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Abstract

Scientific concepts are the building blocks of scientific thought and science communication. Therefore, to achieve scientific literacy it is necessary to construct and define the concepts accurately. In this study, the concept of friction force, which is frequently encountered in science textbooks, is discussed. The explanations of the concept in science textbooks have been found to be inadequate in effectively explaining several situations. To address this issue, this study aimed to examine the concept of friction force in the textbooks and to propose a more comprehensive definition. The study was conducted using the document analysis method. A total of 26 resource books (11 university physics textbooks, 4 science-term glossaries, 2 secondary school physics textbooks, 6 middle school science textbooks, and 3 popular science textbooks) were analyzed in the study. Several inconsistencies in the explanations for the concept of friction force were found. Based on the analysis, a more comprehensive definition was proposed to fully and consistently explain the effects and the direction of friction force.

Introduction

Achieving the goal of "science for all" requires us to educate scientifically literate students. One of the facets of scientific literacy is to understand the concepts and phenomena related to science (Roberts, 2007). In other words, students' ability to learn science as a culture effectively is related to the quality of the conceptual teaching applied in science classes (Akgün, Gönen & Yılmaz, 2005; Yağbasan & Gülçiçek, 2003). Despite the importance of "building block" concepts in science teaching and the many contemporary teaching approaches employed in science classes to teach these concepts, it has been revealed that students still have misconceptions in various subject domains (Atasoy & Akdeniz, 2007; Aydoğan, Güneş & Gülçiçek, 2003; Coştu, Ayas & Ünal, 2007; Küçük, 2005; Tekkaya & Yilmaz, 2000). This is still a pressing issue in science education; misconceptions may negatively affect learners' achievements and reduce their success in science (Driver & Easley, 1978; Kumandaş, Ateşka, & Lane, 2018). However, several studies have emphasized the difficulty of changing the misconceptions that students have (Bilgin & Geban, 2001; Gunstone, White & Fensham, 1988). For this reason, a variety of methods and strategies have been developed so that students can adequately construct science concepts when they are first introduced (Atasoy, Küçük & Akdeniz, 2011; Kinchin, 2000; Novak, & Musonda, 1991).

Concepts need to be defined correctly—before explaining the methods and strategies used to construct the concepts. In this way, the formation of misconceptions can be prevented. A definition explains something using the basic elements and features of the known related concepts. In terms of defining a concept correctly, it is necessary to understand the nature of the basic elements and properties of that concept. During this process, lacking the ability to distinguish the characteristics of a concept, making inadequate associations, making over– or under-generalizations, or misidentifying the concept could cause students to have alternative conceptualizations (Garnett & Treagust, 1992, Tery, Jones & Hurford, 1985, Yağbasan & Gülçiçek, 2003).

Other possible reasons for misconceptions include "lack of information," "no experiments for concretization," "teachers' presentation styles," "previous experiences and thoughts of students," "inadequate associations," and "textbooks" (Coştu et al., 2007). Textbooks are listed among these factors because they sometimes contain information that becomes a source of alternative conceptions or misconceptions. It is also stated that the inscriptions used for narrative purposes in textbooks can cause misconceptions (Sung, Shen, Stanger-Hall, Wiegert, Li, Brown, & Robertson, 2015). Despite their flaws, textbooks will always have an important place in the planning, implementation, evaluation, and development of education and training activities (Güzel, Oral, & Yıldırım, 2009). They are a basic medium that inform and explain the subjects in the curriculum in a planned and regular way, and guide students in the direction of the course as a source of information (Ünsal & Güneş, 2003). Accurate identification of concepts in the textbooks helps teachers, program writers, textbook authors, and teachers in guiding students in their conceptual learning. Since textbooks are one of the most used resources by students, they should be prepared and examined meticulously. For these reasons, it is especially necessary to examine and renew those textbooks that are thought to be a source of misconceptions for science learners (Çapa, 2000).

