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“Never at rest”: developing a conceptual framework for descriptions of ‘force’ in physics textbooks

Abstract

The concept of ‘force’ is abstract and challenging for many physics students, and many studies have revealed misconceptions that hinder students’ understanding and learning in classical physics. One reason for this may be the multifaceted nature of the concept and how textbooks give different definitions and explanations depending on the context. In this article, we present a framework of eight categories for how the concept is described, based on fundamental principles in physics, their historical sources and an analysis of how ‘force’ is described in four physics textbooks used in upper secondary schools in Norway. Examples from one of the textbooks that constituted the empirical basis for the framework are given. These reveal that textbooks may present students with a variety of definitions and explanations of ‘force’. It is argued that students should be made aware of this variability in order to support their motivation and learning in physics, but also to understand the complex and evolving nature of the force concept and other important concepts in physics.

INTRODUCTION

It is well known that understanding the basic concepts and principles of Newtonian mechanics is challenging for students, even after several years of study. Numerous studies have documented students' misconceptions in basic mechanical concepts and principles (see e.g. Alonzo & Steedle, 2009; Coelho, 2012; Viennot, 1979; Warren, 1979). Even if mechanics appear as a concrete strand of physics, students encounter one of the most abstract and in a way difficult concept in physics, namely the concept of force. Consequences of an acting force may be visible, and students have experienced forces in their everyday life, by feeling forces working on their body, or observing the results of a force working on an object. Still, we have no way of directly observing or experiencing 'force' as such (Carson & Rowlands, 2005). As Gamble (1989) has stated: "*Force is an idea: it is not a concrete object such as an egg or a cell.*" (p. 79). This abstract nature of the concept contributes to the challenges in teaching and learning about forces.

Many have suggested that one reason for students' challenges is that the term "force" has different meanings and connotations in everyday language than in physics (see e.g. Halloun & Hestenes, 1985, Brookes & Etkina, 2009). What is less attended to is that the term also holds different meanings in the ways physicists talk about forces, how it has developed historically and how it is represented in textbooks and taught to students. So far, research in physics education has in most cases not investigated these semantic inconsistencies in language use within physics teaching, which may be a cause for students' problems in developing a robust, scientific conception of force.

In this article, we present a conceptual framework for the variation in how the concept of 'force' is defined and explained in physics textbooks. Wong and Yap (2012) have undertaken a meta-study on definitions and identified four challenges in defining physical concepts: precision, circularity, context and completeness. Our framework uses this implicitly, but it has not been the main focus in developing the different categories. The starting point for developing the framework is how Coelho (2010) has identified three main types of definitions of force:

- (i) Force is the cause of acceleration
- (ii) Force is defined by the fundamental equations of dynamics, and
- (iii) Force is obtained by the connection between force and the effort felt by pulling or pushing an object.

These categories are extended and refined based on fundamental principles in physics and their historical sources combined with an inductive analysis of four physics textbooks, where also research on typical student conceptions are taken into account. All these factors are likely to influence how textbooks are shaped by textbook authors, meaning that the categories draw on different sources. We first present the framework in a generalized way and then give examples of how the categories are represented in one of the textbooks that form the empirical basis for the framework.

STUDENTS' CHALLENGES IN UNDERSTANDING FORCE

For several decades, constructivism was a common conceptual frame for science teaching and research (see Driver et al., 1994, Amin et al., 2014). This led to numerous studies on students' conceptions about natural phenomena (see the bibliography by Duit, 2007), and how to use these in teaching in order to foster conceptual change among students (e.g. Bryce & MacMillan, 2005; Dekkers & Thijs, 1998; Strike & Posner, 1982). A considerable number of studies have been conducted within basic mechanics, and per Carson and Rowlands (2005), conceptions of force constitute the dominant theme in the misconceptions' literature. Among the widely-used instruments for probing students' conceptions about force is The Force Concept Inventory (FCI, see Hestenes, Wells, & Swackhamer, 1992). This instrument has been used in schools and universities worldwide for many years, often to evaluate the achievements of teaching methods in mechanics. Results show that the Newtonian understanding of force remains a challenge for students across national contexts and levels of study (see e.g. Caballero et al., 2012; Fulmer, Liang, & Liu, 2014; Savinainen & Scott, 2002). Students on

advanced level may be able to do quite sophisticated mathematical calculations in mechanics, but still hold similar misconceptions or alternative framework as young children. Also, other studies have shown that force and basic principles in mechanics are challenging for and teachers and physics students as well as for children at various age groups (see e.g. (Kruger, Summers, & Palacio, 1990; Trumperdag & Gorskyddag, 1996; Watts, 1983). Many students adhere to Aristotelian thinking rather than Newtonian mechanics (Ebison 1993). They tend to associate force with movement, understand force as something an object carries (“impetus”) that will be used up during movement, and anticipate that large objects are acting with a larger force than small objects in an interaction (see also Alonzo & Steedle, 2009 for an overview of student conceptions).

