Simplifications and Idealizations in High School Physics in Mechanics: A Study Of Slovenian Curriculum And Textbooks

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Abstract
This article presents the results of an analysis of three Slovenian textbooks for high school physics, from the point of view of simplifications and idealizations in the field of mechanics. In modeling of physical systems, making simplifications and idealizations is important, since one ignores minor effects and focuses on the most important characteristics of the systems and processes. In high school physics, simplified and idealized models play a fundamental role in learning physics concepts and laws, so it is of crucial importance that textbooks present them carefully. The review shows that in two textbooks more than a half of analyzed simplifications are not properly presented.
Keywords: Physics curriculum, textbook analysis, simplified models, idealizations

Introduction

Research in recent years and decades shows that science subjects in general and physics in particular are becoming less popular and interesting for students (Osborne, Simon and Collins, 2003; Osborne and Collins, 2008; Osborne and Dillon, 2008; Haste, 2012; Saleh, 2012). One of the main reasons for students' negative attitude is the fact that in school physics teachers are dealing with topics that are quite distant from the student's reality and, as such, are neither relevant to their daily lives nor relevant to the most pressing problems of mankind (Osborne and Dillon, 2008; Zhu and Singh, 2013). Due to the desire to proceed with cases that are analytically solvable, physics textbooks and teachers are limited to idealized and often unrealistic situations that make the most of school physics merely as a set of equations, which is necessary to learn by heart. To solve physics problems, students only need to find the appropriate formula, to insert numbers and calculate the unknown quantities (Schecker, 1994; Raw, 1999). Hestenes and colleagues (1997) argue that this can be overcome with the modeling approach where the entire teaching of physics is organized around a small number of basic models, which are then used in specific situations. It is in contrast with the traditional teaching of physics, where the emphasis is on learning the final models and not at the modeling process. Modeling approach has shown positive impact on the understanding of basic physical structures (Halloun and Hestenes, 1987; Wells, Hestenes and Swackhamer, 1995).

Models form the basis of theoretical and experimental studies and as such are, according to the Brewe (2008), a foundation for the development of knowledge and problem solving skills. Despite the fact that different scientific disciplines define different types of models, there exist some general parallels between them. Gilbert (2004) believes that a model is a representation of a phenomenon, body or idea. According to Bossel (2004), a model always represents a simplified representation of a part of reality and its validity applies only to that part of reality. Bossel illustrates this relationship with the roadmap as a model of the road system. Fuchs (1997), similarly, argues that all models are only simplified reflections of reality and that model can't be right or wrong, it can only be useful in a given situation or not.

In the field of physics education, the main contribution to models and modeling were given by Hestenes and colleagues (Hestenes, 1997; Wells, Hestenes and Swackhamer, 1995; Hestenes, 1987, 1992). They define a model as a representation of the physical structure of the system and its properties and stress that physicists are working with mathematical models. It means that they strive to describe observed features with quantitative variables. Schecker (1998) extended the concept of the model and claimed that, in addition to mathematical models in physics, one can talk about the physical models that represent a body in a simplified form and present it in the changed circumstances, such as a car model as well as the mental models that arise in head of an individual and represent mental constructs generated by the perception and conceptualization of real or imaginary situations. That view is in agreement with ideas of Franco and Colinvaux (2000). Ornek (2008) separates mental and conceptual models, clarifying that conceptual models are simplified and idealized representations of real bodies, phenomena and situations. According to her, the conceptual models include physical, mathematical and computer models.

Etkina and coauthors (2006) write that, in building of a mathematical model, we make several types of simplifications. They introduce a model of a body (for example, a particle), a simplification of an interaction (for example, the air resistance is neglected), the system model, which is a combination of previous two models and a model of a process that describes the changes in the physical system. Since the models are simplifications of real systems, in the process of modeling, making assumptions and idealizations or simplifications of certain properties of physical systems are of crucial importance. Moreover, Romer (1993) says that the knowledge of idealizations and simplifications is important because otherwise we know nothing about the range of applicability of certain models. Therefore, it is important for students to develop physical intuition about which idealizations should be done to make the theoretical treatment possible and, at the same time, not destroy the main features of physical process or situation.