Students' Conceptual Understandings and Misconceptions of Friction Force

The abstract concepts in science make it one of the most challenging subject areas for students to comprehend (Günbatar & Sarı, 2005). Most commonly these concepts are taught as isolated facts (Linn, 2006). In physics, force and friction are the main concepts of classical mechanics (Driver et al., 1994), and—it has been repeatedly found—a common source of student misconceptions (McDermott & Redish, 1999). For example, Aristoteles asserted that there is a need for a force to hold a subject in motion (Atasoy et al., 2011). In the 14th century William realized and proved that once a force is present there is no need for a constant force to maintain it (Cushing, 1998). Despite this conceptual change, multiple researchers have found that students had an Aristotelian understanding of this concept (Atasoy et al. 2011; Driver et al., 1994; Jimoyiannis & Komis, 2003; Palmer, & Flanagan, 1997). Identifying their misconceptions can help teachers understand how students are coming to this outdated conclusion. Without a firm base understanding of previous material (particularly forces and energy), students often struggle with defining friction force in relation to force in general. Studies have shown that even some preservice teachers do not see friction as a type of force (Trumper & Gorsky, 1996; 1997; Yıldız & Büyükkasap, 2006). If friction is not identified as a force, students could develop an intuitive image that constant movement requires a constant force (Driver, Guesne, & Tiberghien, 1985), thus arriving at the Aristotelian understanding.

Studies on students' conceptual structures have revealed several of these kinds of differences in their understanding of friction force. It is important to identify these differences in order to identify the factors leading to the resulting misconceptions and prevent them. For instance, in a recent study Tavukçuoğlu (2018) investigated the cognitive structures that high school students use to understand about friction force. The results indicated that the students mostly expressed ideas on "the variables affecting friction force"; they had limited knowledge of the higher order cognitive skills connected with the subject. Furthermore, they had limited conceptualizations of the direction of friction force. Many students explained friction force simply as the force that has an opposite direction to motion. These issues affected their ability to define friction force correctly.

Researchers have found that most students define friction force as follows: a force that makes movement difficult and has an opposite direction effect on an objects' movement direction (Tavukçuoğlu, 2018). Although the students in one study knew that friction force reduces speed, several had difficulties guessing how an object would move after the friction force was removed from the environment (Nuhoğlu, 2008). As a result of these imperfect definitions and lack of understanding, students hold common misconceptions about the concept of friction force (Tavukçuoğlu, 2018). As researchers identify specific misconceptions that occur in different populations, this information can be used to narrow the definition of friction force and preemptively avoid problem areas in subject instruction and textbook creation.

One common misconception is that friction force is only related to motion and can only be seen when motion is present (Dixon, 2005; Trumper & Gorsky, 1997). Students often confuse reaction force with friction force and think that the two are the same (Nuhoğlu, 2008). Studies indicate that students also make mistakes when determining the direction of friction force; for example, middle school students have a misconception that if the friction force is applied towards the direction of the movement, it increases an object's speed (Tavukçuoğlu, 2018; Prasitpong & Chitaree, 2009). Similarly, Chee (1996) noted that some students mistakenly believe that during the motion of walking or riding a bicycle friction applies a backwards force to the feet and rear wheel. Moreover, students think that the friction force is related to the surface area of the other object (Hançer, 2007). Finally, students believe that friction is a result of the roughness of the surface alone (Genç, 2008; Hapkiewicz, 1992), and that there is not friction on smooth surfaces (Genç, 2008; Akbulut, 2018).

One of the main aims of education and training is to allow for the proper initial construction of concepts rather than solely correcting students' misconceptions. Textbooks are one of the main sources that influence this concept formation. Many of the current science textbooks have been studied in the context of several subject areas to determine their effects on students' conceptualizations (e.g. Staver, & Lumpe, 1993; Leite, 1999; Sung et al., 2015). Nonetheless, little is known about what factors affect students' conceptualizations of the friction force concept. Therefore, the purpose of this study was to examine the way the concept of friction force is presented in textbooks and to provide an explanatory definition of the friction force concept.

