Q-form [Every body *preserves* its state of rest or uniform motion in a right line, *so far as* it is *not* compelled to change that state by forces impressed upon it], and using the modified forms of both its parts, that is, substituting 'preserves' in accord with (*) and 'so far as it is not compelled' in accord with (**), we arrive at the following claim:

$$\frac{1}{\text{rapidity of states exchange}} \ \text{of the body is in proportion [so far as] to the} \ \frac{1}{\text{applied force}}$$

or, equivalently:

rapidity in states exchange of the body is in proportion to the applied force

This form of NFL presents the statement resembling the claim of Newton's Second Law. In a sense, this is even a more general statement. Given this understanding, one may suggest that in his second law:

momentum change of the body is in *linear* proportion to the applied force ...

Newton further refined the first one (we emphasized the changes between the laws and dropped the part of the second law addressing the direction of change). As we see, this analysis justifies the term 'quantitative' for the Q-form, and provides an inversion of the common perception regarding the hierarchical relationship between the first and the second laws.

9. Conceptual Premises for the Linguistic Complexity of NFL: The Discourse on Inertia

As discussed, the Latin original yields two versions of English translation due to the bifurcation of 'perserverare' into 'preserve/continue'. The two versions address complementary settings, T-version is diachronic, addressing time interval and a forceless situation, whereas Q-version is synchronic, addressing a situation at any given time when external forces are employed. In our view, the bifurcation expresses Newton's desire for the most precise expression of his innovative conception of inertia.

At the dawn of modern science, its founders, each in his own way, perceived the idea of inertia. A brief review of their perspectives on this idea reveals an interesting range.

Galileo's ideas regarding what is currently common called inertia changed in the course of his life. His original view was very similar to Aristotle's in that it did not distinguish between inertia and gravity, considering heaviness (weight) the factor impeding motion under the external force ['violent motion'] and causing the body to return to its 'natural' place (Dijksterhuis 1986). Galileo wrote (Drake 1978):

> Heaviness to me (and I believe to Nature) is that innate tendency by which a body resists being moved from its natural place and by which when forcibly removed therefrom, it spontaneously returns there.

Later, through a brilliant thought experiment, when he applied the argument of exhaustion in varying the inclination angle of a body descending on a downward slope, Galileo arrived at the necessity of the inertial motion on the horizontal (along the spherical surface of the Earth!) plane (e.g., Galiley 1632/1953, p. 147). This was, in our terminology, the discovery of Galileo's principle for inertial (spontaneous) movement. It is important to appreciate Galileo's specific perception of inertia: 'indifference to motion and rest and not a tendency to move'. Already in his *Letter on Sunspots* (Galiley 1612/1995) we find the following explicitly expressed conception of inertial movement:

> All external impediments removed, a heavy body on a spherical surface concentric with the earth will be *indifferent to rest and to movements toward any part of the horizon*. And it will *maintain itself* in that state in which it has been once placed; that is if placed in a state of rest, it will *conserve* that: and

> if placed in a movement toward the west (for example), it will *maintain* itself in that movement. (emphasis added)

Skipping over the mistaken idea of ‘circular inertia’ (seldom mentioned in the classroom), we mention here Galileo’s wording – ‘maintains itself’, with regard to the body in inertial motion.

However, the problem remained in Galileo’s mind. Later, in his famous *Dialogo*, Galileo had Sagredo (the host and chairman of the discussion) say (Galiley 1632/1953, p. 213):

> I see in a movable body is the natural inclination and *tendency it has to an opposite motion*. . . . I said ‘*internal resistance*’, because I believe that this is what you meant, and *not external resistances*, which are many and accidental. (emphasis added)

Salviati (Galileo’s representative) readily confirms and refines:

> I wonder whether there is not in the movable body, besides a natural tendency in the opposite direction, another *intrinsic and natural property* which makes it *resist motion* (emphasis added).

That far Galileo went in comprehending inertia: an inherent *resistance* to motion and its neutral *maintaining*. A contemporary reader would decisively combine the *two* perceptions of inertia – resistance to *and* preservation of motion. Indicatively, Galileo, in his narrated texts, voluminously expresses his views and did not produce a compact statement on the subject as Newton did later in the form of his first law, which is extremely inclusive and laconic.

