Do solved problems in Slovenian secondary school physics textbooks emphasize modeling process?

Matej Forjan[1,2], Josip Sliško[3], Marko Marhl[4,5], Vladimir Grubelnik[6]
[1]*School Centre Novo mesto, Novo mesto, Slovenia.*
[2]*Faculty of Industrial Engineering, Novo mesto, Slovenia.*
[3]*Facultad de Ciencias Fisico Matematicas, Benemerita Universidad Autonoma de Puebla, Puebla, Mexico.*
[4]*Faculty of Natural Sciences and Mathematics, University of Maribor, Maribor, Slovenia.*
[5]*Faculty of Education, University of Maribor, Maribor, Slovenia.*
[6]*Faculty of Electrical Engineering and Computer Science, University of Maribor, Maribor, Slovenia.*

E-mail: matej.forjan@sc-nm.si

(Received 24 June 2014, accepted 25 August 2014)

Abstract

This article describes the results of analysis of the content of the two most commonly used Slovenian secondary school physics textbooks, from the standpoint of the presentation of modelling stages in the solved problemas. We investigated the extent to which the four main stages of modelling process are presented in the solved examples of individual physical areas and analysed the results. The analysis shows that the conceptual phase is very poorly presented, while, in most cases, the emphasis is on the stage of model analysis, i.e. solving mathematical equations. The validation stage of modelling process can be hardly detected in solved examples. It means that students are not able to recognize the value of the experiment, when assessing the relevance and accuracy of developed models.

Keywords: physics textbook analysis, modeling method, solved problems.

Resumen

Este artículo describe los resultados de análisis de contenido de dos libros de texto de física que son comúnmente usados en la escuelas preparatorias en Eslovenia, desde el punto de vista de presentación de las fases de la modelación en los problemas resueltos. Hemos investigado hasta qué extension se presentan las cuatro fases principales del proceso de modelación en los ejemplos resueltos en los áreas individuales de física y hemos analizado los resultados. El análisis demuestra que la fase conceptual se presenta de manera muy pobre, mientras, en la mayoría de los casos, el enfásis está en la fase de análisis de modelo, es decir, en la solución de ecuaciones matemáticas. La fase de modelación del proceso de modelación difícilmente se detecta en los ejemplos resueltos. Eso significa que los estudiantes no son capaces de reconocer el valor de experimento, cuando evaluan la relevancia y la precision de los modelos desarrollados.

Palabras clave: análisis de libros de texto de física, método de modelación, solved problems.

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

I. INTRODUCTION

The prevailing opinion of students about physics is that it is boring, too abstract and completely irrelevant to everyday life [1, 2, 3, 4, 5], and as such useless which makes it not worth to learn. Such a view is not so surprising, because in the classroom we often treat such cases where it is necessary only to find an appropriate formula, insert numbers and calculate the unknown quantities [6, 7, 8]. Lillian McDermott [9, page 296] wrote, more than twenty years ago, that the key findings of physics teaching research suggest that "a coherent conceptual framework is not typically an *outcome of traditional* instruction". In the traditional physics teaching, we usually start from the observed physical phenomena, derive equations and show examples of the use of equations in problems solving and all this is supplemented with laboratory work. However, as researches show some shortcomings of traditional physics teaching, in recent decades appear several different approaches, which should improve this situation. All these approaches are, more or less, based on the fact that the students must be mentally active in the classroom, which is one of the main conditions for a functional understanding of physics [10, 11, 12, 13]. Hestenes [14] argues that the situation can be improved with the modelling approach, where the entire teaching of physics is organized around a small number of basic models, which are then used in specific situations. Such a view is in contrast to the traditional physics teaching, where the emphasis is on learning the final models and not on the modelling process itself. Modelling approach has shown positive impact on the understanding of basic physical structure [15, 16, 17], therefore Angell and colleagues believe that modelling is becoming an increasingly important component of modern physics curriculum [18].