Many studies of misconceptions suggest that they form part of students’ alternative frameworks, which needs to be challenged and replaced by more scientific ways of thinking. However, as Graham, Berry and Rowlands (2012) have argued, misconceptions are not necessarily held by students prior to teaching, but might just as well be a result of the teaching process. Therefore, studies of how textbooks present the concept of force are important in order to understand how they may actually contribute to students’ challenges in learning physics.

DEVELOPING THE FRAMEWORK

The framework has a broad basis of disciplinary, historical as well as educational sources, reflecting how presentations in textbooks also are built on multiple sources. The framework is developed by combining studies of research literature and historical sources with analysis of four physics textbooks as empirical material. Analysis of the textbooks is undertaken inductively, with a deductive aspect since Coelho’s categories (Coelho, 2010) were used as a starting point. The analysis is partly semantic, in the sense that we explore the relationship between words, phrasing and meaning.

The four textbooks analysed are:

- Rom, Stoff, Tid 1. (RST 1, Jerstad, Sletbak, Grimenes & Renstrøm, 2007)
- Rom, Stoff, Tid 2 (RST 2, Jerstad, Sletbak, Grimenes & Renstrøm, 2008)
- ERGO 1 (Callin, Pålsgård, Stadsnes & Tellefsen, 2007)
- ERGO 2 (Callin, Pålsgård, Stadsnes & Tellefsen, 2008)

These books represented at the time the study was undertaken the entire offer of textbooks for physics in upper secondary schools in Norway. This means that virtually every secondary physics student in Norway use one or two of these textbooks.

Every paragraph that concerns force in the four textbooks were carefully analysed with regards to how it defines or explains what a force is. The categories were mainly formulated by the first author of this paper, in an iterative process involving discussions between the researchers, consultation of literature and re-categorisation of textbook sequences. New categories have subsequently been added, refined and adjusted to make the framework map the different descriptions of force found in the textbooks precisely but with as few categories as possible. The resulting eight categories gave saturation in the sense that no new textbook sequences gave a need for additional categories.

Some categories are divided into subcategories to reflect how the same main idea is expressed in different ways.

Presentations of force: Categories

Starting with the three categories of Coelho (2010), it became clear from the textbook analysis that these were too coarse and fail to take the gradual development of the concept in textbooks into account. The framework needs to reflect the increasing sophistication in how force is presented. The first category *Force is the cause of acceleration* is therefore divided into three categories, whereof one has four sub-categories. This is consistent with the historical development of the concept. The second

category, *Fundamental equations of dynamics*, is divided into two different categories based on formulations of Newton's second law. Coelho's third category was divided into two categories, one based on Newton's third law and the second on a tactile definition using the Agent-Receiver idea (push-pull). An additional category based on the property of a force to perform work has also been defined, as this description is common in textbooks. The framework thus resulted in eight categories described in the following. They are partly reflecting an increased sophistication not visible in Coelho's categories, and also show some fundamental differences in descriptions of force.

Effect as property

As force gives rise to an effect, the first category focuses on the effect described as a property of force, mainly based on experience and empirical observations. That is, we have a force if we can observe the effect of the force acting on an object. A change in an object's shape (deformation) or a change in motion are signs that a force is present. This description is not necessarily based on knowledge of physics or the physical concept of force, but rather on visual or tactile observations in everyday life in order to enhance students' understanding of a phenomenon.