Kepler’s conception of movement was rather close to that of Aristotle’s, at least in the need of a mover to maintain motion. However, if Aristotle did not expand much on the natural resistance of bodies to motion (Clagett 1959), Kepler was already ahead in this respect. He conceived of matter (of a planet) as having a faculty of impotence, an inherent ‘laziness’, with respect to motion. We read (Jammer 1961):

> transporting power (potentia vectoria) of the sun and the impotence of the planet (impotentia planetae) or its material *inertia* strive against each other (emphasis added)

It was Kepler who introduced the term inertia into physics.[15] Although Kepler correctly related the measure of inertia to the quantity of matter, his inertia corresponds to the intrinsic propensity of matter for rest. Preventing spontaneous motion, inertia returns the body to the state of rest when the mover ceases to act. This although may be similar to Galileo’s perception of resistance, so much different from the Newtonian concept. B. Cohen’s remarkable finding was revealing Newton’s marginal remarks (never published) in the first edition of the *Principia* in which Newton explicitly addressed the essential difference between his and Keplerian inertia. Newton wrote (Cohen 1971):

> I do not mean Kepler's force of inertia by which bodies tend toward rest, but the *force* of remaining in the same *state* whether of resting or of moving. (emphasis added)

The picture would be not complete without looking at Descartes' ideas of what we can identify with inertia. It was Descartes who introduced into physics the spontaneous motion of bodies as true rectilinear and uniform, the motion that we call inertial.

A direct look at Descartes' *Principles* (Des-Cartes 1656, 43), to which the Newton's *Principia* was, to a great extent, a conceptual response, reveals Descartes' 'laws of nature,' as being conceptually parallel to Newton's laws. Descartes addressed the subject of inertial movement in two laws rather than one (Descartes 1644/1984, 59–60):

- The first law of nature: that each thing, *as far as is* [*quantum in se est*] in its power always *remains* [*perseveret*] in the same state; and that consequently, when it is once moved, it always *continues* to move' (emphasis added)
- The second law of nature: that all movement is, of itself, along straight lines; and consequently, bodies which are moving in a circle always *tend* (*tendo*) to move away from the center of the circle which they are describing. (emphasis added)

This presentation, clearly formulated as Laws of Nature, was formally superior to that of Galileo's and appears very close to that which will be written in the *Principia*. We read Descartes' further elaboration (ibid. p. 63):

> One which is at rest has some force to remain at rest, and consequently to *resist* everything which can change it; while a moving body has some force to *continue* its motion, i.e. to continue to move at the same speed and in the same direction. (emphasis added)

Although Descartes' *resistance* may resemble previous ideas of Galileo, his continue moderates initial *perseveret*. One should not be mistaken by the expression 'body_has_some_force', which may remind Newton's *visa insita*. Descartes' view was different in that he seemingly considered inertial movement of objects as those being '*situated*, and so disposed to move' (ibid. p. 112). Although addressing *inertial motion* as the 'power to *remain* in a state', Descartes explicitly rejected the concept of *inertia* as an *inherent* faculty of the matter. 'I do not recognize any inertia or natural tardity in bodies.. ... ' wrote Descartes in his letter to Mersen in December 1630.[16] This apparent paradox – the rejection of inertia and adoption of inertial motion – can be explained by the reduction of this phenomenon to contact forces due to obeying the conservation of motion.[17] Then, what one may perceive as inertial force becomes only a matter of interpretation. In Descartes' view, the body remaines absolutely passive and neutral until a collision, an impact with another body occurs.[18] This understanding of inertial movement as a mere passing from place to place, lacking any inertial intrinsic *activity* of the body *itself*, is in striking contrast with Newton's perception of 'perseverare'.[19]

Finally, another giant of modern science, Huygens, in 1673, fourteen years before the *Principia*'s first edition, made his try to address inertia. In his first law (hypothesis), he stated:

> If gravity did not exist, nor the atmosphere obstructs the motion of bodies, a body would *maintain* forever a motion once impressed on it, with uniform velocity in a straight line.[20]

In this perception, one can recognize only one facet of the inertia concept as being addressed. Instead of the chosen term 'maintain', B. Cohen quoted the same text, using 'continue' (Cohen 1999). Both terms, however, obviously contrast Newton's 'perseverare'. Huygens' however, made a sophisticated claim with regard to the *inertial motion* of the center of gravity of two isolated bodies regardless of their motion (Westfall 1977). Although breaking with Aristotelian physics, Huygens' claim did not improve upon Descartes' conception.