In addition to teaching methods, a textbook is also an important part of the educational process. The textbooks reflect and implement curriculum, define the sequence of content in them, the laws of physics are explained and a very important part of the textbooks are also solved tasks. Research shows that students when solving physics problems often resort to solved tasks in textbooks and seek analogies that help them in solving [19, 20]. From this perspective, it is important that solved examples in physics textbooks present in detail all the steps in solving the problem. In particular, this applies to solving problems related to complex dynamical systems, where knowledge and proper use of the various phases of mathematical modelling plays an important role in the process of problem solving. Knowing the phases of mathematical modelling combined with experimentation is the basis for solving problems and understanding of systems in various fields of social and natural sciences [21, 22, 23, 24].

In the light of this issue, we focus our attention on the representation and presentation of the various phases of mathematical modelling in the solved examples in Slovenian secondary school physics textbooks. The importance of our research is in finding correlations between the representation of the various phases of mathematical modelling in textbooks and efficiency of solving complex physics problems. The reason for poorer results of Slovenian students in international researches of physics knowledge in problem solving that require higher cognitive skills [25, 26], could therefore be, at least partially, explained by the lack of the various phases of mathematical modelling in textbook examples. In a previous study [27], we have already shown that secondary school physics textbooks don't give enough emphasis on accurate presentation of idealizations and simplifications, which we usually assume when dealing with problems in secondary school physics. In present study we further expand this analysis on the remaining phases of mathematical modelling.

In this articles, we first describe in detail the concept of modelling and model and define each stage of mathematical modelling, which is, in our opinion, essential in solving physics problems at the secondary education level. To get a better insight into the current state, next to review of all the tasks, we do an analysis of individual domains of secondary school physics. Then we present the results of research, where we analyse the representation of the various modelling stages in the two most commonly used Slovenian secondary school physics textbooks. In the end, we discuss the results and we give guidance to achieve better results in solving physical problems that require higher cognitive skills.

II. MODELING METHOD IN PHYSICS EDUCATION

According to several authors [28, 29, 30, 31, 32], knowledge of the models and the modelling process is crucial for understanding how the science works. Therefore, it is important that we accurately present models which are used in physics teaching. Hestenes, in several articles [14, 33], defines a model as a physical representation of the structure of the system and its characteristics, and explains that in physics we work with mathematical models, which means that we strive to present the observed properties with the quantities. Mathematical model we simulate interprets results and evaluates the validity of the model so that the results of the model are compared with experimental data [34]. The model is then developed to match the simulation results with the experimental results reasonably. We do this as long as this correspondence is not at a satisfactory level. Etkina and colleagues [35] recorded that in setting up a mathematical model we do several types of simplifications and they introduce a model of a body, a model of interaction, a model of the system, which is a combination of first two models, and a model of the process that describes the changes in the system. A more detailed description of the various stages of modelling can be found in works of several authors [36, 37, 38]. Based on the analysis of these methods, we define the phases of mathematical modelling, which in our opinion are appropriate or necessary to deal with the complex physics problems at secondary education level (Figure 1).

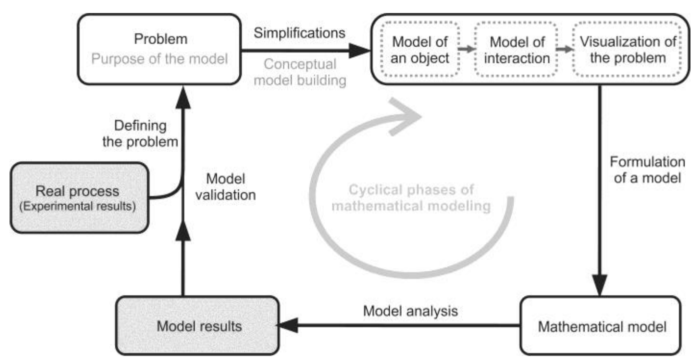

FIGURE 1. Proposed method of mathematical modelling in secondary physics education.