This category has the obtained effect of a force as the main feature, the observed effect is important. If we look at two common ways of talking about forces, namely

"A force can change the speed of an object, and a force can change the form of an object"
and

"The effect of an acting force on an object is that the object changes speed or is deformed."

we observe that they are not equivalent. The semantic differences lie in the use of the words "can" and "or", which may have different connotations in different languages. Instead of stating that a force *can* change the speed, it is possible to say that a force *may* change the speed, or that a force *will* change the speed. This contextual factor is important for how this category is formed. It can be interpreted as this category has many dimensions, which in a sense is true but such an interpretation depends on the semantic context of the language. In our case, where the language is Norwegian, the category has two dimensions. One description based on the possibility that a force *may* give rise to an effect and one where a force *will* give rise to an effect, where the former being less precise within this category as we can apply our experience a force without an apparent effect.

Force and motion

As many perceive force as being the cause of motion, the second category focus on the relationship between force and motion. The need for an agent or force (mover) acting to have or uphold motion is an ancient idea and has been part of the framework of many natural philosophers. Aristotle describes the concept of a universal cause, prime mover, that is the ultimate cause of motion in the universe (Jammer, 1999). The idea of a prime mover is also present in the work of Newton, but less dominant. In the work of Aristotle, the idea that there must be a cause to motion was considered systematic, but the concept of force as we know it today was non-existent, yet the word was used. Aristotle identified "force" as the cause of motion, unlike objects being at rest, but this conception of "force" is not the one we use today. We will not go into detail on this beyond stating that the idea that force and motion are connected forms the major idea of this category.

This category is based on a textual description, without a mathematical formalism. The concept of motion is not well defined and gives rise to four sub-categories: *Force as a maintainer of motion*, *Force as the cause of motion*, *Force determines motion* and *Force can change motion*. The force as such is the same but it is the relation to how motion is described that differs between the sub-categories. The difference is not entirely semantic but shows increasing sophistication in describing how motion is affected by a force.

“Never at rest”: developing a conceptual framework for descriptions of ‘force’

a) Force as maintainer of motion

The origin of the sub-category can be found in Aristotelean physics, where a force is required to maintain motion. Considering that motion, regardless of how it is defined, can be observed and explained by the continuous presence of force.

b) Force as the cause of motion

This sub-category breaks with the previous in the sense that a force causes motion but is not necessary to maintain the motion. That is, we get a causality with a force acting and causing motion.

c) Force determines motion

The next sub-category takes a further step towards a complete description. Here the force is not only defined as being the direct cause of motion but also determines the motion. That is, the force can be used to describe the motion. The distinction between 2b) and 2c) may be considered semantic and therefore somewhat problematic. One motivation for making such a distinction is to show the problem with interpretation in different languages.

d) Force can change motion

In this sub-category, the concept of force is developed further as being able to change motion. From the first sub-category where the connection between force and motion was established, the second where force is the cause and third determining motion, the refinement now gives the *change* of motion as an ability of force but without mentioning acceleration.

Force is the cause of acceleration

This category is based on a description of force as the cause of acceleration and gives a direct and explicit connection between force and acceleration. Coelho (2010, p. 103) identifies this definition is the most common in textbooks:

“In a sample of about a hundred textbooks, it was found that “force is the cause of acceleration” is the most common definition of force.”

This is a further sophistication from the previous category by coupling force and acceleration, and to say that force is the *cause* of acceleration.

Considering that acceleration is more precisely defined than motion, as in addition to being measurable, one might argue that this category is a sub-category to *Force and motion*. It could also be a sub-category to *Force and Newton’s second law*. However, as noted above, we make use of the clearer definition (acceleration), as it provides a clear distinction between the former categories. The category does, however, not include a clear mathematical definition of Newton’s second law, since this is on a higher level of sophistication and forms a new category.

Force and Newton’s second law

Having specified a category where a force is the cause of acceleration, there is also a need for a category based on Newton’s second law. We specify this category in the sense that a mathematical formalism is necessary to distinguish it from the *Force is the cause of acceleration* category. The formalism makes it possible to perform numerical calculations allowing for increased predictive power.

Included in the category are the different acceleration-based representations of Newton’s second law, as a sum of forces in vector form or scalar form:

$$\begin{aligned}\sum \vec{F} &= m\vec{a} \\ \sum F &= ma\end{aligned}$$

In most cases, the first presented definition is in the scalar form and considering only one force present:

$$F = ma$$

The category also includes presentations of Newton's second law from an acceleration point of view, especially when treating motion without introducing forces first (kinematics) and then introduce forces (dynamics):

$$a = \frac{F}{m}$$

The category has similarities with *Effect as property*, as we define a force by its effect, in this case, acceleration. However, as noted above, the categories follow an increasing sophistication, that is, we include more precise definitions and refined mathematical expressions in the category *Force and Newton's second law*.