This brief review of ideas regarding the genesis of inertia may not only illuminate the knowledge available to Newton, but also testify as to the novelty of Newton's idea of inertia. Newton's priority is clear in *simultaneously* addressing the faculty of inertia in its *two* facets, the body's resistance to being set in motion (or, as often interpreted, *resistance* to motion) and *maintaining* the motion. These two concepts are contradictory at a first glance, and usually discerned as such by 'everyone'. In fact, both concepts existed prior to Newton as resistance and impetus. Let us listen to him again in his explanation provided to Definition III of the *vis insita* (1978, p. 5):

> ... this *vis insita*, may by most significant name, be called inertia (*vis inertiae*) or a force of inactivity. ... and the existence of this force may be considered as *both resistance* (*resistencia*) *and impulse* (*impetus*); it is resistance so far as the body, for maintaining its present state, opposes the force impressed; it is impulse so far as the body, by not easily giving way to the impressed force of another, endeavors to change the state of that other. Resistance is usually ascribed to bodies at rest, and impulse to those in motion; but motion and rest as commonly conceived are only relatively distinguished ...

Note the mature use of rest-motion relativity. This was classic Newtonian synthesis, the invention of which, as we see, Newton had no competition.

An important aspect of our purpose in this study is the discussion of the revolutionary semiotic change introduced by Newton. We can imagine the problem faced by Newton in trying to find the proper words and style to express his idea, in light of the earlier attempts to account for the same phenomena. Newton was well aware of each of these attempts, and was apparently dissatisfied with all of them. By painstaking efforts he suggested an original metaphoric way to animate the matter

(Descartes explicitly rejected such an approach[21]), and thus include the duality-of-inertia phenomenon. This special goal was achieved in Newton's dual meaning linguistic form 'preserve/continue – so far as [it is] not/until', which can teach us much more about inertia than any predecessor of Newton. It was an exquisitely succinct elaboration of a conceptual break with all antecedent theories. This result justifies a careful analysis of the original text of NFL. The appropriateness of such an approach was stated already by Koyré (1968), the prominent expert of Newton's legacy. Addressing NFL he wrote:

> Every word of this formulation is important both *in se* and for Newton, who as we know now, was an extremely careful writer, who wrote and rewrote the same passage, sometimes five or six times, until it gave him complete satisfaction. . . . Each and every word is important, for instance, the 'perseverare', which is rather badly rendered as 'continues'.

This vision guided our study.

10. NFL in Physics Literature after Newton

Several examples can illustrate the use of NFL in physics texts after Newton. Although Motte's translation (E_1) was seemingly the most popular, we find in Maxwell's lectures (Maxwell 1956) and the famous Mach's treatise on Mechanics (Mach 1960) the Q-form (not T-form) of the law:

> Every body *perseveres* in its state of rest, or of moving uniformly in a straight line, *except in so far as it is not* made to change that state by external forces.

(although substituting 'external forces' for 'impressed forces'). Mach's severe critique of Newton's laws with respect to their logical rigor became well known and heralded the introduction of positivism into science. He pointed to the logical 'vicious circle' created, in his view, by Definition IV and the First Law. Force is defined as the factor causing any deviation from a state of rest of uniform rectilinear motion (Definition IV), leading to the First Law, which claims no deviation from that state unless an external force is impelled.[22] Thus, NFL was reconsidered, and its theoretical status was reduced to a mere convention, convenient for representing certain data.[23] The above analysis, which revealed the extended meaning of NFL in its Q-form, may shed a new light on the subject and refute, at least partially, Mach's critique.

The positivistic critique made Newton's laws a subject of revision and reconsideration. It was a new era that replaced a long period of unlimited respect and veneration. During the 18–19th centuries, Newton's mechanics served as an exemplar to be copied in various areas of physics, other sciences, and even philosophy. The positivistic trend of scientific epistemology inspired the thought of Hertz in his attempt to reformulate mechanics excluding the 'metaphysical' concept of force. Yet, after excluding the 'impressed force', he preserved the rest of NFL text, using *perserverare* (not continue) with regard to the state of the system. Seemingly reflecting the ideal of academic expression, the first law appeared in Latin (the only Latin sentence in the treatise) and was named Fundamental Law (Hertz 1956):

> Systema omne liberum *perserverare* in statu suo quiescendi vel movendi uniformiter in directissimam. (emphasis added)

Careful treatment, respect and recognition of its importance was given to NFL by Einstein and Infeld (1938, p. 8) who used Motte's form for NFL (E_1). While addressing the broad public, their book discussed fundamental ideas of man's understanding of nature as they evolved in the course of history. One can observe there the tradition of many popular science texts – that is to equate NFL with Galileo's principle regarding undisturbed horizontal movement.[24] This approach obscures the special contents of NFL. Above, we addressed the relevant views of Galileo who spoke about *inertial motion* and only rhetorically asked about *inertia*. We might also add, based on our teaching experience, that confusion between Galileo's relativity principle[25] and his law of inertial movement, which are close in context and different in meaning, is common.