Table 1. Examined textbooks and detailed information

Title	Author(s)	Level	Date	Publisher
Physics in the modern world	Jerry B. Marion	University	1989	Technical University Press
Essentials of Physics	Sidney Borowitz, Arthur Beiser	University	1982	Bursa University Printing House
Physics for Scientists and Engineers, Cilt: 1	Raymond A. Serway, Robert J. Beichner	University	2003	Palme Publishing
Physics for Scientists and Engineers	Paul M. Fishbane, Stephen Gasiorowicz, Stephen T. Thornton	University	2003	Arkadas Publisher
Scientific Principles of General Physics and Technology	Metin Orbay, Feda Öner	University	2006	Pegem Akademi Publishing
Modern University Physics	James Austin Richards, Francis Weston Sears, M. Russell Wehr, Mark W. Zemansky	University	1989	Çağlayan Bookstore
General Physics I: Newtonian Force and Motion Theory	Mehmet Fatih Taşar, Metin Orbay	University	2008	Pegem Akademi Publishing
Principles of Physics	Frederick J. Bueche, David. A. Jerde	University	2003	Palme Publishing
Sear’s and Zemansky's University Physics with Modern Physics	Hugh D. Young, Roger A. Freedman	University	2010	Pearson Educatıon Publishing
Physics for Scientists & Engineers	Douglas C. Giancoli	University	2009	Akademi Publishing
Physics	Frederick J. Keller, W. Edward Gettys, Malcolm J. Skove	University	2005	Literatür
Physics Terms Dictionary	M. Ali Avundukluoğlu, Şeref Turhan		2007	Ötüken Publication
Physics Terms Dictionary	Şakir Aydoğan		2007	Aktif Publisher
Science and Art Terms Dictionary	Commission		2018	Turkish Language Foundation
Turkish Science Terms Dictionary	Commission		2018	Turkey Academy of Sciences
The Visual Dictionary of Physics	Jack Challoner	Popular science	2008	TÜBİTAK Publications
Illustrated Dictionary of Physics	Chris Oxlade, Corinne Stockley, Jane Wertheim	Popular science	2010	TÜBİTAK Publications
What’s Science All About?	Alex Frith, Hazel Maskell, Lisa Jane Gillespie, Kate Davies	Popular science	2012	TÜBİTAK Publications
Physics	Canan Sever, Demet Türeci, Nadire Artar, Orhan Dağ	High school-9th grade	2017	Ministry of National Education
Physics	Ali Seyfi Koyuncuoğlu	High school - 11th grade	2017	İpekyolu
Science and Technology	Commission	Middle school-7th grade	2012	Ministry of National Education
Science	Emine Tuncel	Middle school-7th grade	2016-2017	Mevsim Publishing
Science	Gülçin Gündüz	Middle school-7th grade	2016-2017	Sonuç Publications
Science	Seval Akter, Hatice Betül Arslan, Meltem Şimşek	Middle school-5th grade	2017-2018	Ministry of National Education
Science	Hülya Özdoğan	Middle school-5th grade	2015-2016	Semih Ofset
Science	Commission	Middle school-5th grade	2016	Ministry of National Education

Methods

In this study, the document analysis method was used to investigate the definitions of friction force found in science education books (Merriam, 2009). Resource books and textbooks used in Turkey at the university, secondary, and middle school levels were considered as data sources. We analyzed a sample of 26 books via convenience sampling based on the recommendations of experts in physics education. The sections where friction force was mentioned in the books constitute the data analysis unit of the study. The data obtained in the study were analyzed by the content analysis method. Content analysis allows in-depth analysis of the data to reveal previously unfamiliar themes and patterns (Miles, & Huberman, 1994). A total of 26 resource books—11 university physics textbooks, 4 science-terms glossaries, 2 secondary school physics textbooks, 6 middle school science textbooks, and 3 popular science textbooks—were examined in the study. Detailed information on the books examined is presented in Table 1.