Force and momentum

In the previous category, the acceleration formulation of Newton's second law served as the basis. It should be noted that Newton did not use this formulation in the *Principia* (Newton, et al., 1687, 1999), but based his formulation on momentum.

In the *Principia*, the second law is stated as:

"A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed."

(Newton, et al., 1687, 1999, p. 416),

where «motion», is defined in the *Principia*, Definition 2:

"Quantity of motion is a measure of motion that arises from the velocity and the quantity of matter jointly."

(Newton, et al., 1687, 1999, p. 404).

which we recognize as momentum.

Cohen stresses in the guide to the *Principia* (Newton, et al., 1687, 1999) that Newton means motion as in definition 2, that is momentum and not the loose definition of motion used in the previous definitions:

"Def. 2 states that the measure of motion adopted by Newton is the one arising from the mass and velocity, our momentum. Although Newton does not say so specifically [...] it is this quantity of motion that he means when, as is often the case, he writes simply of 'motion'. For example, in law 2, Newton writes that a 'change in motion' is proportional to the motive force.' Here he means 'change in the quantity of motion' or, in our terminology, change in momentum."

(Newton, et al., 1687, 1999, pp. 95-96).

Stating Newton's second law as

$$\sum \vec{F} = \frac{d\vec{p}}{dt}$$

relates force to momentum, or rather to the change in momentum (impulse). As with acceleration, momentum is a quantity that is clearly defined and can be measured.

The form of Newton's second law used in this category is not equivalent to the form in the *Principia*. The difference is that we use a continuous force while Newton included the possibility of an instantaneous force, an impulse or impulsive force. An important aspect of using the momen-

tum-form of Newton’s second law is that momentum is a conserved quantity, while the acceleration is not conserved.

Force and Newton’s third law

This category includes Newton’s third law as the basis for a definition of force. There exist different ways to formulate the law, but all of these can be used for the description of force in this category.

It should be noted that Newton’s third law, unlike the first and second laws, in principle does not involve motion, yielding that descriptions of force in this category often do not have a direct connection between force and motion. Newton’s third law may in many ways be said to be a “book of rules” for how forces work, and these rules define a force.

In the Principia, the third law is stated as:

“To any action, there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction”

(Newton, et al., 1687, 1999, p. 417).

Brown (1989) presents five ideas as particularly important in conjunction with Newton’s third law:

- (i) A body cannot *experience* a force in isolation. There cannot be a force on a body A without a second body B to exert the force.
- (ii) Correspondingly, a body cannot *exert* a force in isolation. A cannot exert a force unless there is another body B to exert a force on A. We then say that A and B are *interacting*.
- (iii) At all moments the force A exerts on B is of the same magnitude as the force B exerts on A.
- (iv) An important implication of the above point is that neither force precedes the other force. The force body A exerts on body B is always simultaneous with the force B exerts on A.
- (v) In the interaction of A with B, the force A exerts on B is in a direction exactly opposite to the direction of the force which B exerts on A.

Using Brown’s ideas, the emphasis is on the interaction between two objects, that is, the force acting between them. As with the category *Effect as property*, the category presents force as interaction. However, while *Effect as property* involves that the effect of the force defines force, Newton’s third law does not describe a specific effect, but rather how a force represents an interaction between bodies. This category can hence be an abstract version of the *Push-Pull* category, where the tactile experience is important.

Force and work

With the progression in the sophistication of how forces are presented, force is coupled to other concepts not directly associated with motion. This category is related to energy, through the concept of work. We have chosen to avoid a more sophisticated subcategory and include all references to work and energy to a single category.

In dynamics, work is defined in terms of applied force and displacement:

$$dW = \vec{F} \cdot d\vec{s}$$

A force is said to do *work* when it acts on a body so that there is a displacement of the point of application in the direction of the force. Thus, in this category a force is described by the work it does on a body, in this example resulting in a movement.

The kinetic energy of an object with a specific mass and a speed v can be defined as the work done to accelerate the object from rest to the speed v . As work is related to the sum of forces acting on an object, force may be included in the definition of kinetic energy. This means that a force may alter the kinetic energy of an object. This implies a possible overlap with other categories, such as

Force and motion and *Effect as property*. It is, as specified above, the use of the concepts work and energy that defines this category and the higher degree of sophistication compared with the other categories.

