Simplifications and idealizations in high school physics in thermodynamics, electricity and waves: A study of Slovenian textbooks

Matej Forjan[1,2], Josip Sliško[3]
[1]*School Centre Novo mesto, Šegova 112, SI-8000 Novo mesto, Slovenia.*
[2]*Faculty of Industrial Engineering, Šegova 112, SI-8000 Novo mesto, Slovenia.*
[3]*Benemérita Universidad Autónoma de Puebla, México.*

E-mail: jslisko@fcfm.buap.mx

(Received 16 March 2014, accepted 20 June 2014)

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 themes of thermodynamics, electricity and waves. Understanding simplifications and idealizations is crucial for the modeling of physical systems, since one ignores irrelevant properties and minor effects and focuses on the most important characteristics of the systems and the processes. In high-school physics, simplified and idealized models play a fundamental role in learning physics concepts and laws, so it is very important that textbooks present them carefully. This study shows that in all three textbooks more than a third of analyzed simplifications are not properly presented and clarified. Also, we almost could not find any explicit comment on assumptions and approximations used in the solved problems.

Keywords: textbook analysis, simplified models, modeling in physics.

Resumen

Este artículo presenta los resultados de un análisis de tres libros de texto eslovenos para la física en bachillerato desde el punto de vista de simplificaciones e idealizaciones en los temas de termodinámica, electricidad y ondas. La comprensión de simplificaciones e idealizaciones es crucial para modelar sistemas físicos, porque uno desprecia efectos propiedades irrelevantes y efectos menores, y se fija en las características más importantes de los sistemas y procesos. En la física estudiada en bachillerato, los modelos simplificados e idealizados juegan un papel fundamental en el aprendizaje de leyes y conceptos físicos, entonces es muy importante que los libros de texto los presenten cuidadosamente. Este estudio muestra que en todos los tres libros de texto más que un tercio de las simplificaciones analizadas no se presentan y clarifican adecuadamente. Además, en los problemas resueltos casi no pudimos encontrar un comentario explícito sobre suposiciones y aproximaciones usadas.

Palabras clave: análisis de libros de texto, modelos simplificados, modelaje en física.

PACS: 01.40.E-, 01.40.gb **ISSN 1870-9095**

I. INTRODUCTION

Since Galileo's time, the way science works is, more or less, related to two basic structural elements whose order may vary: (1) the careful observation of natural phenomena to discover patterns and regularity in data, and (2) the development and verification of models, which should explain the data and predict new phenomena. One can say that models and process of their formation, use and evaluation, which is called modeling, are the basis of scientific work and understanding. Similarly, many authors [1, 2, 3, 4, 5] consider consider that the knowledge about models and modeling process is crucial for studensts' understanding science. In the field of physics education, the main contribution to models and modeling were given by Hestenes and colleagues [6, 7, 8, 9]. They define a model as a representation of the physical structure of the system and its properties and explain that physicists work with mathematical models. It means that they strive to describe the observed features with quantitative variables. When setting up models, scientists are holding to the rule written by Bossel [10]: "model should be as simple as possible, but as complex as necessary." Hannon and Ruth [11] agree with this statement and pointed out that this is the first and basic principle of modeling. One of the key things in the modeling process is that certain characteristics of the phenomenon must be neglected to simplify it to such an extent that it is easier to focus on the most important features of the phenomenon. They introduce a model of a body (for example a particle), a model 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. Portides [12] also believes that idealizations and simplifications of the physical system are very important facts that affect the process of building the model. In high school physics we mainly deal with simplified and idealized models, which play an important role in learning physics concepts and their application in everyday situations. 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. Since textbooks are one of the main factors that affects teaching, it is important that to accurately and clearly present assumptions, simplifications and idealizations of physical systems and the validity of the models that are based on these assumptions.

Since a review of simplification and idealizations in physics textbooks was not made 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 thermodynamics, electricity and waves. 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 [13, 14]. 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 structure of the article is as follows: first we present the basic characteristics of high school physics curriculum in Slovenia and analyzed the curriculum from the perspective of models and simplification. Then we compare how the three most commonly used textbooks for high school physics in Slovenia present some of the most common simplifications and idealizations in the fields of thermodynamics, electricity and waves and present the results.