Findings

Within the scope of the study, explanations about friction force were pulled from the textbooks that comprise the primary data source. These explanations were looked at individually and analyzed regarding their definition of the concept of friction force, the situations where friction force is effective, and the direction of friction force. How friction force is defined in the source books is examined first. We found two conceptual definitions of friction force: “motion” and “slide.” Slide and motion concepts are scientifically defined as follows (Ayverdi, 2008):

> **Sliding**: “(Something or someone) Moving over something wet, lacquer, or slippery without being subject to the floor”
>
> **Movement**: “Move, or move the position, position or status of an object or part of an object.”

Table 2. Example definitions for the concept of friction force in source books

Category	Book	Definition
Motion	Physics for Scientists and Engineers, Volume: 1, Palme Publishing	If an object is moving on a rough surface or in a viscous environment such as air or water, there is resistance to movement due to the interaction with the environment. We call such resistance a friction force (Serway & Beichner, 2003, p. 112)
	Physics Terms Dictionary, Ötüken Publication	The force of two objects’ contact surfaces that intersect each other and the forces of attraction between the molecules cause the motion to slow down, thus counteracting the direction of movement and equal to the opposite sign of the coefficient of friction and the product of normal force (Avundukoğlu &Turhan, 2007, p. 352-353)
	The Visual Dictionary of Physics, TÜBİTAK Publications	Friction is a force that slows or prevents movement (Challoner, 2008, p. 14)
	Physics, Highschool-9th grade, Ministry of National Education	The contact force between the surfaces is called friction force against movement or forcing. (Sever, Türeci, Artar & Orhan, 2017, p. 150)
	Science, Middle school-7th grade, Mevsim Publishing	The resistance of the two materials in contact with each other is called the friction force. (Tuncel, 2016, p. 96)
	Science, Middle school-5th grade, Ministry of National Education	It is called friction force which is formed between the surface that touches the object and makes the motion of an object difficult (Akter, Arslan & Şimşek, 2017, p. 93)
Slide	Physics for Scientists and Engineers, Arkadaş Publisher	Friction, a well-known concept, is a contact force that prevents sliding. (Fishbane, Gasiorowicz & Thornton, 2003, p. 119)
	Turkish Science Terms Dictionary	Resistive force that acts on an object and prevents or slows it to slide relative to the second object or surface where the object is the contact (Commission, 2018).

Table 3. Example situations where friction force is effective

Books	Explanations
Physics for Scientists and Engineers, Cilt: 1, Palme Publishing	Friction forces are very important in our daily life. This force is necessary for us to walk, to run, to stop, to move and stop the cars (Serway & Beichner, 2003, p. 112).
Physics for Scientists and Engineers, Arkadas Publisher	With this force people can walk, cars can move on the roads, and even nails and screws stay in place thanks to this force. Reduction of friction on moving machine parts is possible by lubricating the friction surfaces. In the automobile, 20 percent of the motor's power is spent to defeat internal friction, and wear begins where the friction is (Fishbane, Gasiorowicz & Thornton, 2003, p. 119).
Sear's and Zemansky's University Physics with Modern Physics, Pearson Education Publishing	The oil used in car engines reduces rubbing between the engine parts. If there is no friction between the car wheels and the road, we can neither drive nor control the car. Without the friction, the nails did not stand in place, the lightbulbs could easily get out of their socket (Young & Freedman, 2010, p. 149)
Science and Technology, Middle school-7th grade, Ministry of National Education	So, does the friction force always prevent movement? The athlete seen in the adjacent photo uses an acceleration block to start the run faster. When we walk or run, there is a friction force between our feet and the ground. This frictional force that is created makes it easy for us to move forward (Commission, 2012, p. 94)
Science, Middle school-5th grade, Ministry of National Education,	In the winter, attaching chains to the tires of cars will increase the friction force and prevent the car from sliding. The wheels attached to the bottom of the suitcase to move a heavy suitcase easily reduce the friction. So the object is moved more easily (Commission, 2017, p. 98)

Example definitions describing are given in Table 2, separated into "motion" and "slide" categories. Based on our analysis, we found that a total of 17 books used *motion* and 9 books used *slide*. While each of the source books define friction force, they also discuss its effects in practice and ways of reducing friction in daily life. Table 3 provides examples of the given situations. One contradiction or inconsistency is noteworthy when examining the above explanations of cases where friction force is effective. Friction force is described as an inhibiting force, and it is also considered necessary to ensure movement.