Push-Pull

This category is not based on a concrete context or any form of physical expression or law. It is based on descriptions of forces as “push” or “pull”, and consists of a set of descriptions of force, which are intended to help students understanding the concept.

Forces are either a “push” or a “pull”. This can make it easier to understand the concept of force, since everybody has physical experiences of pushing and pulling things in everyday life, to get the desired effect. The category might be considered as a tactile category where the experience is important. It is important to note that this category does not limit itself to contact forces, as one can also experience long-range forces such as gravity and magnetic forces.

Even if the category is not primarily based on physical laws, it has an important conceptual dimension in physics and the history of physics. The fundamental idea is based on pre-Newtonian mechanics, where philosophers such as Aristotle and Rene Descartes believed that only contact forces were possible. That is, an object could only act upon another object with a force if they are in direct contact with each other or contact with a solid mediator (Jammer, 1999). Descartes tried to construct a theory of gravity based on contact forces in order to explain the movement of the planets, since “action at a distance” didn’t exist in his philosophy. Jammer (1999) describes this in his book:

“For, rejecting any possibility of an action at a distance, Descartes constructs his vortex theory to account for the remote heavenly motions. To assume some action at a distance for their explanation would be tantamount, he claims, to endowing material particles with knowledge and making them truly divine, «as if they could be aware, without intermediation, of what happens in places far away from them.”

(Jammer, 1999, p. 104).

If we look at Newton’s concepts of force, we see that it differs from Descartes’ concept. Cohen and Smith (2002) describe the different forces found in the Principia:

“Centripetal forces differ from percussion and pressure in one notable aspect. Percussion and pressure are the result of some kind of observable physical action. In both, there is a contact of one body with another, typically providing visual evidence of a force acting, for example, a billiard ball striking another billiard ball. These are the kinds of force on which the so-called “mechanical philosophy” was built, in particular, the philosophy of Descartes, These forces display the principle of matter in contact with other matter to produce or alter a motion”

(Cohen & Smith, 2002, pp. 62-63).

In the push-pull category, forces may be considered as either a push or a pull between two objects in contact or as a tactile experience of a force. Even if force described this way has strong historical roots, it is often described with reference to an everyday setting, as we can see in University Physics:

*“In everyday language, a **force** is a push or a pull. A better definition is that a force is an interaction between two bodies or between a body and its environment.”*

(Young & Freedman, 2012, p.108)

This description refers to force as in the Push-pull category. The category differs in origin from the other categories that go deeper into physical definitions, in having human experiences as its basis.

“Never at rest”: developing a conceptual framework for descriptions of ‘force’

Coelho (2012) indicates a class of definitions of force that is based on “the effort felt by the pulling and pushing of an object”:

“In contemporary textbooks on mechanics, three kinds of definitions of force were found. [...] In some textbooks, a connection between force and the effort felt by the pulling or pushing of an object has been established.”

(Coelho, 2012, p. 1339).

The category can be summarized as conceptualising force as a “push” or a “pull”. It is here important that it is the force that is defined - not the effect of force.

Newton’s first law as a category?

In this framework, Newton’s first law is not utilised directly in any category. One reason for this is that the first law describes what happens in the *absence* of forces and does not speak of forces as such. It may be argued that it is possible to say a lot about forces that are absent, and thus cause no effect and compare this with situations where forces are present. An interpretation of the first law is that if you get an effect, change in motion, there must be a force. However, this interpretation is not complete.

Newton presented the first law in 1687 as (see Newton, Cohen, & Whitman, 1687, 1999):

“Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed.”

(Newton, Cohen, & Whitman, 1687, 1999, p. 416)

One might consider the first law as a combination of two definitions «Definition 3» and «Definition 4»:

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

(Newton, Cohen, & Whitman, 1687, 1999, p. 404)

“Impressed force is the action exerted on a body to change its state either of resting or of moving uniformly straight forward.”

(Newton, et al., 1687, 1999, p. 405).

With these definitions, Newton talks about two “forces”, though physicists today would consider the “inherent force” as “inertia”, and the “impressed force” as an external force on a body.