Quoting Newton's words, and not just his ideas, characterizes the old scientific culture. This approach has been gradually disappearing since the middle of the 20th century. Thus, we can find NFL in the following form (Pomeroy 1964):

> A body at rest will remain at rest, and a body in motion will remain in motion unless some outside force acts on the body.

The appreciation of original textual definitions remains primarily in the domain of the mathematical culture. Newtonian mechanics has been replaced in modern physics, and the whole paradigm of Newton's mechanics was abandoned in favor of a more appropriate pluralistic picture of the world. Nevertheless, NFL remains an essential constituent in the basic knowledge of construction engineering, still providing a precise tool to treat a wide range of macroscopic physical phenomena. As such, it constitutes an undisputable item for introductory physics courses, facilitating an account of everyday experience.

11. NFL in Physics Textbooks

As mentioned, Motte's translation of NFL (E_1) was the one normally utilized in physics textbooks in the past.[26] Since then, however, standards and teaching style have changed, and this tradition declined. One may criticize this development based on the progress in our understanding of learning. Thus, many experts in education ascribe to the language and lexical form of knowledge the central role in the learning process and the establishment of conceptual knowledge in general (Vigotsky 1986). The direct influence of lexical forms on meaning in physics statements in instruction was also discussed (Touger 1991). One may perceive a certain collision of these ideas with the view that prevailed in the 19th and the first half of the 20th century with regard to science. Then, importance was ascribed to the 'essence/meaning' of the scientific law, regardless of the textual form chosen for its representation (thus the best tool to represent and apply knowledge is mathematical formulas). As NFL has no mathematical form, one can observe this tendency in numerous rephrasing, all seemingly aimed at representing the essence of the subject in the simplest and clearest manner. Here are few examples from textbooks of that time:

- A body at test would rest forever, or if uniform motion would move forever in a straight line, unless kept from doing so by some force outside of itself (Cooley 1881).
- Every body continues in its state of rest, or of uniform motion in a straight line, except in so far as it is compelled by impressed force to change that state. (Jeans 1907, 1947; Lemon and Ference 1943).[27]
- A particle left to itself will maintain its velocity unchanged in direction and magnitude (Ames and Murngham 1937).
- If a body in translation is not acted by any external force, its linear momentum remains constant (Millikan et al. 1965).
- A body at rest remains at rest and a body in motion moves in a straight line with unchanged velocity, unless some external force acts on it (Osgood 1937).
- A particle on which no forces are acting has zero acceleration (Hartog 1961).
- All bodies, if unimpeded, move at constant speed in a straight line, in technical terms, with uniform velocity (Russell 1959).

Indicative of this approach, the authors never even mentioned that they modified the formulation of the law, as they believed it was not essential.

Taylor's important textbook (1959) was innovative in presenting an introductory physics course of high-school/college level within a historical perspective. Referring to Russell, Taylor decisively diminishes NFL. The fact that he was addressing freshmen, not experts, with such an evaluation was an act of special educational implications. Taylor started by mentioning the 'logical redundancy in Newton's laws', and proceeded to the position currently held by many:

> Since Newton's first law is thus merely a special case of the second, the question may be raised as to why it is separately stated at all. Is it not merely a redundancy? The answer to this is clearly in the affirmative. The second law having once been stated, the first is definitely a redundancy and is not logically required. Nevertheless, it is almost always retained and explicitly stated as one of the separate laws of motion. Aside from its being an inescapable historical fact that it was in this form that Newton stated his laws, an added reason for the retention of the first law could justifiably be that it possesses some value to the beginner in science. Though it describes a special case of the second law, the case is so special and requires so much consideration, and the consideration of

> it is withal so profitable, there is a distinct advantage in isolating and studying it in its own right. However, the first law could have been stated more logically as a corollary to the second law, which it is, than as an independent law which it is most certainly not.

This blunt conclusion is very clear: NFL was no longer perceived as an independent theoretical unit, and if it needed to be preserved, should be done only as a historical context. Indeed, the presentation (Kittel et al. 1973):

> A body remains in its state of rest, or constant velocity (zero acceleration), when no external force acts upon it.

can hardly be considered anything else but a special case of the second law, a clear decline of status. In Russia, the country where the dualistic translation of NFL was introduced (academic publication of the *Principia*), no textbook followed that innovation. The approach to consider NFL to be a trivial special case of NSL became a norm, in the advanced level textbooks, as well (e.g., Chaikin 1963).