II. THE CURRICULUM FOR HIGH SCHOOL PHYSICS IN SLOVENIA

High school in Slovenia (called Gymnasium) carried out a general secondary educational program that prepares students for continuing education in higher education, encourages creativity and develops the knowledge, abilities, skills and other personal qualities necessary for later success in career and life [15]. In general, high school physics program is one of the obligatory subjects, which can be implemented on the basic level, selection level and “matura” level. The latter one represents the highest level of high school physics, giving a suitable basis for studies in the fields of science and technology [16]. Among the general objectives, there is a goal: "students learn about the nature of physical thinking". This goal is further elaborated in the section on expected achievements of students, where, among others, scientific method for studying of natural phenomena is exposed.

Scientific method is described in detail in the section on didactic recommendations. It says that students should, among other things, use and understand terms model and modeling. Students are also expected to know the main characteristics of scientific method, "which includes the observation of natural phenomena and designing models that best describe the specific phenomena, describing phenomena with mathematical methods and verifying the predictions of these models with a multitude of experiments". Detailed examination of the content objectives that the students should learn shows that between them the word model appears five times.

In three cases it is a physical model (model of the electric DC motor, model of electric generator, model of the camera) and in two cases the conceptual model (the model of a traveling sine wave, the wave model of light), while the content objectives nowhere explicitly mention any mathematical model or the development thereof.

In addition, we were interested in whether the curriculum emphasizes simplification and limitations of mathematical models. We found that in the curriculum of the 454 content objectives there are only three of them that relate directly to the limitations:

- 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,
- students know that Ohm's Law does not apply to all conductors.

To these we may add two limitations, which are not explicitly written:

- oscillation of the simple pendulum is sinusoidal, when the amplitude of the oscillation is small compared to the length of the string,
- students know that all bodies fall to the Earth with the same acceleration, regardless of mass, if they are affected by gravity only.

Despite the fact that the curriculum emphasizes models and modeling as an important part of high school physics the students should master, among the content objectives models and simplifications are very little mentioned. This finding is consistent with the findings of Boujaoude [17], who analyzed science curriculum in Lebanon schools. He came to the conclusion that, although in general objectives it is mentioned that students should learn about scientific method, in the content objectives this isn’t so obvious.

III. ANALYSIS OF TEXTBOOKS FOR HIGH SCHOOL PHYSICS IN SLOVENIA

In Slovenia, the official textbooks are confirmed 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. Three of the most used official textbooks in Slovenia are presented in Table I.

First editions of textbooks B and C were written before new curriculum for high school physics came into use. Irrespective of the changes in curriculum, the content of two books remained the same over the years and in later editions only minimal changes were made.

In this way, the textbook A is the 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 much additional material for teachers and students.

TABLE I. Three of the most used 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 in ostali	Mehanika in toplota	2000	2009
		Elektrika, svetloba in snov	1997	2011

In this study, we didn’t analyzed DVDs or workbooks or other material, limiting ourselves to textbooks, and examine how an individual textbook emphasizes and clarifies certain simplifications, which we do when dealing with physical phenomena in the fields of thermodynamics, electricity and waves. In doing so, we are focusing on eight simplifications that are often used in the physics domains. They are presented in Table II.

TABLE II. Results of review of approximations and idealisations in the fields of thermodynamics, electricity and waves.

Approximations and idealisations	Textbook A	Textbook B	Textbook C
1. Ideal gas	✓	X	X
2. Constant coefficient of thermal expansion	✓	✓	✓
3. Stationary heat conduction	✓	✓	✓
4. Point charge	✓	✓	✓
5. Electric field of the large plate	✓	✓	X
6. Ideal connection wires	X	X	X
7. Plane and circular waves	X	X	✓
8. Thin lenses	X	✓	✓

A. Ideal gas

In thermodynamics, the concept of an ideal gas is very important because the equation of state of an ideal gas can be theoretically derived. Despite the fact that the equation of state is valid only for dilute gases and very low pressures, under a mentioned conditions it represents a good approximation for real gases too.

Textbook A explains that we speak about the ideal gas when the forces between the molecules are completely negligible and the molecules can be considered as particles and that this assumption is a valid for rare gases at high temperatures. Out of the four solved exercises in the book, in two cases the ideal gas is mentioned while in two cases treated gas is air but the assumption that it can be modeled as an ideal gas is not mentioned.