Coelho (2010) addresses Newton’s first law from a historical perspective and how the law is presented in textbooks. He points at a problematic aspect of the law, namely that it is not possible to prove in an experiment, as a situation total free from external forces cannot be constructed. Thus, follow an interpretation that the first law can be interpreted as a special case of the second law. When no forces are present, the acceleration is zero, and therefore any motion will remain constant. This interpretation can be found in several textbooks, as pointed out by Coelho (2010). Whether this is problematic or not depends on how, and the context in which one chooses to formulate the first law. As Coelho (2010) points out, the first law defines a reference-state or reference-motion, when no external forces are present. The first law then works as an axiom, necessary for explaining that if there is an effect there must be a cause. The first law is necessary to explain unambiguously that if there is an effect due to a force there must be a force in connection with the laws of gravity. In terms of our categories, this is an inverted version of the category *Force can change motion*, as it couples a change in motion to the existence of a force.

This line of thought might not appear in textbooks but gives the background why we have not included a category based on the first law in the framework. Since the first law is based on basic assumptions of the existence and absence of forces, it does not describe what a force is, just if it is present or not.

Summary

The categories for descriptions of force is summarized in table 1.

Table 1. Categories for the description of force.

Category	Description
1. Effect as property	The effect of a force serves as the definition of what a force is.
2. Force and motion 2a) Force as a maintainer of motion 2b) Force as the cause of motion 2c) Force determines motion 2d) Force can change motion	The concept of a force is explained through its relation to motion. Sub-categories are introduced as precision progresses.
3. Force is the cause of acceleration	Acceleration is a consequence of a force acting.
4. Force and Newton’s second law	Force is defined by Newton’s second law.
5. Force and momentum	Force is defined using the quantity of momentum, and Newton’s second law.
6. Force and Newton’s third law	The concept of force as described in Newton’s third law.
7. Force and work	Force defined using the “ability” of a force to do physical work.
8. Push-Pull	A force is either a “push” or a “pull” (on a body). All forces can be regarded as “push” or “pull”.

REPRESENTATIONS OF CATEGORIES: TEXTBOOK EXAMPLES

In the following, we give examples of how categories in the described framework are represented in one physics textbook used in the course Physics 1 (year 11) in Norwegian upper secondary school. Thereafter, we give an overview of occurrences of the categories in all the four textbooks that form the empirical basis for the framework.

Since the formal curriculum strongly frames the content of textbooks in schools, we present the curriculum aims for the main subject area named “classical physics” in Physics 1 in Table 2. The concept of force appears explicitly mainly within this main subject area but is also found within the other areas, which are “modern physics”, “explaining nature through mathematics”, “the young researcher” and “physics and technology”.

As we can see from Table 2, the curriculum document gives in itself no explanation of what ‘force’ means, but rather the various context where students should apply it and the calculations and qualitative descriptions they are supposed to master through the course. The general formulation of the Norwegian curriculum leaves the interpretation of how to present the concept to the textbook authors and teachers. It is therefore likely that they will, in turn, get inspiration from the textbooks they are familiar with from their education and work. Therefore, the textbooks are likely to mimic each other, rather than relying entirely on the curriculum.

Table 2. The curriculum aims for classical physics in Physics 1 in the curriculum for Norwegian upper secondary school (from www.udir.no)

Physics 1. Students should be able to:
- identify contact forces between objects and gravitational forces on objects, draw force vectors and apply Newton’s Three Laws of Motion
- give an account of the concepts of energy, work and effect, carry out arithmetic calculations and discuss situations where mechanical energy is conserved
- give an account of situations where friction and air resistance mean that the mechanical energy is not conserved, and perform calculations in situations with constant friction
- state and discuss the first and second laws of qualitative thermal physics
- define the terms current, voltage and resistance, and apply the principles of conservation of charge and energy to simple and branched direct current circuits
- define and carry out calculations with the terms frequency, period, wavelength and wave speed, and explain qualitative bending and interference phenomena

Textbook examples: The case of “Rom Stoff Tid 1”

In our case, we consider the textbook “Rom Stoff Tid 1” (RST 1, Jerstad, Sletbak, Grimenes & Renstrøm, 2007). This textbook is regarded as rather traditional, except that it starts with topics from modern physics rather than mechanics. Therefore, forces are not mentioned in the first chapters. The chapters 5, 6 and 7, “Motion”, “Force and motion” and “Work and energy” respectively, constitute the part of RST 1 covering classical mechanics, and we hence limit our case study of RST 1 to these three chapters.