Current physics courses[28] usually do not quote NFL, replacing it by less rigorous propositions, simplified narratives, in some cases, without even referring to Newton (e.g., AAAS 1990). Given this situation in which quotations rarely occur,[29] even those which praise NFL ascribing to it the highest historical and cultural value,[30] only highlight the prevailing neglect.

An important variation in the interpretation of NFL in physics textbooks occurs when the author consideres NFL to be a definition (Arons 1990):

> We can interpret Law I as giving us a *qualitative operational definition of force*, namely that action by an agent external to the moving body, that imparts a change in velocity, and the change includes both magnitude and direction.

This is a break with Newton, who specifically stated this idea as a law, and presented his definitions in a different chapter. The analysis of NFL presented above elaborated upon the new paradigm of motion introduced into science by NFL. These contents are unique to the law and thus may justify Newton's separation of the two.

In another approach, NFL is modernized, entirely losing its original form (Reif 1995):

> Newton formulated these hypotheses in the form of the following three 'laws of mechanics' (summarized here somewhat more clearly than Newton did):
> – There exist reference frames (called inertial frames) relative to which every non-interacting particle moves with constant velocity.'[31]

This form of the law draws on the modern understanding of mechanics, and employs the notion of frames of reference, a conceptual tool unknown to Newton. This approach touches on the problem of whether this new knowledge should replace Newton's ideas. The answer depends on one's perception of the values and preferable form of physics education. Thus the approach focused on problem solving may justify this orientation, whereas a broad cultural perspective on an introductory physics course would avoid the removal of the original NFL from the knowledge transferred to the new generation of physics learners.

Many textbooks present NFL as a statement based on accumulated empirical evidence (e.g., Giancoli 1988), emphasizing the epistemological aspect of science. Others present NFL as a new idea by which scientists broke with the old force-motion conception of Aristotle (e.g. Hewitt 1998), yet refrained from presenting the old paradigms of motion and inertia with which Newton performed an active discourse.

To summarize, one can notice a clear tendency towards the disappearance of NFL from the discussion in many physics textbooks, seemingly reflecting the classroom situation. It is also important to note that in those current textbooks that do quote NFL, Cajori's translation (E_2), the least accurate translation of the law, is cited. This fact could contribute to the genesis of the present unfortunate situation with regard to NFL's status in physics instruction.

12. Discussion

We have reviewed and analyzed NFL from a number of perspectives (Figure 1). Whereas our work has implications in several areas, we will address those, which we believe have major ramifications in science education in general, and physics courses specifically. The revealed non-triviality of NFL, imbedded in its Latin original, illustrates the importance of the original expressions by the pioneers of conceptual progress in science. Koyré foresaw this importance in his call for careful study of the wording used by Newton himself.

The original text of NFL yields dual representation – temporal and quantitative forms, which are complementary both in physical meaning and the situations they address. The complexity originates from the novelty of the Newtonian idea of inertia, which integrated two faculties of matter, separately recognized by Newton's predecessors: resistance to motion and motion maintaining (impetus). It was especially in its quantitative form that NFL reflected a radical conceptual change in the understanding of motion, eliminating the motion-rest opposition. Actual motion in the presence of forces, as in real life, was conceived by Newton as a sequence of states continuously replacing each other under the influence of an external force. This idea, embedded in the quantitative form of NFL, was seemingly lost in the inaccurate translations and enumerated restatements which sought simplification (which the author of the original could not prevent). This understanding is very relevant in physics instruction aimed at a conceptual understanding, but is not communicated currently in a regular physics class.

The history of NFL illustrates that insisting a scientific law, be necessarily simple in form and that it univocally encapsulates a certain idea, may lead to a serious conceptual degradation of its original meaning, yielding a result very distant from the author's intentions. It is especially true regarding the texts establishing a