Review of the literature shows that the simplification processes have already been studied by some scientists, mainly in terms of philosophy of science (Matthews, 2004; Nola, 2004; Portides, 2007), while there has been almost no research on how the textbooks approach this matter. Textbooks are, namely, one of the main factors that affect teaching, because they don't contain only factual knowledge students are supposed to learn but also suggest a teaching methodology of how to treat the content.

The textbooks mirror and implement curriculum, define the sequences of content and explain laws of physics. An important part of the textbooks are solved and unsolved tasks. The significance of the impact of textbooks on physics knowledge of students is reflected in the results of international research TIMSS Advanced (Mullis et al, 2009), where in all participating countries, except Slovenia, more than 85% of the students said that they have been taught by teachers who have been using textbook in classroom. The importance of textbooks for teaching physics had also been recognized by the researchers in the field of physics teaching. In recent years, the research on physics textbooks is a growing field.

One can find research on what terminology is used in textbooks (Shavelson, 1971; Geeslin and Shavelson, 1975; Merzyn, 1987; Härtiga, 2014), on the development of visual representations in textbooks (Dimopoulos et al, 2003; Bungum, 2008), on how the certain physical concepts are presented (Dall'Alba et al, 1993; Barrow, 2000; Ibanez and Ramos, 2004; Bryce and MacMillan, 2009; Doige and Day, 2012), on the use of gender (Walford, 1980; Sunar et al, 2012), on presenting the connections between physics and technology

(Gardner, 1999), or on errors that appear in textbooks (Lehrman, 1982; Iona, 1987; Bauman, 1992a, 1992b;1992c; Slisko, 1995, 2006, 2009; Slisko and Krokhin, 1995; Sawicki, 1996; Gearhart, 1996; Gauld, 1997; Blickensderfer, 1998; Santos-Benito and Gras-Marti, 2005). In the field of modeling, Harrison (2001), in an extensive study, presented eight different types of models, and analyzed the extent to which these models are presented in science textbooks. He found that chemistry textbooks contain more models than physics textbooks. More general research on scientific literacy, which includes modeling, has been undertaken by Chiappetta and colleagues (1993). In their analysis of textbooks, they studied the extent the textbooks emphasize four areas of scientific literacy: science as a set of facts, science as a means of exploration, science as a way of thinking and collaboration between science, technology and society. In doing so, they found that the analyzed textbooks extensively highlight the first two terms of scientific literacy, while "science as a way of thinking", which includes the use of assumptions and models, practically doesn't exists in textbooks.

Since a review of simplification and idealizations in physics textbooks was not carried out in previous studies, we decided to analyze that aspect in three textbooks of physics, which are widely used in Slovenian high school, paying a special attention on how they introduce eight common simplifications and idealizations in the fields of mechanics. Such a research is sensible because the results of Slovenian students in international evaluation of physics knowledge in the past show that, while the Slovenian students are good at solving routine problems, they have difficulties with tasks that require higher cognitive skills (Beaton et al, 1996, Mullis et al, 2009). Given the fact that setting models and understanding the assumptions and idealizations encourages a deeper understanding of physics content, such an analysis may represent a first step in improving the situation. The year of the last TIMSS Advanced 2008 research is the year when in Slovenia came into use new curriculum for high school physics, which explicitly mentions that students should (1) know the concept of the model, and (2) understand the basics of the scientific method, which includes designing models that best describe the specific events and checking their validity (Planinšič et al, 2008). Therefore, this study would also reveal the extent to which textbooks follow the recommendations of the curriculum.

The structure of the article is as follows: First we present the basic features of high school physics curriculum in Slovenia and analyze the curriculum from the perspective of models and simplifications. Then we compare how the three most widely used textbooks for high school physics in Slovenia present some of the most common assumptions and idealizations in the fields of mechanics and present the results.

Overview of Simplifications and Idealizations in The Curriculum for High School Physics in Slovenia

High school in Slovenia (called gymnasium) carries out a general secondary educational program and one of the main objectives of this program is to prepare students for continuing education in higher education (Zakon o gimnazijah). In this program, physics can be taught on different levels of difficulty. The highest level of high school physics is designed primarily for students who wish to continue their education in the fields of science and technology. The most important document for teachers is high school physics curriculum, which defines general and operational objectives as well the detailed didactic recommendations. In order to shed the light on the extent to which the assumptions, such as the simplifications and idealizations, appear in the current curriculum for high school physics, we analyzed it within the framework, which Chiappetta and colleagues (Chiappetta, Fillman and Sethna, 1991) used to analyze different textbooks for Physics, Chemistry and Biology in America from the perspective of scientific literacy. Following them, the aspects of scientific literacy are: the knowledge of science, the investigative nature of science, science as a way of knowing and interaction of science, technology and society. BouJaoude (2002) used the same framework for the analysis of science curricula in Lebanon and later the same framework was often used for the analysis of science curricula (Cansiz and Turker, 2011; Erdogan and Köseoglu, 2012). First, we analyzed all of the explicit written operational objectives in the curriculum, while additional comments on certain objectives were not included in this analysis. The results were following:

- the knowledge of science – 45,8 %
- the investigative nature of science – 48,3 %
- science as a way of knowing – 0,8 %
- interaction of science, technology and society – 5,1 %.

The analysis reveals that aspects of scientific literacy are unequally represented among operational objectives. While the first two aspects are quite strongly represented, there are very few objectives, which can be related to the third and fourth aspect of the science literacy. Especially "Science as a way of knowing", which includes the use of assumptions, can be hardly found.

We further reviewed, which objectives are directly related to the assumptions of limited validity of certain physical principles, which is the result of simplifications and idealizations of physical systems. In curriculum we found only two such objectives:

- students are aware of the limited validity of Hooke 's law,
- students are aware that the term $\Delta Ep = mg\Delta h$ has limited validity when moving away from the Earth.

Under the objective "students repeat Ohm's law and the definition of resistance" there is the comment "students know that Ohm's law does not apply to all conductors".

Current curriculum for high school physics is the first one in independent Slovenia that explicitly mentions that the students should understand the concept of scientific models and the main characteristics of scientific method. On the basis of analysis, we can see that there is not given too much emphasis on the simplifications or idealizations that are necessary for theoretical treatment of physical processes and systems.

Analysis of Textbooks for High School Physics in Slovenia

Beside the curriculum, textbook is also an important factor in physics teaching. So we analyzed textbooks for high school physics in Slovenia from the standpoint of simplifications and idealizations. In Slovenia, the official textbooks are aproved by the Council of Experts for General Education, after ascertaining their conformity with the objectives of the curriculum and their content, didactic and methodical adequacy. Currently there are five official textbooks for high school physics in Slovenia (table I). First editions of textbooks B, C, D and E were written before the new curriculum for high school physics came into use. Irrespective of the changes in curriculum, the content of these four books remained the same over the years and in later editions only minimal changes were made. In this way, the textbook A is only one that has been written after the new curriculum came into use. It represents the most modern textbook for high school physics and is equipped with a DVD, which has a lot of additional material for teachers and students.

Because we were interested in how often the individual textbooks are used, we conducted a survey between the 66 Slovenian schools that implement a general or technical high school program and analyzed which textbook every school will use in the next school year. The results are shown in the figure I.

Figure I shows, that while in the first year almost 50% of the schools use a modern textbook A, in the second year there is only 25% of such schools. Low number of modern textbooks usage in the third year is due to the fact that a third book of this textbook wasn't on the market until June 2014 and will be used for the first time in the next school year. Of the older textbooks, B and C are mostly used, while textbooks D and E are used only in two schools. Under 5% of schools is using internal materials, or do not use anything. From the two schools we were unable to obtain the data. In view of the fact that according to the abundance of use, the textbooks A, B and C are standing out, our further analysis is limited only to these three textbooks. In this study, we didn't analyzed DVDs or some other material.

***Table 1**. Official textbooks for high school physics in Slovenia.*

Textbook	Authors	Title of the textbook	Year of the first edition	Year of the edition of analyzed textbook or the year of the last edition
A	Aleš Mohorič, Vitomir Babič	Fizika 1	2012	2012
		Fizika 2	2013	2013
		Fizika 3	2014	2014
B	Rudolf Kladnik	Gibanje, sila, snov	1993	2009
		Energija, toplota, zvok, svetloba	1994	2009
		Svet elektronov in atomov	1995	2010
C	Marjan Hribar and others	Mehanika in toplota	2000	2009
		Elektrika, svetloba in snov	1997	2011
D	Janez Strnad	Mala fizika 1	2003	2013
		Mala fizika 2	2004	2004
B	Ivan Kuščer and others	Fizika za srednješolce, 1. Del	1999	2009
		Fizika za srednješolce, 2. Del	2000	2009
		Fizika za srednješolce, 3. Del	2003	2010