Textbook B defines the ideal gas like a textbook A but it does not describe the conditions under which real gas can be treated as ideal and also there is no consideration about the range of validity of the gas equation. From the field of the gas equation, we can find six solved problems in which the assumption about an ideal gas is nowhere mentioned. As the limited validity of the ideal gas equation is nowhere mentioned, students can get a feeling that is always applicable. This wrong idea can be further induced by some unsolved problems in which we can find such an absurd statements that the pressure is 970 bar! With such a high pressures, the results of the ideal gas equation are no more consistent with the experiment, but in the textbook the equation is still used without any further comment.

Textbook C derives ideal gas equation and explains that at the atmospheric pressure and room temperature almost all gases can be considered as ideal. However between the unsolved examples appear tasks in which for example the gas temperatures are -43°C and 100 ° C and pressure is 7.5 bar. These values are far away from the normal air pressure and ambient temperature.

B. Constant coefficient of thermal expansion

In thermal expansion of solids the elongation *dl* is proportional to the initial length *l* and the temperature difference ΔT which leads to the equation $dl = \alpha l dT$. This linear approximation is useful, if the temperature difference is small enough. At higher temperature differences, we need to consider yet another term in the Taylor series or write that we will make estimation or that we will calculate with the average coefficient of thermal expansion.

Textbook A, in the case of the thermal expansion of the solids, says that the temperature coefficient of linear expansion may vary slightly with temperature. It presents three solved problems and in all three problems expresses written assumptions: once the temperature coefficient of linear expansion is assumed constant, once it is calculated with average value and in third problem it is written that is an estimate of elongation.

Textbook B, after exposing the basic relationship between the relative elongation and change of temperature, mentions only that the temperature coefficient of linear expansion must be measured for each temperature interval separately. In three solved problems, it is not clear that this is an estimate or the average temperature coefficient of linear expansion.

In the unsolved problems at the end of chapters, there is no assumption mentioned, but, nevertheless, one of the problems involves a temperature change of 500 K.

The textbook C presents equation for thermal expansion and mentions that the detailed data for the temperature coefficient of linear expansion can be found in the reference books from which we can learn that it is temperature dependent. In this textbook there are no solved problems, but, at the end of the corresponding chapter, there are seven unsolved problems with no mentioned assumptions. Interestingly, this textbook also points out that the equation for linear expansion is valid only if the temperature changes are not too large, but, nevertheless, in unsolved problems the change in temperature of 200 K occurs.

C. Stationary heat conduction

The law of heat conduction $P = -\lambda S \Delta T / x$ is in this form useful only for stationary conditions and for conduction through evenly thick layers and walls. Textbook A tells us that the expression for the conduction rate can be used if temperatures aren't changing and thus for short time intervals, for bodies with high heat capacity or for the bodies which are at constant temperatures. It also comments in detail that otherwise time interval should be divided into shorter intervals at which the temperature does not change significantly and then we calculate conduction rate for a short time interval with a mean temperature difference. Whole transferred heat is then calculated by summing the contributions from shorter time intervals. In only one solved problem assumptions are not needed, while in five unsolved problems it is pointed out three times that it is a stationary situation and twice an explicit statement that the temperatures are constant is written down.

Textbook B clarifies, from the start, the distinction between the non-stationary and stationary distribution of temperature, commenting that the conduction rate in generally varies with time, since it depends on the temperature differences in the material which are decreasing with the conduction of heat. For stationary conditions, it writes an equation for conduction rate and later considers non-stationary situations. In all three solved and five unsolved problems it states clear that the temperatures are constant.

Textbook C defines the conduction rate and comments that, in the case of variable conduction rate, the term in the equation represents an average conduction rate. It mentions that the steady state occur when the temperatures of the materials do not change and it writes down equation for conduction rate for the stationary case. In this textbook equation of the conduction rate is used in one solved problem in which it states that the temperatures are constant.

D. Point charge

Coulomb's law quantifies the force between charged particles or point charges, which have a certain mass while their size is neglected. Similarly as with a model of the particle, the model of a point charge is useful in cases when the distance between the bodies is much greater than their dimensions.

Textbook A tells students that the Coulomb's law applies only to point charges, while, in the case of the extended bodies, the corrections must be taken into account. Later case is treated on the added DVD.

Despite of that, in three unsolved tasks at the end of chapter, it uses the words "small balls" but there is nowhere an suggestion that these balls can be modeled as a point charge.

The textbook B describes that the Coulomb's law was experimentally determined with help of charged spheres and that *r* in the equation is the distance of their centers. Then it writes down the clarification that if the charge is not uniformly distributed on the spherical body, the bodies must be sufficiently small compared to the distances between them. Nevertheless, between the unsolved tasks we can also found an example of a large storm cloud, where nowhere states it to be spherical or that an estimate is made.