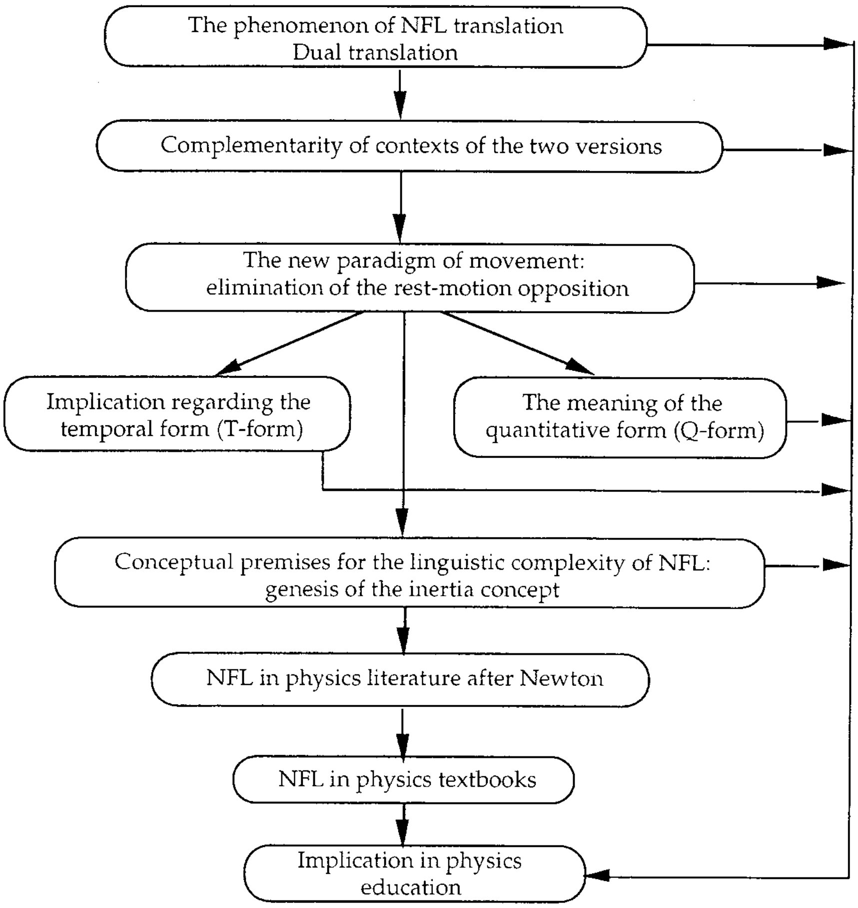

Figure 1. Flow-chart of the paper.

new scientific paradigm that often introduces a semiotic change. The NFL history illustrates that the nature of the process of conceptual discovery without any new empirical data reflects an intensive scientific *discourse* including different ideas and ways to conceptually account for inertia. Although Newton's approach won, it can be adequately perceived solely within the conceptual environment of the discourse on the subject.

Furthermore, the modern reader is in a position to better understand the interesting phenomenon of the dualistic form of NFL. The non-unique meaning of a text is consonant with the character of the modern culture beyond science. The question of whether the inherent complexity of non-uniqueness may thereby enter education brings us a new perspective on instruction.

In our view, 'a rigid array of simplified statements of truth' presents a deficiency. It results in a discipline incorporating anonymous pieces of knowledge, pretending to be objective and fully independent of the human minds that constructed it.

We suggest another format, that of *discoursive instruction*, within which various aspects of scientific conceptions, rules and laws, should be presented, juxtaposed and compared with regard to their contexts and areas of validity. This approach reproduces the discourse that took place historically in real science with its debate, complementary perspectives regarding the same subject, and representations, often associated with different personalities. The format of discourse revealing different facets of the evolving scientific truth can be illustrated by teaching NFL as a part of the discourse on inertia. This study may provide contents for an instructional unit addressing Newton's first and second laws as an exemplar of discoursive teaching. Other existing elaborations of the conceptual history of dynamics (Stinner 1994; Westfall 1971; Whitrow 1971) may further fortify the contents of such a unit.[32]

Regarding the legitimate search for simplicity in science instruction, we should always be aware that both opposite extremes – the too complex scientific theory or its over-simplified presentation – are equally undesirable. Although present day authors still appear to be mainly afraid of the former (unlike the approach adopted in humanities for the same age group of students), one however may discover the danger in the latter as well. A profound remark made by Niels Bohr regarding the truth about nature deserves mentioning. Once, when asked to name the concept complementary (in the physical sense) to the truth, he answered – 'clearness'.[33] The inverse relationship between truth and clearness is one of the central features, which distinguishes our modern culture from the doctrine of a unique truth, universal, clear and self-evident, which prevailed, as an ultimate goal, in the classical science starting from Aristotle.[34]

The two complementary readings of NFL, temporal and quantitative, together can bring the student to a genuine understanding of inertia as an integrative concept. For Newton, NFL never was a special case of his second law. Q-form of NFL addresses the momentary situation of active external force and in a sense is a more general statement. This is definitely a new perspective for physics instruction. As an appropriate framework to present this subject within a discourse mode of teaching, we may suggest discussing the different approaches of Newton and Galileo to the description of Nature. While Galileo established laws for an idealized world, Newton showed an extraordinary sensitivity to always remain in his considerations within real situations (Koyré 1968). Inertia presented for Newton a very real entity conflicting with applied forces. Currently, however, inertia is rarely discussed in high school and college physics classes, although its relevance extends beyond classical mechanics, into relativistic theory and electrodynamics.