Any mathematical description of the real process requires from us to define the scope of the problem that we are interested in, as well as the goal and purpose of the model. The purpose of the model is important because it leads us to make choices about the complexity of the model, the accuracy of the involved parameters, of the boundaries of the model and other factors. Richardson and Pugh [39] argue that "model without purpose is like a ship without a sail." By selecting the purpose of the model, the criterion is defined, under which the appropriate system and its boundaries are selected. The next step is to decide how the body or system of bodies will be simplified, which means choosing an appropriate model of the body (eg. particle body, rigid body).

We also need to decide which model of interactions will we choose - which interactions will be considered and which not. After selecting the model of the body and the model of interaction, we select physical quantities, which we believe could affect the behaviour of the body or system of bodies. Then a visualization of the problem follows to demonstrate more clearly the important aspects of physics and highlight the given information. It is important to present as many information about the assumptions as possible. The pictures, graphs, diagrams of forces, motion diagrams, charts rays or any other visual tools can be of great help in this presentation. On the basis of the model of the body and the model of interactions in second modelling stage, also called the formulation of the model, the functional relationships between the variables are developed, thus obtaining a mathematical model of the entire process. Models of the process can be state equations that describe how one or more properties of the system changes with respect to each other, or causal equations describing how the properties of the system change due to interactions with the environment. The result of the second phase is the mathematical representation of equations which must be solved. The third phase is the model analysis and in this phase the equations are solved and the process characteristics and implications of the model are analysed. In the validation phase of the modelling process we compare the results of the mathematical model with the results of the experiment and validate the reasonableness of the results obtained. In the case of discrepancies the whole process of modelling is repeated.

III. ANALYSIS OF SOLVED PROBLEMS IN TEXTBOOKS FOR SECONDARY 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 suitability. For secondary school physics, there are five approved textbooks, but according to the abundance of use, the two textbooks are standing out and our further analysis is limited only to these two textbooks [40, 41, 42, 43, 44, 45]. While the first edition of the Kladnik textbook has been written in the nineties and their concept didn’t change through the years, the Mohorič and Babič is a modern textbook for secondary school physics, which was written in the last three years. In both textbooks there is a large number of solved examples (Mohorič and Babič textbook - 281 solved examples, Kladnik textbook - 201 solved examples), which were analysed from the perspective of the various stages of modelling process.

In the context of the conceptualisation phase we first analysed, whether in the text of the example or in the solution the simplifications, the idealizations or other assumptions, which we assume when dealing with problems, are explicitly mentioned.

The conceptual stage of modelling includes also the visual representation of the problem, so we analyse how many solved examples are equipped with a sketch, diagram, graph, or other form of visual aids that helps us to illustrate the problem. In order to determine the extent to which the formulation stage of modelling is represented, we reviewed all the examples and determine whether the derivation of the final equation from all assumptions can be clearly seen or it is just written without detailed explanations or derivations. Based on experience, we expect that in solved examples the analysis stage of modelling is the most common one. In the final step, we analyse whether the obtained solutions are validated, if their reasonableness is assessed or whether the solutions are compared with any experimental data, which we include in the validation stage of the modelling process. The proportion of the individual stages of modelling in both analysed textbooks is presented in Figure 2.

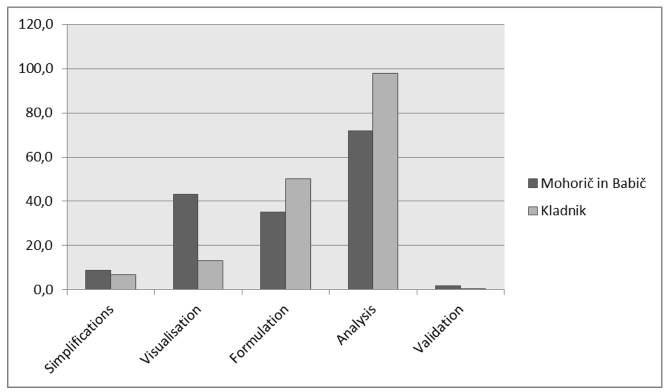

FIGURE 2. The representation of the various stages of modelling process (in %) in both textbooks.