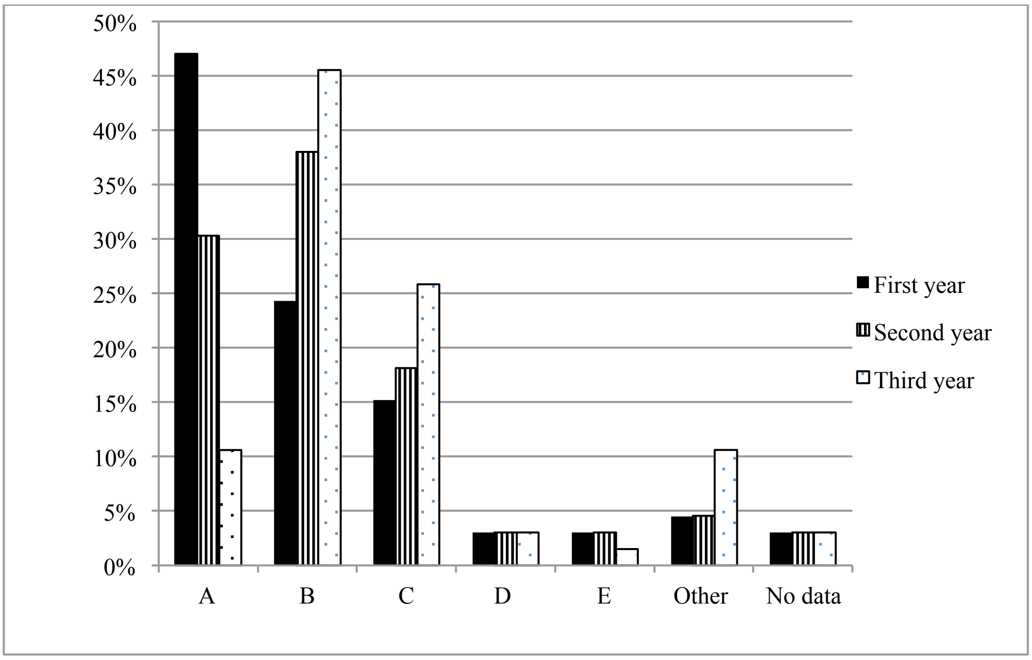

Figure 1*. The use of textbooks in Slovenian high schools. The column "other" denotes schools where textbooks are not used or internal materials that are not approved by the Council of Experts for General Education are used.*

We limited ourselves to the textbooks, and examine how an individual textbook emphasizes and clarifies certain simplifications, which we do when dealing with physical phenomena in the field of mechanics. In doing so, we are focusing on ten simplifications and idealizations that are often used in this physics domain. They are presented in Table II.

Table 2*. Results of the review of simplifications and idealizations*

Simplifications and idealizations	Textbook A	Textbook B	Textbook C
1. Particle model	✓	✓	✓
2. Free fall	✓	✓	✓
3. Hooke's law	✓	X	X
4. Law of friction	✓	✓	✓
5. Smooth surface	✓	X	X
6. Massless cord	X	X	X
7. Impulse approximation	✓	X	X
8. Incompressible fluid	✓	✓	X
9. Validity of $E_p=mgh$	✓	X	✓
10. Small damping model	✓	X	X

When considering kinematics in high school, there are two key idealizations. The first is a particle model and the other is a model of the motion of free falling bodies, which does not take into account the air resistance. The first idealization is due to the fact that we are only interested in the motion of objects regardless of their details. The other is usually done because in the fall with air resistance we get equations, which students do not know how to solve analytically with their mathematical knowledge. In the textbooks A, it is written that the treatment will be restricted on motion of the particles, which are bodies that are small compared to the dimensions of the observed motion. If the body is extended, one should choose a point on the body and observe only the movement of that point. The textbook B mentions that the authors will restrict themselves on the motion of a particle and says that under this concept one understands the body that is sufficiently distant or small enough that its dimensions are not important in the description of the motion. Textbook C defines that when one observes the movement at distances that are large compared with the size of the body, the body can be represented as a point. Despite the fact that all textbooks define the concept of a particle, in the solved tasks this idealization is not given more attention and it is overlooked.