This important perception is in conflict with the present status of NFL in physics instruction as it has emerged from reviewing commonly used textbooks in physics. NFL, if quoted at all, appears in a somewhat temporal form, often simplified and modified to the point of losing any resemblance to the original. As such, it is often reduced to a trivial special case of Newton's second law addressing a forceless situation. Only a few texts preserve the emphasis on the importance of NFL, and usually after 'modernizing' its contents. Consequently, NFL today plays a diminished role in the physics curriculum, especially in courses utilizing a problem-solving approach, commonly prevalent in the training of prospective scientists and engineers.

The complexity of NFL can be revealed to students in stages in a spiral-ascending curriculum, not a new approach in science education (Bruner 1960). For example, it can be presented within the first instruction in junior-high and high schools in a T-form and then refined and developed to its dual form, T and Q-forms together, in the instruction in high school (advanced placement), college and university levels.[35] This approach matches the widely known viewpoint of recapitulation in education: repetition by an individual ('ontogenesis') of the developmental stages of the collective scientific knowledge ('phylogenesis'). As in culture, a generally simpler, univocal perception of truth is replaced by a multivocal, (post)modern conception. In fact, such an approach is broadly utilized with regard to most physical concepts, such as force, weight, energy, heat, light. This approach promises to be just as attractive and rewarding with regard to NFL.

13. Conclusion

We may conclude with another item of physics folklore. Physicists, when they want to dismiss the worthiness of considering a certain question, may say: 'This is either incorrect, or trivial.' This approach may be justified with regard to texts of 'traditional semantics' (not introducing new concepts). In contrast, Newton's First Law belongs to texts of 'productive semantics,' about which we can say that each new generation reads and discovers it for itself. The more we immerse in the process of learning NFL, the more meaning and new aspects we reveal. These ideas present a recommendation for adoption in instruction and textbooks. This hopefully will facilitate the kinds of instruction geared toward an audience of various levels and orientations, and restore to Newton's First Law the status it deserves.

Newton's First Law is far from just a trivial special case of Newton's Second Law. As such, NFL can, and should, be carefully preserved and studied in the corpus of physics knowledge transmitted through the generations. As to the form this could be done in science education, we suggested a framework of *discourse* which can provide the student with an awareness of how scientists wrestle with the construction of new principles in physics. Their debate, internally and with others, reveals an adequate perspective on science as a human culture enterprise.

Acknowledgment

We feel obliged to the late Prof. Michael Marinov from the Technion in Haifa who had read the manuscript, provided thoughtful comments and encouraged our study.

Notes

[1] One should not confuse this remark with the evaluation of naïve views and alternative conceptions that children spontaneously develop, in their need to make sense of the world. We did not intend to dismiss the conflict of scientific correctness and need to encourage conceptual change in learning science. Our attention here is on the freshness of perception of those who contributed to conceptual revolutions in science. In their attempts to persuade others (and themselves) they often exposed much more of their argumentation and ideological intentions than subsequently appeared in the textbooks.

[2] Seemingly, this motivated Galileo to leave this commonplace in science and write his Dialogues in Italian. Later in the 17th century, Descartes still apologized for writing his 'Discourse on Method' in French and not in Latin.

[3] In the third and last Latin edition of the *Principia*, NFL appeared in a slightly different form: 'Corpus omne *perseverare* in statu suo quiescendi vel movendi uniformiter in directum, *nisi quatenus* illud a viribus impressis cogitur statum suum mutare.' (Newton 1726). The difference with the first version is however, minor from the perspective of the present discussion.

[4] The important fact for physics education is that the paperback English edition of the *Principia* (until recently the only one) was the Motte-Cajori version, reprinted in 1962. It was adopted also by the Britannica Great Books series (Newton 1978).

[5] Few physics textbooks presently quote the original formulation of NFL. Hecht (1996) is among the few. Although in the recent past it was more common, e.g., Pippard (1972), Cajory's edition was common in the educational milieu.

[6] In fact, the same version of NFL appeared already in Ball's *Essay* in 1893.

[7] The Latin affirmative form correspondent to the negative 'nisi quatenus' would be 'quantum in se est' – 'insofar as it is' (White and Oxon 1948).