Table 4. Directions of the friction force in the source books

Books	Explanations
Modern Universty Physics, Çağlayan Bookstore	When an object slides on another object, it applies a friction force parallel to the sliding surface. This force is opposite to the relative movement of objects relative to each other. (Richards, Sears, Wehr & Zemansky, 1989, p. 33)
Physics for Scientists and Engineers, Cilt: 1, Palme Publishing	The results of the experimental observations can be summarized by the following friction laws: 1. The static frictional force between two opposing surfaces is opposite to the applied force 2. The kinetic frictional force acting on a moving object always arises in the opposite direction of the objects' movement (Serway & Beichner, 2003, p. 113)
Physics for Scientists and Engineers, Arkadas Publisher	Static friction affects the strength applied to the sand opposite the surface component. Kinetic friction is effective on the opposite direction of the moving objects' speed and one or more contact points (Fishbane, Gasiorowicz & Thornton, 2003, p. 120)
Science, Middle school-5th grade, Ministry of National Education	The direction of movement of the object is reversed (Akter, Arslan & Şimşek, 2017, p. 93)
Science, Middle school-5th grade, Ministry of National Education	Friction force occurs in the opposite direction, which provides movement of the object between surfaces touching each other (Commission, 2016, p. 86)
Science, Middle school-7th grade, Mevsim Publishing	The direction of the frictional force is opposite to the direction of movement (Tuncel, 2016, p. 97)
Science, Middle school-7th grade, Sonuç Publications	Friction force is always opposite to objects' movement (Gündüz, 2016, p. 83)

However, in some sources friction force is defined by the concept of "motion", but it is also revealed by being associated with the concept of "sliding". For example, it is stated that while the friction force is given as an obstructive force against movement in the 5th grade science course textbook, the friction force prevents the sliding of the cars. In this case, it is understood that there is no separation between the concepts of "motion" and "sliding" in textbooks. To define the effects of any force it is important to explain the force's direction. Explanations found in the data for determining the direction of friction force are given in Table 4

In the data sources, it is often incorrectly stated that friction force acts in the opposite direction of the motion of an object. However, some university textbooks state that friction force against static objects will affect the object in a direction opposite to the horizontal force applied. Many of the textbooks use visual instructional materials that indicate the direction of forces. Examples of diagrams related to friction force in the textbooks analyzed are given below. The direction of motion of both the objects in the figures and the forces affecting these objects are shown with the help of vector expressions.

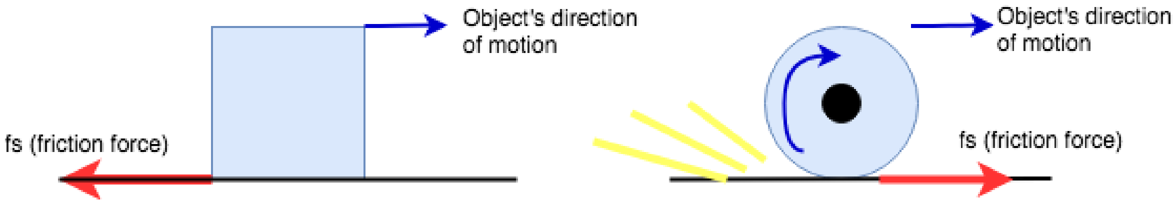

Figure 1. Figures based on the figures in Sever, Türeci, Atar, & Dağ, 2007

The rectangular body in Figure 1 (i.e. figures recreated by the authors based on the figures in Sever, Türeci, Artar, & Dağ, 2017, p. 153) is affected by friction in the opposite direction of its movement, while the circular disc is affected in the direction of movement. Similarly, in a figure in Fishbane, Gasiorowicz & Thornton (2003, p.124), the friction force acting on the tires of the car in motion is shown in the same direction as the car. As can be seen in Figure 1, the circular disk drive moves clockwise at the point where the force is in contact with the ground. Thus, in Figures 1 frictional force in circular discs appears to move in the direction of object's movement.