As expected, the stage of model analysis is the most frequent one. In the textbook from Kladnik the 98 % of solved examples are the classical computational problems, where the model analysis is the main part of problem solving. Such a large percentage of computational examples further reinforces the view that physics is a science in which we solve problems for which it is necessary only to find the right formula, insert numbers and calculate the desired quantity. In textbook from Mohorič and Babič this percentage is smaller, with 72% of such problems in which the model analysis is explicitly presented. This smaller number is attributed to the fact that in this textbook there are more such examples that qualitative treat certain physical problem. A more detailed overview of the various areas of physics, which is shown in Figure 3, exposes an interesting fact that in textbook from Mohoričev and Babič the minimum percentage of computational examples is in the introductory chapter of mechanics. In this chapter, the authors give a greater emphasis on qualitative understanding of basic physical concepts, in which they followed the instructions from the physics curriculum [46]. In curriculum states, that the teaching of physics should be based on qualitative treatment of the subject matter. This qualitative aspect is especially important for students who first encounter with secondary school physics, because in such a way we teach them from beginning that in solving physical problems they must favour a qualitative analysis of the problem in front of a mere computation.

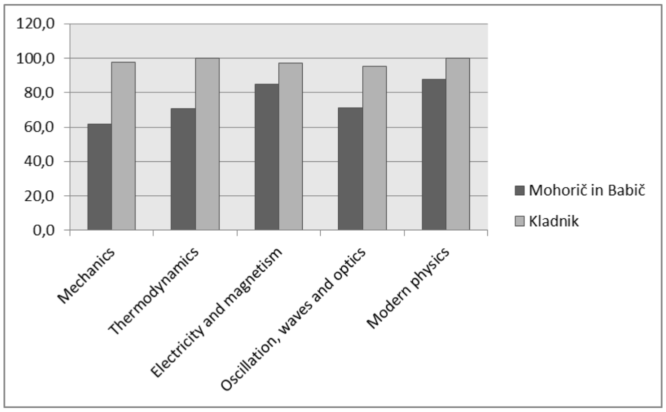

FIGURE 3. The proportion of solved examples in both textbooks (in %), that explicitly present the model analysis stage of the modelling process.

At the formulation stage on the basis of basic physical laws in a particular area, together with the models of the bodies and interactions the final equations are recorded. From those equations are in the model analysis then the results calculated. A comparison of two textbooks in Figure 2 shows that the formulation of the model in both textbooks is presented in approximately twice the smaller number of cases as the model analysis stage. This means that in half of computational examples the process of a mathematical model setup from of the initial assumptions to the final equation isn't obvious. In some cases, only a trivial calculation of certain physical quantities is needed and the formulation of the model is not required, but from the examples in the textbook, however, is expected to present a meaningful whole process of physics problems solving in which the formulation of a mathematical model is also included. Detailed representation of model formulation stage in individual physical fields is shown in Figure 4. It reveals that in the textbook from Kladnik 70% of all solved examples in the field of mechanics the model formulation stage is explicitly presented. To students that learn from this textbook, particularly in sections of kinematics and forces, a significant number of solved problems with a clear presented and detached model formulation and model analysis stages are available. Unfortunately this is not the case in other chapters where this percentage decreases to 30% and in these chapters the classical computational tasks such as "compute capacity of the capacitor, if you know the voltage between the plates and the charge on the plates" dominate. In a recent textbook the deviations between physical areas regarding the representation of the model formulation stage are smaller, but similar as in textbook from Kladnik the smallest proportion of problems that contain this stage is in the field of electricity and magnetism.