Chapter 5: “Motion”

Chapter 5 does not deal directly with forces but introduces the reader to the central quantities in mechanics: displacement, position, speed and acceleration. These are presented as scalar quantities, and it is mentioned towards the end of the chapter that the quantities are in fact vector quantities. One can thus summarize the chapter as an introduction to basic quantities, enabling the student to describe motion without the introduction of force.

Chapter 6: “Force and motion”

This chapter introduces forces in the domain of classical mechanics. In the introduction, “force” is established as an important concept in physics. The reader is given a brief explanation as to how the chapters 5 and 6 are connected: “In the previous chapter the subject of study was how to describe and measure motion, without considering the forces behind the motion. In this chapter, however, force in relation to motion is the subject of study.” (RST 1, p. 105). The implication is that the quantities introduced in chapter 5, position, speed (velocity) and acceleration, are descriptive quantities with regards to motion. Force, on the other hand, seems to be more of an explanatory quantity through its relation to motion. This is an indication that the *Force and motion* category is represented, but perhaps not yet a specific sub-category, as the phrase “force in relation to motion” is not a clear statement.

The first statement of the chapter is: “A force is an interaction between two bodies.” (RST 1, p. 106). Thus, the notion of an “interaction” appears already in the very first sentence of the chapter. This first statement might be said to serve as a definition (though, it is not highlighted as a definition, as are other laws and definitions in the textbook) of what a force is – an *interaction*. The use of the term “interaction”, and the fact that RST 1 specifies that a force involves two bodies, indicate the presence of the *Force and Newton’s third law* category.

This initial statement is immediately followed by an explanation: “By this, we mean that two bodies can interact with each other in such a way that their velocity and/or shape are changed.” (p. 106, RST 1). This can be categorized as being a description of *Effect as property* as the textbook deals with what a force has the ability to do¹. The focus is on the fact that a force actually has an effect or an “impact”. Then follows an example and a list of three points summarizing the content of these initial statements as to the properties of a force: “1. A force always acts *from* one body *to* another. Thus, there are always *two* bodies involved. 2. A body being acted upon by a force from another body, always act with a force on the other body. 3. A force can² change the speed (velocity) and/or the shape of a body.” (p. 106, RST 1). The second statement can be categorized as *Force and Newton’s third law*.

“Interaction between two objects: Newton’s third law” is the following sub-chapter. It is interesting to note that the textbook does not present Newton’s laws in “numerical” order. That is, Newton’s third law is introduced before the first and second law. RST 1 justifies this by stating that “Newton’s third law is important to gain a better understanding of the concept of force before we introduce Newton’s other laws” (p. 110, RST 1). This sub-chapter focuses on the fact that all forces come in pairs, as described in Newton’s third law, placing the presentation in the *Force and Newton’s third law* category.

The introduction of Newton’s first and second laws is given in a dedicated sub-chapter called “The relation between forces and motion: Newton’s first and second law” (p. 114, RST 1).

Newton’s first law is stated as: “An object will remain in a state of rest or in a state of rectilinear motion with constant speed unless forces compel it to change this state” (p. 114, RST 1). While it is obvious that force appears in the category *Force and motion* through the statement of Newton’s first law, the choice of words is worth noting: As it appears, a force has the ability to change the state of motion of an object, which is the sub-category *Force can change motion*.

Newton’s second law is stated, using both the mathematical expression as well as textual explanations. It is stated that the speed of a body will change when the sum of the forces acting is non-zero. That is, force is related to motion through the mathematical expression of Newton’s second law and appears in the category *Force and Newton’s second law*. An example following Newton’s second law considers the act of pushing a car in order to push-start the car (p. 117, RST 1). The “pushing”, together with all other forces acting on the car (the sum of the forces) is identified as the cause of the acceleration of the car, thus linking the category *Force is the cause of acceleration* to the more refined category *Force and Newton’s second law*.

Chapter 7: “Work and energy”

The introduction of this chapter states that if we know all the forces acting upon a body, we can use Newton’s second law to calculate how the motion of the body changes (RST 1, p. 131). In addition it is also possible using the principle of conservation of mechanical energy as an alternative, which is a less complex method of calculating the motion of a body.

¹ This refers to the translation of the Norwegian word “kan”, which we chose to translate with the English “can”.

² In this context, we have chosen to translate the Norwegian word “kan” with the English “can”. One could perhaps have chosen the English “may” as a suitable translation. This is a matter of interpretation, as is the case of every piece of translated text presented in this article. The translations in this article are the authors’ own.