Textbook C describes the Coulomb's law applies to balls only if the charge on them is evenly distributed and that this is the case when the distance between the balls is large compared to the diameter of the spheres. The force is then such as there were point charges in the centers of the spheres. In unsolved tasks it sticks to this definition because in nine out of ten tasks the involved body is described as a ball.

E. Electric field of the large plate

When dealing with electric fields, in addition to the electric field of the point charges, we usually discuss electric field in the vicinity of an infinite large plate. We define such a field as homogeneous and write down the equation for calculation of the strength of this field. Of course, no real plate is infinitely large but can be regarded as infinite if the distance of the considered point from the plate is much smaller than its distance from the edge of the plate where the field isn't homogeneous anymore.

In this respect, the textbook A claims that experiments show the field near the middle of a large flat panel is homogeneous and generalizes that, if the plate is infinite, the field is homogeneous over the whole area around the plate. In deriving out the equation for the capacity of the capacitor, the textbook says that the field between the plates is homogenous and that electric field is equal to zero in the exterior of the capacitor. Once again, it is emphasized that this only applies to an infinite large plates. If the plates aren't infinite, the field is homogeneous only in the central part of the interior of the condenser and is increasingly inhomogeneous toward the edges and extends to the outside of the condenser. Among unsolved examples it uses the terms "large wall" and "large plate" and in one of the tasks writes explicit assumption that the edge effect is neglected.

In the textbook B, we find out that one can apply the equation for the electric field between the plates in the ideal case when the plates are evenly electrified and infinitely large. Actually, the panels have finite size and only inside them and away from the edges the field is approximately the same as between the plates of infinite size. One can we make such and assumption if the plates are close to each other and their spacing is small compared to their transverse dimensions. In both solved examples this assumptions aren't mentioned. In two unsolved tasks refers only to a plate or a wall and in the third one it mentions "a very large plate."

The textbook C displays pictures of electric fields and writes down that the electric field between the capacitor plates is constant in its direction and size. Before introducing the expression for the magnitude of the electric field, it speaks about the electric field between the extended plates but one can find no record about the validity of the equation. When deriving the formula for capacity of the parallel plate condenser, it is assumed that the spacing between the plates is small compared to the dimension of the plates. Then one can suppose that the charge density on the plates is constant and it is proportional to the magnitude of the electric field around the plate. In unsolved problems, the textbook holds the assumptions about the small spacing between the plates.

F. Ideal connection wires

When dealing with electrical circuits, we normally assume ideal wires that have no resistance, which means that there is no voltage drop on them. This assumption is valid when the resistance of the wires is much smaller than the resistance of the resistors. If this assumption is not highlighted sufficiently clear the students, they can become confused when dealing with transmission of electrical energy, where one is calculating the losses that arise precisely because of the resistance of the wires.

In the textbook A, we found only the comment that ideal wires conduct current which does no work on them. Unlike these, the real wires do receive some electrical work. In the solved and unsolved tasks, it is nowhere mentioned that the resistance of the wires can be ignored or that ideal wires are assumed.

The textbooks B and C, while treating electrical currents, nowhere mention ideal wires or the possibility of negligible resistance.

G. Plane and circular waves

Plane wave is approximation that is used far from its source in a limited part of space in the selected direction. If there is no absorption, the intensity of the plane wave does not change. Although there are no ideal plane waves in nature, a lot of waves that are of practical interest, can be modeled as a plane wave. Circular waves result from a circular source or from a source that is small compared to the wavelength. Intensity of the circular wave decreases with the square of the distance from the source.

The textbook A describes that the plane wave travels in one direction perpendicular to the line and circular which comes from the particle spreads in all directions radially outwards. The textbook does not clarify when one can use an approximation of plane or circular wave. In one unsolved task, it is explicitly stated that a source emits a spherical wave that spreads in all directions equally and it also mentions the assumption that in the matter the waves are not absorbed.

The textbook B defines that the waves are plane, if the wave lines are straight and parallel. It also states that such a wave occurs when the source is long and straight. Wave lines of circular waves are concentric circles which origin from a common center where the source of circular waves is. This should send waves equally in all directions equally. The textbook suggests that usually source of the wave is not long and straight nor is it point source or circular source but far from the source (compared with the size of the source) all waves are circular. There are no solved exercises in the textbook B on plane and circular waves. In three unsolved problems, the type of wave isn't mentioned.