The free fall is also well explained in textbooks. In the textbook A, the free fall is defined as a movement in which the body falls and during the falling the body is not affected by anything. With no air resistance all bodies, that are left go from the same height at the same time, fall to the ground simultaneously and with the same speed. The equations of free fall and vertical throw are derived and followed by two simple computational examples, which do not mention that air resistance is ignored or why it is ignored.

The textbook B, in the treatment of free fall and vertical throw, states that, if one neglects air resistance, the speed of falling is increasing directly proportional to time. It states that this is a reasonably good approximation for objects near the earth's surface and presents an experiment in which the air is sucked out from the tube and the pen and the ball are released to fall in the tube. Based on the experiment, it is suggested that all bodies should fall with the same acceleration. At the end of the chapter, it is briefly mentioned that, if air resistance is not negligible, the acceleration isn't constant anymore. By increasing the speed, the air resistance, that hinders the fall, increases, too. Nevertheless, the functional relationship between speed and air resistance isn't presented.

In the textbook C, on the basis of the experiment, the value of free fall acceleration is written down, followed by the claim that all bodies, not hindered by their surroundings, fall with this acceleration. It continues with evacuated tube experiment and equations of free fall.

In no textbook a consideration can be found on when the air resistance is negligible or how one can validate whether the result of calculation, based on negligible air resistance model, makes sense. Although all textbooks correctly present limitation of the equations of free fall (valid only, if one neglects the influence of air or in the absence of air), none of the textbooks, but textbook B in the chapters on kinematics, suggests how to deal with cases where the air resistance isn't negligible. Textbook A and C explain in more detail air resistance in chapters on dynamics and fluids. The textbook C is the only one that briefly mentions the possibility of numerical computation and difference equations for the cases when the air resistance is not negligible.

The third, fourth and fifth simplifications refer to the two forces, which belong to the standard repertoire in mechanics. These are the elastic (spring) force and friction force. When considering the force of the spring, the textbook A says that in the case of the spring linear proportionality between force and elongation applies to the load limit, which depends on the material. Textbooks B and C, when discussing the forces, don't mention the limited validity of Hooke's law for spring.

In dealing with the friction forces, all three textbooks underline that the equation for friction force is only an approximation, where the friction force does not depend on the speed of an object or the size of the contact area between an object and a surface. In some cases, the friction force is negligible, and then we usually speak about the smooth surface. Textbook A doesn't use the term "smooth surface", but in the textbooks B and C its definition is unclear.

Textbook B, while introducing the sliding down a slope, writes "the perfectly smooth slope ($\mu = 0$) ...", but, in solved problem at the end of the chapter on friction, it writes "on the smooth frozen surface of the lake we throw the plate with an initial speed of 20 m/s. At what distance and how much time it takes to stop the plate, if the coefficient of friction is 0.1?" To a watchful student will not be clear if we neglect friction when the surface is smooth or when it is completely smooth.

The textbook C mentions that the friction is greater on the rough surfaces and smaller on smooth ones. Nevertheless, in one of the examples, it states: "What happens if the slope is smooth and friction can be neglected?" It is difficult for the students to understand, when "smooth surface" means low friction and when it means the friction can be negligible.

The sixth simplification refers to one of the most widely models in mechanics, a light string. At the beginning of treatment of the Newton's second law, all three textbooks make use of the classical experiment with cart on the table and weight, which are connected by a string over a pulley. Through the experiment, all textbooks come to the relationship between mass and acceleration and finally write down Newton's second law.

In all textbooks it is stated that the string runs over the light pulley, but it is nowhere mentioned that the weight of the string can be ignored and, because of this approximation, the force in each point of the wire is the same, which means the string only transfers the force. In one of the previous articles it has been shown that it is not self-evident that the mass of the string is negligible (Forjan, Marhl and Grubelnik, 2014).

The key model that is assumed in collisions is as follows: during the collision, in addition to internal forces between the participating bodies, there can also be other forces at work. The latter ones are usually much smaller than the forces between the participating bodies. One may therefore assume that, in the short time of collision, these forces are negligible and therefore the initial and final momentum of the involved bodies, just before and just after the collision, is the same. In the case of a collision of two cars, in the most of real cases, during the collision one can ignore friction force and air resistance, which are much smaller than the force of one car on another.

Textbook A describes the use of conservation of linear momentum in the case of two carts on the slide. It considers that the experiment is performed under conditions in which the friction and air resistance are small and can be neglected. Argument is reinforced by the tabular and graphic display of the results of the real experiment, in which the collision of two carts is inelastic.