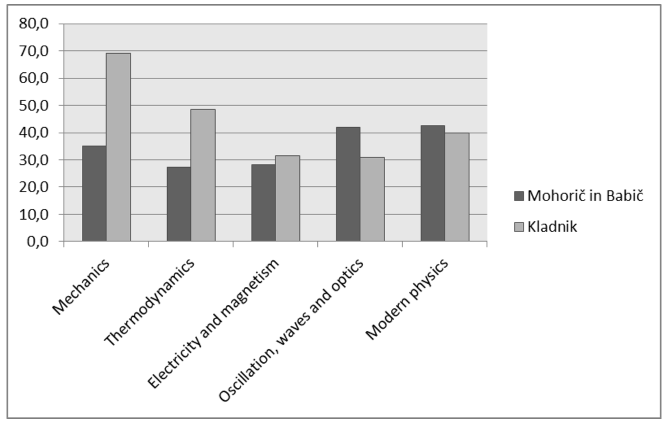

FIGURE 4. The proportion of solved examples in both textbooks (in %), that explicitly present the model formulation stage of the modelling process.

Simplifications and idealizations are a key part of the solution of physical problems and so are all the more surprising results presented in Figure 2 that in both the analysed textbooks there are less than 10% of solved tasks where the default assumptions are explicitly presented. A small number of assumptions in the textbook from Mohorič and Babič can be attributed to the fact that the model of bodies and interactions are explained in the text, so the authors didn't further interpreted those models in solved examples. In previous study [27], we showed that in textbook from Kladnik the simplifications and idealizations in the text are not explained in detail, so we expected them to be described in greater detail in the solved examples. The analysis of the solved tasks did not confirm our expectations.

Figure 5 shows the percentage of solved cases in various physics fields, where the default assumptions are explicitly present. It can be seen that in both textbooks the thermodynamics stands out, where the majority of the default assumptions are relating to the model of an ideal gas, or the stationary heat conduction. In the field of mechanics the proportion of the solved tasks with these assumptions is small, which especially in textbook from Kladnik leads to tasks that do not have too much contact with reality. For example, in the chapter on linear motion we can find an example of the hunter airplane that descends at a speed of 300 m /s and drop a bomb, for which from the equations of the free fall is calculated that over 10 seconds it will fall to the ground with the velocity 400 m/s.

Despite the velocity that is greater than the speed of sound in air at normal conditions, the reader doesn't find out, why the equations of free fall are applied. As the obtained result is not commented, similar tasks can cause confusion regarding the applicability of equations of the free fall. In our opinion for that task would be appropriate to clarify that, while air resistance in this case is not negligible, by using equations of the free fall we can estimate the order of magnitude of the falling time, while for a more accurate determination of that time we must also take air resistance into account.

With such a clarification the use of model of the free fall becomes more meaningful and students start from the very beginning to think that greater precision requires a more sophisticated models.

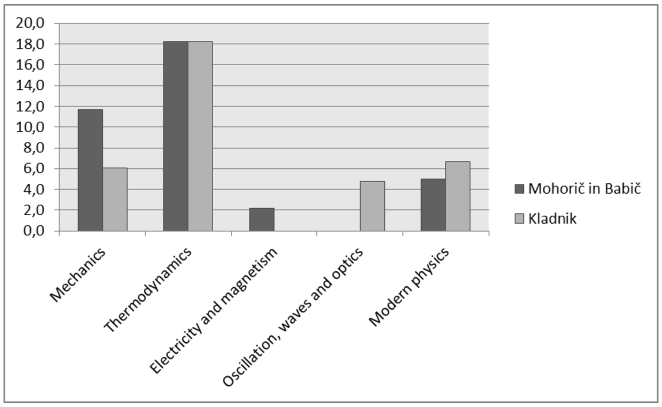

FIGURE 5. The proportion of solved examples in both textbooks (in %), that explicitly present the default assumptions or models of the body and interaction.