Textbook C indicates that the circular wave is obtained if the source is circular. If one touches the surface with a small board, the waves near it are plane. Even a small part of the circular wave can be treated as plane in a large distance from the source. There is only one unsolved tasks on this topic. In calculating the intensity, the approximation of the small source is not assumed and, despite of that, the equation for the intensity around a point-like source is used.

H. Thin lenses

Thin lenses are those whose thickness is much smaller compared to the focal length and distances of objects and images. It is assumed that refractions in thin lenses occur in the plane of the lens and that all the distances are measured from this plane. The assumption of thin lenses is fairly good for most practical cases and together, with the assumption one analyzes rays which are near the optical axis, it makes it easy to deal with geometrical optics in high school.

The textbook A claims that it searches for the image formation with a thin converging lens and that the derivation is valid only for rays which are near the optical axis, Nevertheless, the idea and validity of a thin lens approximation is nowhere explained. In two solved and twelve unsolved problems, the thin lens approximation isn't anywhere mentioned.

The textbook B clearly defines the assumption that the lenses are thin and strongly flattened and that the thickness is small compared to the radius of curvature of the two interfaces or the distances to objects or images. Then it says that one obtains a clear and correct image of the object only if the rays are passing almost vertically through the central portion of the lens, so that the beams enclose small angles with the optical axis of the lens. The object must be small and must be located in the immediate vicinity of the optical axis. Since these conditions are often not met, the image formation with the lenses gives the incorrect image of the object. Then, the textbook makes the clarification that this error will be ignored. In the solved and unsolved tasks assumptions of thin lenses is not mentioned.

The textbook C defines a thin lens as such where the distance between the apices is small compared with the diameter of the lens and then makes the derivation of a thin lens equation. In the derivation of the equation, it indicates the assumption that the rays are close to the optical axis and that their deviation is small. In none of the six unsolved it uses the assumption of thin lenses.

IV. CONCLUSIONS

This review of some of the most common simplification and idealizations in the fields of thermodynamics, electricity and waves in Slovenian high school textbooks indicates that all three of the commonly used textbooks in roughly equal measure present and explain certain approximations and idealizations, which one assumes when dealing with physical examples of the above-mentioned fields. However, a detailed analysis shows that there are significant differences between the textbooks.

In the field of thermodynamics textbook A very carefully and logically presents the three analyzed approximations and it uses them in solved examples so that students can see a practical example of using these simplifications. Textbooks B and C clarify which molecular properties are neglected in the model of an ideal gas, but they tell students nothing about what conditions must be satisfied that this model can be used and they said nothing about the limited validity of the ideal gas equation. But in solved tasks the ideal gas equation is used, even in cases in which appearing thermodynamic quantities of a gas make no sense (gas density of 1.5 kg /l). Because of that, students do not develop the understanding of models and improving them when one encounters examples where the model results are no longer consistent with the experiment.

The second and third simplification of the field of thermodynamics are correctly presented in both textbooks, but the solved tasks on thermal expansion neither use the written assumptions nor they explain why they act in contrary to what they write down in the definition of the coefficient of linear thermal expansion and use a large temperature ranges in solved and unsolved tasks.

In analysis on the idealizations in the field of electricity and wave, the textbook C deviates from the other two because in this textbook there are no solved examples. While both the assumptions from the field of waves and a point charge model are clearly described, this textbook does not sufficiently precisely define when a plate can be considered as infinite. Textbooks A and B well describe both assumptions from the field of electrostatics, but the textbook B, in some solved tasks, doesn't take into account the defined assumptions. It is also an interesting fact that none of the three textbooks presents the model of ideal wires, while all three define specific electrical resistance and they calculate the resistance of different wires. If we want our students to develop a sense of precision and exactness, then in this issue we must said them that all wires have some electrical resistance but, in some cases, it doesn't need to be taken into account.

The textbook A, for none of the analyzed assumptions in the field of the wave, doesn't define them with sufficient clarity or mentions their validity range. Similarly, the textbook B defines well the concepts of plane and circular wave, but doesn't describe under which conditions some waves can be treated as one or the other.

The assumption of thin lenses is, in the textbook B, explained in great detail, but it is no longer mentioned in solved tasks.