Diagrams in Akter, Arslan and Şimşek (2017, p.95) and Challoner (2008, p.15), however, show a different picture. Each diagram indicates visually that the friction force acting on spherical moving bodies acts in reverse to the objects' motion. In figures that were used in these primary education and popular science books, the friction force direction is incorrectly assigned. This confirms the findings in Table 4, indicating that some (or most) of the available textbooks suggest that the direction of the friction force is determined by the object's movement. Determining the causes of these mistakes will allow for clearer instruction for students and pre-service teachers on how to make direction determinations.

Discussion, Suggestions, and Conclusion

In this study, the authors examined definitions of "friction force" in textbooks. Several issues appear. First, all the definitions in middle school science textbooks and secondary school physics textbooks explain friction force in relation to the concept of *motion*. Mostly, friction force is expressed as a "force to inhibit movement." When inhibition is emphasized, friction is defined as an obstructive force, even though in some cases it is necessary to *enable* movement. Thus, friction force is simultaneously explained as both a movement inhibitor and a driving force, despite the fact that these two conditions are naturally incompatible. One explanation for this conceptualization in the textbooks might be due to the colloquial use of the term friction (Shen & Linn, 2011), which might sometimes indicate an "influential factor" opposite to movement (Sung et al., 2015). A clear definition should be able to explain naturally occurring events and to display internal consistency. For this reason, we conclude that referring to the concept of "motion" might not be a suitable choice when describing friction force.

Second, friction force is defined by using the concept of "sliding" in some university textbooks and science glossaries. Similar conflicts can be seen in the literature; there are inconsistencies presenting concepts even within the same textbook. For example, Flodin (2007) investigated how a biology textbook dealt with the gene concept. The results showed that the concept was used inconsistently across the book in several different ways. For example, it is sometimes described as a trait, an information-structure, an actor and later referred to as a regulator and a maker. Similarly, in this study the texts explained friction force using several different "daily life" cases related to sliding in addition to motion. For example, we can move across surfaces by walking or rolling where the friction is strong because the sliding does not occur between the surfaces. In the absence of friction, objects can move by sliding. In cases where friction is present, we can walk, so we can move because the sliding situation does not happen. In this context, it is understood that the friction force is not a force to inhibit movement but a force to inhibit sliding.

One problem factor in using motion to explain friction is the concept of rolling motion. Rolling bodies move forward due to friction between their own surface and the ground. The horizontal force acting on the contact point causes rolling motion when it is less than the maximum friction force generated between the object and the ground. The friction force between the object and the contacted surface will cause the object to slide if it is less than the horizontal force acting on the object; this distinction is the key reason motion and sliding must be differentiated in the definition.

When explaining friction force, the textbooks studied used the concept of "motion" to define or explain friction force, while the idea of "sliding" was used to describe situations where friction is encountered in everyday life. This misrecognition of difference indicates that the concept of "motion" alone is an over-generalization, not suitable for describing the friction phenomenon. When the definitions of each term are examined, it is evident that the concept of "motion" expresses a more general condition than the concept of "sliding." In other words, movement can be achieved without sliding, though sliding cannot occur without motion. Researchers argue that textbooks should avoid using simplifications and vague statements when defining scientific concepts to avoid these issues (Sanger & Greenbowe, 1999). Therefore, one potential resolution of this conflicting conceptualization is to define and explain friction force in relation to the concept of "sliding" instead of "motion."