Textbook B illustrates the conservation of momentum with the experiment in which two carts push off one another. The textbook states that the sum of force of gravity and normal force is zero, while nothing is said about how it is with the forces in the horizontal direction.

The textbook C also presents the conservation of momentum with two carts on an air slide, where they can move with almost no friction. It states that the carts can be considered as a closed system, on which the surrounding has no effect, except in the vertical direction with the force of gravity and the normal force of the slide. Internal forces between the two carts aren't mentioned and this textbook neither consider anything about the horizontal external forces nor the fact that, only for a short running time of collision, one can assume that the linear momentum of system doesn't change.

When dealing with pressure in liquids, one assumes a model of an incompressible liquid, which is in most real cases justified.

Textbook A, in the derivation of equation for hydrostatic pressure, considers that the density is everywhere in the column about the same.

In the textbook B, one finds the assumption that the fluid is incompressible; while in the textbook C this assumption is not mentioned.

An important simplification in mechanics is also limited validity of the equation for the gravitational potential energy.

In the textbook B there is no record of this limitation; while the textbook A claims that the equation does not apply when the acceleration due to gravity is no longer a constant. The textbook C also mentions, in calculating the potential energy of the bodies in the space around the Earth, that one must have in mind that weight varies with the distance and then presents the equation for the potential energy that should be used in this case.

In considering the oscillation emphasis is usually on the un-damped oscillations, but all three textbooks also explain damped oscillations. In doing so, the textbook A is most consistent, since it states that, if the cause of damping is resistance force, which is proportional to the velocity of the pendulum, the result is the exponential decline in amplitude. The textbook suggests this is valid as long as the damping coefficient is much smaller than pendulums angular frequency and, in the case of the strong damping, the pendulum non-periodical approaches to the equilibrium position. In the textbook B, one can't find the equations of damped oscillation, but there is a consideration that, in addition to decreasing the amplitude of the oscillation, the frequency decreases also. It is an interesting observation that, despite the bold text states the damped pendulum oscillates more slowly than un-damped, in the time graph, where both cases are presented, this is ignored. The textbook C presents the equation for time decreasing of the amplitude of oscillation and the equation of time decreasing of energy of oscillation, while there is neither justification why in both cases there is an exponential decline nor it is written what in this case happens with the time of oscillation.

Discussion

Idealizations and simplifications of physical systems are an important part of the conceptual phase of modeling and their value is obvious to scientists, while in teaching of physics this part is usually only mentioned. Usually, a greater emphasis in problem solving is given to mathematical steps. Because the positive effects of modeling on understanding of physical concepts by the students were recognized, and because the modeling process is also explicitly mentioned among the objectives in the curriculum for high school physics, we investigated how consistent are the most often used Slovenian textbooks for physics in the presentation of certain idealizations and simplifications in the field of mechanics. In reviewing the curriculum, we found that in the operative objectives the simplifications and idealizations are very poorly represented.

Review of the textbooks showed that the textbook A, which is also the only one of the analyzed textbooks that is written after the new curriculum for high school physics came into use, correctly and very carefully introduce the most of the analyzed simplifications. In the textbooks B and C, more than half of the analyzed simplifications weren't presented. Given the fact that the curriculum for physics is already six years in use, and that models and modeling appear in it as an important objective, one would expect that the writers of these textbooks in future editions make the textbook content closer to the curriculum and more accurately define the validity of physical models and their limitations.

Because the students in learning with textbook often use the solved tasks as an example to follow, we have also examined how explicitly the assumptions are set out in solved tasks of mechanics in all three textbooks. Textbook A has 113 solved problems in the field of mechanics and we found explicit assumptions in 13 cases. In the textbook B in five cases (of 92) and in the textbook C in five cases (of 55) idealizations and assumptions are explicitly stated. These results show that, despite the textbook A correctly presented simplifications in the text, only in one out of ten solved problems the supposed assumptions are explicitly stated. This is too small percentage for the students to realize their value. So, it makes sense that the next releases of textbooks put more emphasize on the simplifications in solved problems or to put more emphasis on the conceptual part of problem solving rather than mathematical.

Since the present analysis is made only in the field of mechanics, we recommend a study to review the situation in other areas of physics in order to get a broader picture of the presentation of idealizations and simplifications in high-school physics textbooks.

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