In the review of solved tasks that were related to analyzed idealizations and simplifications, we have found that they contain almost no explicitly written simplifications, so we expanded the analysis and review of solved tasks on the whole fields of thermodynamics, electricity and waves.

In the textbook C, the solved examples are only in chapters on thermodynamics. There are fourteen of them and explicit assumptions are written in two cases.

The textbook A contains 101 solved tasks in the fields of thermodynamics, electricity and wave and explicit assumptions were found in nine cases, while in the textbook B we found them in seven cases (of 86). The results show that, while textbooks, in most cases, correctly present simplifications in the text, the simplifications are, in a much lesser extent, suggested to the students in solved examples, giving them a sense their importance for analyzing and solving problems in physics.

Since, according to Romer [18], "modern science would not have started if Galileo and Newton insisted on exact description of falling bodies and circulating planets" and should not made simplifications, it is important to help students that they already in high school physics develop a sense for making reasonable approximations and idealizations.

An interesting study on this topic would be to what extent this sense is developed by solving computational tasks which are usually practiced in traditional physics course.

REFERENCES

[1] Gilbert, J. K. and Boulter, C. J., *Learning science through models and modelling*, in Fraser, B. J. and Tobin K. G., International Handbook of Science Education, Dordrecht, Kluwer, pp. 53–66, (1998).
[2] Harrison, A. G., and Treagust, D., *Learning about atoms, molecules and chemical bonds: A case study of multiple model use in Grade 11 chemistry*, Science Education **84**, 352–381 (2000).
[3] Gilbert, J. K., *Models and modelling: Routes to more authentic science education*, International Journal of Science and Mathematics Education **2**, 115-130 (2004).
[4] Brewe, E., *Modeling instruction in introductory physics*, Am. J. Phys. **76**, 1155-1160 (2008).
[5] Viiri, J. E., Tolvanen, P., Planinšič, G. and Sliško J., *Student's ability to construct mathematical model*, Frontiers of Physics Education*:*selected contributions, 380-385 (2008).
[6] Hestenes, D., *Modeling methodology for physics teachers*, in The Changing Role of the Physics Department in Modern Universities, edited by Redish, E. and Rigden, J., American Institute of Physics, Woodbury, NY, 935–957 (1997).
[7] Wells, M., Hestenes, D. and Swackhamer, G., *A modeling method for high school physics instruction*, Am. J. Phys. **63**, 606-619 (1995).
[8] Hestenes, D., *Toward a modeling theory of physics instructions*, Am. J. Phys. **55**, 440-454, (1987).
[9] Hestenes, D., *Modeling Games in the Newtonian World*, Am. J. Phys. **60**, 732-748, (1992).
[10] Bossel, H., *Systeme, Dynamik, Simulation: Modellbildung, Analyse und Simulation komplexer Systeme (*Books on Demand GmbH., Norderstedt, 2004).
[11] Hannon, B. and Ruth, M., *Dynamic modeling*, (Springer, Berlin, Heidelberg, New York, 1994).
[12] Portides, D., *The Relation between Idealisation and Approximation in Scientific Model Construction,* Science & Education **16**, 699–724 (2007).
[13] Beaton, A. E., Martin, M. O., Mullis, I. V. S.,Gonzalez, E. J., Smith, T. A. and Kelly, D. L., *Science achievement in the middle school years*: *IEA's Third International Mathematics and Science Study*, (Boston College, Chestnut Hill, 1996).
[14] Mullis, I. V. S., Martin, M. O., Robitaille, D. F. and Foy, P., *TIMSS Advanced 2008 International Report: Findings from IEA's Study of Achievement in Advanced Mathematics and Physics in the Final Year of Secondary School,* (TIMSS & PIRLS International Study Center, Boston College, Chestnut Hill, 2009).
[15] *Zakon o gimnazijah,* <http://www.pisrs.si/Pis.web/pregledPredpisa?id=ZAKO450>, visited in July 20 (2014).
[16] Planinšič, G. *et al*., <http://portal.mss.edus.si/msswww/programi2008/programi/media/pdf/ucni_nacrti/UN_FIZIKA_strok_gimn.pdf>, visited in July 20 (2014).
[17] BouJaoude, S., *Balance of scientific literacy themes in science curricula: The case of Lebanon*, International Journal of Science Education **24**, 139-156 (2002).
[18] Romer, R. H., *Reading the equations and confronting the phenomena: The delights and dilemmas of physics teaching*, Am. J. Phys. **61**, 128-142 (1993).