Visualization of every physical problem is an important step in the conceptualisation stage, because with the help of the picture, graph, diagram, or other means for the visual presentation of the problem it is easier to present and organize our knowledge. Textbook from Mohorič and Babič, where 43% of solved examples are visualized (Figure 2), at first glance gives the visualization great importance, but on closer inspection, which is shown in Figure 6, we find some interesting things. For example, this textbook in chapters on mechanics presents a large number of solved examples that are visualized and the percentage of such examples exceeds 50%. But when dealing with other physical fields the number of solved tasks as well as the percentage of visualized tasks decreases despite the fact that there are treated subjects whose visualization is crucial, such as geometric optics, or electric and magnetic fields. In these areas of physics apply other visualization means, such as drawing ray diagrams of electrical circuits or diagrams of magnetic fields. It is important for students to acquire and understand as many different ways of visual presenting problems in physics, because in this way they are expanding range of cases, which they can solve with the systematic modelling approach. As shown in Figure 6, textbook from Kladnik gives very little importance to visualization, because only 27 cases out of 207 examples contain visual presentation. More than half of these cases are in the chapter on forces, where clearly illustrates the use of diagrams of forces in the analysis of the problems that fall within the scope of Newton's laws. Especially particular is the fact that in all areas of physics except for the mechanics there is almost no trace of solved examples that show how to visually represent a specific physical problem, which raises the question to what extent do students that use this textbook understand the importance of visual presentation for models building and problem solving.

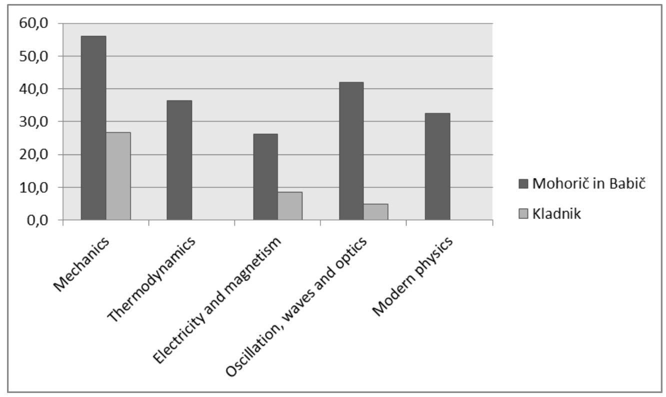

FIGURE 6. The proportion of solved examples in both textbooks (in %), that visualize the described problem.

The last phase of modelling, this is the stage of the model validation, is in solved tasks in both textbooks presented only for the sample (Figure 2). While in the textbook from Kladnik we found only one task where the model result is compared with the results of the experiment, there are five such cases in the second textbook, which, given the large number of solved tasks remains insignificant number. The fact that the model validation phase practically does not occur in the solved examples in textbooks, presents a serious problem, because students in assessing the correctness of a model when working with textbooks do recognise the value of an experiment. One of the reasons that the validation phase is in solved tasks very poorly represented is also that these tasks usually do not arise from the experiment, but from an already well-defined problem, where it is necessary to get the results of a mathematical model. For validation we need experimental results that can be compared with the results of the model, therefore, the writers of textbooks in the future should consider to involve a larger number of such examples, which are directly related to the experimentally obtained data.

IV. CONCLUSIONS

Setting up a mathematical model of a phenomenon and experimental verification of their validity are the main methods of science, so it is surprising that only in the last two decades the modelling is paving the way in the field of physics teaching. In obtaining an understanding of the modelling process and its importance for developing a conceptual understanding of physics, it is important that also solved examples in textbooks adequately represent all stages of model setup. In this paper we present an analysis of solved tasks in the two most commonly used secondary school physics textbooks in Slovenia, where we focus on the different modelling stages and their representation in these tasks.

We have found that by far the most represented stage is model analysis, which is in line with expectations and one of the textbooks is even going so far that almost all solved tasks in it explicitly present this computational part of modelling. Model formulation stage is less represented. One of the reasons is because there are many quite trivial computational examples where the whole modelling process is not necessary. Model conceptualization stage is excluding the area of mechanics and thermodynamics in both analysed textbooks very poorly presented. While in the chapters of mechanics and thermodynamics in both textbooks there is about 10 % of solved tasks such that the models of the body and interactions are explicitly written down, in the remaining chapters there are only 3 % of such examples.