In introducing the concept of work, the textbook presents a large rock falling from a cliff into the sea. In analysing this situation, it is said that: “[...] gravity pulls it [the block of rock] downwards, ever-increasing its speed. We say that the speed of the block of rock is continuously increasing because gravity is doing work on it” (RST 1, p. 132). The sequence presents gravity as a “pulling” force with the ability to do work”, that is, both the “pulling” and the “doing work” is associated with a change in the speed of a body. One uses the category *Force is the cause of acceleration* to introduce the concept of “work”. In other words, this chapter mentions “work” as something a force “does”. Following the example of the rock, it is defined that the physical quantity work is the product of force and displacement (RST 1, p. 132). Such a notion of a force can be categorized within the category *Force and work*.

As the chapter concludes, the description of work is refined taking into account that a force might not act in the same direction as the displacement vector.

Occurrences of categories in textbooks: Overview

Table 3 presents what categories that occur in each of the four textbooks that together form the empirical basis for the framework. As presented in detail in the foregoing, six of eight categories are represented in the book RST1. The table shows that also the other textbook contains a multiplicity of descriptions of force. Noteworthy, however, is that the category “Force and momentum”, which lies closest to Newton’s original formulation of the concept of force, is not represented in any of the textbooks.

Table 3. Categories of force represented in the textbooks RST 1 (year 11), RST2 (year 12), ERGO1 (year 11) and ERGO2 (year 12).

Category	RST1	RST2	ERGO1	ERGO2
Effect as property	x	x	X	X
Force and motion	x	X	X	X
Force as the cause of acceleration	x	-	X	-
Force and Newton’s second law	x	X	X	X
Force and momentum	-	-	-	-
Force and Newton’s third law	x	x	x	x
Force and work	x	-	-	x
Push-pull	-	-	x	-

FINAL DISCUSSION AND CONCLUSION

This article has presented a framework of eight categories for how the concept of ‘force’ is described in physics textbooks for pre-university level. The framework illustrates that the concept is multifaceted and that definitions and explanations can be traced back to different historical sources. Analysis of textbooks by means of the framework reveals a large diversity in how the concept of force is presented, and students must deal with this diversity in the same book and even in the same chapter. It is natural that textbooks switch between descriptions appropriate for each purpose depending on the context and the specific topic to be presented. This is in line with how Gamble (1989) has pointed to the fact that ‘force’ is an idea, not a concrete object that can be directly observed, and with how ‘force’ is an

evolving concept also in the development of physics itself. The variability may, however, contribute to conceptual problems in understanding and using the concept appropriately as demonstrated through e.g. the Force Concept Inventory (Hestenes et al., 1992). When the descriptions of force students encounter in various contexts in physics textbooks appear contradictory to each other, they may stick to intuitive everyday conceptions that may relate to Aristotelian understanding as described by Ebison (1993). Making students aware of the multifaceted nature of the concept might support their understanding. It may also enhance their motivation and sense of confidence in demonstrating that the ambiguity lies in the complex and evolving nature of physics concepts and not in their skills.

Several authors have suggested that including aspects of the history of physics may help students to understand not only how physics has developed as a human construction, but also to gain a better understanding of the concepts involved (e. g. Coelho, 2010; Gauld, 2014). Historical approaches also have the potential to make students aware of the fact that the principles we refer to as Newton's laws today look quite different from what Isaac Newton originally formulated. This may help them notice and make sense of the various conceptions or descriptions of force they encounter in textbooks. Of particular interest in this regard is how our textbook analysis has shown that none of the four textbooks investigated contains the category *Force and momentum* that lies closest to Newton's original formulation. Even if the analysis is based on Norwegian textbooks, the general formulation of the Norwegian curriculum has not influenced the textbook presentation. The presentation rather seems to be based on how the concepts are presented historically and in other textbooks. This means that the framework can be used more generally.

More research should be undertaken in order to examine the ways in which the multiplicity of definitions and explanations of force is present in physics textbooks in other countries and on other levels of education. The framework presented in this paper offers a constructive tool for this purpose. It also has the potential for analysing classroom teaching and student responses about forces. This may contribute to illuminating how different conceptualizations of force and the variability may influence students' understanding and their learning processes. The developed framework gives opportunities to make the variability explicit and to improve physics teaching by making students aware of the multifaceted nature of one of the most essential concepts in physics.

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