[8] *perseverare* contains *continue* among possible translations, although not as the first meaning and it is accompanied with 'steadfastly', 'in some effort', 'in spite of difficulty' (White and Oxon 1948).

[9] The translation of F. Cajori was addressed by B. Cohen in his *Introduction to Newton's 'Principia'* (1971: XVI): 'The unsatisfactory result achieved by the late Florian Cajori serves as a warning to anyone who may be tempted merely to modernize the text of Motte's contemporaneous translation of 1729 . . . Cajori's modernization of Motte's translation introduces so many infelicities that it may serve as a cautionary object-lesson in not tampering with older translations. Again and again scholars have been misled by Cajori's version, which must be used with the greatest caution, and always checked against the original.'

[10] Quoted according to Encyclopedie Scientifique (1930).

[11] Equivocalness, rather than ambiguity, refers to the two meanings we believe Newton specifically had in mind.

[12] Below, it will become clear why Krilov chose the term 'quantitative'.

[13] Ball performed a fragmentary translation in 1893 (1972).

[14] This process of integration was not unique in history. A similar integration of knowledge took place in the eighteenth century with regard to various forms of electricity: those originating from friction, heating, animals, atmospheric phenomena and contact of materials were all recognized as different modes of the same concept (Wolf 1952).

[15] As mentioned by Jammer, this induced Auguste Comte to call the principle of inertia 'la loi de Képler', which since then was adopted as such in French educational materials (e.g., Platrier 1954, p. 108; Painlevé, 1895, 2).

[16] Quoted in Koyré (1968: 69).

[17] 'I hold that there is a certain Quantity of Motion in all the created matter that never increases or diminishes . . . this same quantity of motion does not give as much speed to the larger as to the smaller, and because of that we can say, in this sense, that the more matter a body contains, the more natural inertia it has.' from the letter to Mersen in December 1630. Quoted in Koyré (1968: 69).

[18] A more comprehensive analysis of Descartes' views on the subject may be obtained from Garber (1992: 211–230).

[19] Descartes was clearly the starting point for Newton. An undergraduate student of Cambridge, Newton enunciated the principle of inertia in terms very close to those used by Descartes (Westfall 1977: 144).

[20] Huygens Ch. *Horologium Oscillatorium*, quoted in Taylor (1959: 130).

[21] As Descartes wrote in his 'The World': 'I do not want any one to imagine on account of that that it has in itself a thought or volition that pushes it there, but only that it is disposed to move in that direction'.

[22] Definition IV states: 'An impressed force is an action exerted upon a body, in order to change its state, either of rest, or of moving uniformly forward in a right line.' (Newton, 1978: 6).

[23] The approach was first suggested by Poincare and developed by Mach and Duhem, the scientists who were logical positivists (e.g., Duhem 1991, Frank 1957).

[24] In light of this study one can appreciate the inaccuracy of presentation in which Galileo's perception replaces NFL. In Peierls (1956) one reads: 'The most fundamental law of mechanics is then the inertial law of Galileo, which states that if left to itself a body will move with uniform velocity in one and the same direction.'

[25] Galileo's relativity principle claims the equivalence of physical reality in all inertial systems of reference (those in which NFL holds).

[26] Some authors (e.g., R. A. Millikan, D. Roller and E. C. Watson 1937) also recommended that all students read Newton's laws in the original.

[27] After forty years, in 1947 (1947: 191), Jeans returned to Motte's form (E_1).

[28] Our survey covered more than forty textbooks of introductory physics courses on the high school, college, and university level, published in English and Hebrew and representing textbooks most commonly used.

[29] And always in Cajory's (E_2) form!

[30] 'I consider this law to be the greatest single intellectual "leap" ever achieved by a scientist' (Reichert 1991).

[31] One may see this approach in Resnick et al. (1992). It is adopted in advanced courses published in Russia (e.g., Landau et al. 1969, Saveliev 1998).

[32] The natural limits of this publication cannot permit a comprehensive discussion of the discoursive mode of teaching science, which is only schematically outlined here.

[33] Complementarity of a pair of concepts, in its physical sense, presumes a relationship when an augmentation of the certainty of knowledge regarding one, implies a correspondent diminution of the same regarding its pair. Thus, extrapolation of this principle beyond a physical context, generally a very problematic step, may yield that the greater clarity of understanding may result in lesser content, which sounds reasonable. The simplest facts are very clear, whereas profound scientific statements are normally associated with a great degree of obscurity, as testified by many experts.

[34] According to Aristotle, a fundamental principle of science should present a self-evident truth.

[35] Currently, NFL is taught in exactly the same way in junior high school, high school, college and university.

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