Third, the literature shows that students have misconceptions about friction force across different subject contexts (Sağlam, Kanadlı, & Uşak, 2012). Friction is often understood at the macroscopic level and as a result students do not develop cognitive structures related to microscopic phenomena (Tavukçuoğlu, 2018). In a similar study, Kurnaz and Ekşi also noted that most students think of friction at the macroscopic level and have difficulties conceptualizing it at the microscopic level (Kurnaz & Ekşi, 2015). Excessive generalization of friction force in relation to motion is thought to factor into such conceptualizations. Concepts need to be defined specifically and correctly so that students can conceptualize at different levels of context and explain facts and events accurately across subject areas (Sanger & Greenbowe, 1999).

For a concept to be correctly defined in this way, its nature must be understood. For this reason, when describing the concept of friction force, it is necessary to know how friction occurs. The formation of friction is expressed in textbooks as follows (Giancoli, 2009, p. 113):

> It is thought that the atoms on the surface of a surface can come very close to the atoms on the other surface and the attractive electrical forces between the atoms can "bond" as if a thin source exists between the two surfaces.

When the formation of friction is examined, it is seen that friction is a contact force and that contact surfaces have a nature that interferes with certain interactions with each other. If friction force is considered only in this context, it can be explained accurately and consistently while avoiding the other issues that arise with more problematic explanations. The definition proposed by this paper can be summarized as:

> Friction force is a force that prevents sliding.

When we look at the explanations in the textbooks about friction force, there is a noteworthy misconception about its direction. Textbooks state that friction force acts in a direction opposite to motion. This directionality, as expressed in the context of motion, can only be regarded as correct in limited situations, i.e., for objects that move by sliding—when there is no movement, there is still friction force. These kinds of inconsistencies in the data pool mirror a previous study showing that there are inconsistencies in accurately representing science concepts in textbooks, which in return could contribute to student misconceptions in physics (Wong & Chu, 2017).

The example of walking or rolling motion is also problematic because of its complexity and the partial role that friction plays in the process. In visual materials in primary education and popular science books, the friction forces acting on rolling objects are often drawn incorrectly. In the case of walking and rolling, contrary to the case of sliding, the direction of the friction force is in the same as the direction of movement of the object. If the maximum friction force between the ground and the object is not exceeded in rolling and walking situations, sliding does not occur but movement can still be achieved. Note that the movement of the entire system is mentioned here, not movement because of sliding on the contact point. Such movement is affected by the friction at the contact point and other forces acting on the system. Here friction causes objects not to slide, while other forces acting on the system cause the movement. When the direction of the friction force is determined, the motion of the entire system is taken into consideration. Thus, there is a mistake in determining and illustrating the direction of the friction force. One of the main reasons for the emergence of these mistakes is neglecting causal relations (Chiappetta, Sethna, & Fillman, 1991), which are among the primary elements of scientific thought. When the friction force's directional determinations are made, the reasoning is based only on the results, neglecting some of the factors at play. In fact, the direction of the friction force should be determined in terms of the force causing the sliding. During sliding motion, friction force moves in the opposite direction, which forces the object to shift. In the same way, in the walking and rolling situations where there is no sliding motion, the direction of the friction force is opposite to the force which wants to shift the body. In this case, the direction of friction force can be expressed as:

> Frictional force occurs in the opposite direction of the tendency to slide, or more accurately, in the opposite direction of the force working/attempting to slide the object.

This study examined friction force definitions and explanations in a sample of textbooks, alongside knowledge of common student misconceptions confirmed by the existing literature. The misconceptions and inconsistencies among the definitions found in the books have been explained with examples. As a result, the authors propose a new definition, explaining the concept of friction force in more concrete terms for the purposes of science education. A more coherent and consistent explanation for determining the direction of friction force has also been introduced. Ideally, the results of this study will guide course developers and textbook authors, therefore shaping the conceptual development of teachers and students. However, one should note that the results are limited due to the small number and convenience factor in the sample of books chosen. Although the literature indicates that students have misconceptions about friction force, the current study does not quantify to what extent the use of friction force terminology influences these misconceptions. Therefore, future empirical studies should investigate how textbook terminology affects students' conceptualizations in science education, specifically in relation to the friction force concept and other building blocks of science knowledge.

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Appendix.Reviewed Books

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