In this way, the students do not see the importance of idealizations and simplifications in physics problems solving, which is why they also have problems in understanding the limitations and validity of developed models. The last modelling stage is the key to validity of the model, so it is all the more important that students understand the importance of this stage. Last but not least, the modern science began only with Galileo, who realized the importance of systematic and rigorous experimentation for validation of hypotheses and arguments.

It is therefore all the more negative the fact that both analysed textbooks do not expose the importance of the validation of obtained results, because in the solved tasks we detected only a very limited sample of cases where the results are compared with the experimentally obtained values. If we want students to know and understand the importance of modelling and experimentation for the development of science and understanding of the world around us, it will be necessary that solved examples in textbooks equivalently show all the modelling stages. Future textbooks will have to adopt to that.

This study represents the first step towards gaining a better insight into the problems that students have in solving physical problems. In the future, it makes sense to upgrade it with a detailed analysis of performance in solving physics tasks on "matura" exam, which is the graduation exam in secondary school education in Slovenia. Then it will be possible to make a more detailed connection between representation of the modelling stages in solved examples in textbooks and knowledge of the students.

REFERENCES

[1] Freedman, R. A., *Challenges in Teaching and Learning Introductory Physics*, <http://web.physics.ucsb.edu/~airboy/challenge.html>, visited in November 20 (2014).

[2] Osborne, J., and Collins, J., *Pupils' Views of the Role and Value of the Science Curriculum: a Focus group Study*, Int. J Sci. Educ. **23**, 441-467 (2001).

[3] Osborne, J., Simon, S., and Collins, S., *Attitudes towards science: a review of the literature and its implications*, Int. J Sci. Educ. **25**, 1049-1079 (2003).

[4] Osborne, J., and Dillon, J., *Science education in Europe: Critical reflections*, (Nuffield Foundation, London, 2008).

[5] Haste, H., *Science in my future: a study of values and beliefs in relation to science and technology amongst 11 - 21 year olds*, (Nestle Social Research Programme, London, 2004).

[6] Hribar, M., *Računske naloge pri pouku fizike*, Obzornik za matematiko in fiziko **39**, 113-116 (1992).

[7] Schecker, H., *System Dynamics in High School Physics*. Proceedings of the 1994, International System Dynamics Conference, 74-84 (1994).

[8] Raw, A. J., *Developing A-level physics student's mathematical skills – a way forward?*, Phys. Educ. **34**, 306-310 (1999).

[9] McDermott, L. C., How we teach and how students learn. A mismatch?, *Am. J Phys.* **61**, 295-298 (1993).

[10] McDermott, L. C., *Physics by Inquiry*, (John Wiley and Sons, New York, 1996).

[11] Mazur, E., *Peer Instruction: A User's Manual*, (Prentice–Hall, Upper Saddle River, 1997).

[12] Sokoloff, D., and Thornton, R. K., *Interactive Learning Demonstrations*, (John Wiley and Sons, Hoboken, 2004).

[13] Van Heuvelen, A., and Etkina, E., *The Physics – Active learning Guide*, (Pearson Education, San Francisco, 2006).

[14] 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).

[15] Halloun, I. A., & Hestenes, D., *Modeling instruction in mechanics*, Am. J Phys. **55**, 455-462 (1987).

[16] Wells, M., Hestenes, D., and Swackhamer, G., *A modeling method for high school physics instruction*, Am. J Phys. **63**, 606-619 (1995).

[17] Constantinou, C. *The Cocoa Microworld as an Environment for Modeling Physical Phenomena*, IJCEELL **9**, 201-213 (1999).

[18] Angell C., Kind P. M., Henriksen E. K., and Guttersrud, O., *An empirical-mathematical modelling approach to upper secondary physics*, Phys. Educ. **43**, 256–264 (2008).

[19] Chi, M.T.H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R., *Self explanations: How students study and use*

[20] VanLehn, K. Analogy events: *How examples are used during problem solving*, Cogn. Sci. **22**, 347-388 (1998).

[21] Hannon, B. and Ruth, M., *Modeling Dynamic Biological Systems*, (Springer, New York, 1997).

[22] Hannon, B. and Ruth, M., *Dynamic modeling*, (Springer, New York, 2001).

[23] Ruth, M., Hannon, B., and Forrester, J. W., *Modeling Dynamic Economic Systems*, (Springer, New York, 1997).

[24] Sterman, D. J., *Business Dynamics : Systems Thinking and Modeling for a Complex World*, (Irwin McGraw-Hill, Boston, 2000).

[25] 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).

[26] 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).

[27] Forjan, M. & Sliško, J., *Simplifications and Idealizations in High School Physics in Mechanics: A Study of Slovenian Curriculum And Textbooks*, Eur. J Phys. Educ. **5**, 20-31, (2014).

[28] 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, (Kluwer, Dordrecht, 1998), pp. 53–66.

[29] Harrison, A. G. and Treagust, D., *Learning about atoms, molecules and chemical bonds: A case study of multiple model use in Grade 11 chemistry*, Sci. Educ. **84**, 352–381 (2000).

[30] Gilbert, J. K., *Models and modelling: Routes to more authentic science education*, International Journal of Science and Mathematics Education **2**, 115-130 (2004).

[31] Brewe, E., *Modeling instruction in introductory physics*, Am. J. Phys. **76**, 1155-1160 (2008).

examples in learning to solve problems, Cognitive Sci. **13**, 145-182 (1989).

[32] 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).

[33] Hestenes, D. *Modeling Games in the Newtonian World*, Am. J Phys. **60**, 732-748 (1992).

[34] Leisen, J., *Didaktische und methodische Aspekte beim Einsatz von Modellbildungssystemen*, Praxis der Naturwissenschaften Physik **48**, 1-3 (1999).

[35] Etkina, E., Warren, A., & Gentile, M., *The Role of Models in Physics Instruction*, Phys. Teach. **44**, 34-39 (2006).

[36] Roberts, N., Andersen, D., Deal, R., Garet, M. and Shaffer, W., *Introduction to Computer Simulation: A System Dynamics Modeling Approach*, (Pegasus Communications, Waltham, 1983).

[37] Hestenes, D., *Toward a modeling theory of physics instructions*, Am. J Phys. **55**, 440-454 (1987).

[38] Schecker, H., *Physik-Modellieren, Grafikorientierte Modellbildungssysteme im Physikunterricht*, (Ernst Klett Verlag, Stuttgart, 1998).

[39] Richardson, G. P., and Pugh III, A. L., *Introduction to System Dynamics Modeling with DYNAMO*, (Pegasus Communications, Waltham,1981).

[40] Kladnik, R., *Gibanje, sila snov*, (DZS, Ljubljana, 2009).

[41] Kladnik, R., *Energija, toplota, zvok, svetloba*, (DZS, Ljubljana, 2009).

[42] Kladnik, R. (2010). *Svet elektronov in atomov*, (DZS, Ljubljana, 2010).

[43] Mohorič, A., and Babič, V., *Fizika 1*, (Mladinska knjiga, Ljubljana, 2012).

[44] Mohorič, A., and Babič, V., *Fizika 2*, (Mladinska knjiga, Ljubljana, 2013).

[45] Mohorič, A., and Babič, V., *Fizika 3*, (Mladinska knjiga, Ljubljana, 2014).

[46] Planinšič, G., Belina, R., Kukman, I. and Cvahte, M., *Učni načrt za fiziko*, <http://portal.mss.edus.si/msswww/programi2008/programi/media/pdf/ucni_nacrti/UN_FIZIKA_strok_gimn.pdf>, visited in November 23 (2014).