Interdisciplinary Description of Complex Systems 12(2), 176-186, 2014

PHYSICS CURRICULUM FOR THE 21ST CENTURY

Katalin Martinás* and Bálint Tremmel

Eötvös Loránd University
Budapest, Hungary

DOI: 10.7906/indecs.12.2.6
Regular article

Received: 11 March 2014.
Accepted: 1 April 2014.

ABSTRACT

In this paper we argue that, in Kuhn's term, phenomenological thermodynamics and Newtonian physics are incommensurable, while phenomenological thermodynamics, naive physics and Aristotelian physics are commensurable paradigms. Teaching based on phenomenological thermodynamics eliminates the incommensurability problem.

Also, a physics curriculum based on phenomenological thermodynamics is outlined, in which Newtonian equations are introduced only at a later stage, as a well-working model of the world.

KEY WORDS

physics teaching, paradigms, Aristotle, phenomenological thermodynamics, exergy

CLASSIFICATION

JEL: I23, I25

PACS: 01.40.Di, 01.40.gf

*Corresponding author, η: martinas@elte.hu; +36 1 2090 555 Ext 6360;
Atomfizikai tanszek, ELTE, Pazmany Peter setany 1, H – 1117 Budapest, Hungary

INTRODUCTION

Challenges of 21st century demand a more effective science education which is relevant not only to scientists but a large fraction of the population. As it was summarized by IUPAP in "The Importance of Physics to Society" statement [1]:

"Physics is an exciting intellectual adventure that inspires young people and expands the frontiers of our knowledge about Nature.

Physics generates fundamental knowledge needed for the future technological advances that will continue to drive the economic engines of the world.

Physics contributes to the technological infrastructure and provides trained personnel needed to take advantage of scientific advances and discoveries.

Physics is an important element in the education of chemists, engineers and computer scientists, as well as practitioners of the other physical and biomedical sciences.

Physics extends and enhances our understanding of other disciplines, such as the earth, agricultural, chemical, biological, and environmental sciences, plus astrophysics and cosmology - subjects of substantial importance to all peoples of the world.

Physics improves our quality of life by providing the basic understanding necessary for developing new instrumentation and techniques for medical applications, such as computer tomography, magnetic resonance imaging, positron emission tomography, ultrasonic imaging, and laser surgery."

Nevertheless, present efficiency of physics teaching is relatively low. There are quite a few students who dislike physics and have difficulty in understanding physics [2]. Furthermore, some learn physics only in the form to manipulate the formulas. However, ability to solve physics problems does not necessarily mean the understanding of the underlying concepts [3, 4]. Teaching physics in higher education is also problematic, as Zirbel wrote [5]: "Students often enter introductory courses lacking a consistent conceptual framework about natural sciences." For some students teaching has no effect at all as "Students exit physics classes with their intuitive beliefs pretty much intact."

There are several explanations for this catastrophic situation, with plenty of solution proposals. Our point of view is that physics curriculum based on Newtonian mechanics demands the acceptance of two paradigm changes during the learning process. The first one is the shift from the naive paradigm to the Newtonian one, and the second one from the Newtonian paradigm to the paradigm of modern physics. Those students who refuse to accept the first paradigm change will not be able to follow and understand the physics courses.

A change in the paradigm of physics education from the Newtonian foundation to a phenomenological thermodynamic basis could eliminate the need for these paradigm changes in the learning process.

NAIVE PHYSICS

Naive physics refers to the common-sense beliefs that people think about the way the world works.

Mainstream physics education considers this naive picture as a mistaken belief about mechanics, which must be forgotten first to be replaced by the physics based on Newton's laws, which provides the right, the scientifically true description of Nature [6]. It means that students are obliged to forget their own experiences to be replaced with the experiments shown by the teachers. Common opinion is that the problem of understanding physics originates from the fact that either the teachers do not have sufficient skills, or the students have insufficient knowledge in mathematics. Perhaps they are unmotivated, or simply unable to follow the advances of modern physics. Nevertheless, some new results give another explanation: "Fraction of students who complete a physical science major in college is determined more by the students' ability to tolerate traditional physical science instruction, than by their ability to do science" [7].

The alternative approach is to accept naive physics as a distinct, non-Newtonian paradigm. Stella Vosniadou, in the paper "On the Nature of Naive Physics" [8], stated that naive physics is neither a collection of unstructured knowledge elements nor a collection of stable misconceptions to be replaced. It is a complex conceptual system that organizes children's experiences, a coherent explanatory framework that provides the capabilities necessary to function in the physical world.

Problem is that naive physics, like common sense, is hardly definable. It changes from person to person and depends on the actual experiences of the person. However, there are some characteristics which distinguish it from the Newtonian physics. Some of the basic concepts in Newtonian physics, i.e. vacuum, inertial system, motion without friction, action at a distance, are non-existent in naive physics. Also, the naive concept of force is more general than it is in Newtonian physics. It is a different paradigm.

It implies that physics curriculum demands from the students to accept two paradigm changes. First they have to replace their naive paradigm by the Newtonian one, and later to accept the paradigm of modern physics (quantum mechanics and relativity). However, the majority of students do not change their paradigm. Their resistance to paradigm changes explains the failure of physics teaching. The proposed solution is that children should be trained in naive physics [9] first. Some similarities of Aristotelian and layman reasoning are well-known. For instance, Shanon in 1976 found that many people reasoned, like Aristotle, that objects will fall at a constant velocity proportional to their mass [10]. We propose that Aristotelian physics is an archetype and, therefore, a good representation of naive physics.

But first of all, is Aristotelian physics a scientific paradigm in the sense of modern science? The answer is not simple. Generally accepted opinion is that Aristotelian physics is not a science of Nature. We cite Delbrück [11], who admired Aristotle as a biologist, but also he knew the opinion of the physicists. He wrote: "(Aristotle's) Physics was practically non-existent and also there was very little interest along that line. Nobody would deny that Aristotle's physics was pretty much a catastrophe, while his biology is abounds in aggressive speculative analysis." Delbrück later added: "I should like to suggest, furthermore, that the reason for the lack of appreciation among scientists for Aristotle's scheme lies in our having blinded for three hundred years by the Newtonian view of the world."

Differences of Aristotelian physics and Newtonian mechanics lead Kuhn to the discovery of paradigm changes. The most important differences are just those properties, which are also the differences between thermodynamics and mechanics.

Kuhn's way to the discovery of paradigms was summarized by Horgan: "In 1947 while reading Aristotle's Physics, Kuhn had become astonished at how 'wrong' it was. How could someone who wrote so brilliantly on so many topics be so misguided when it came to physics?" [12].

In one of his papers Kuhn wrote: "The question I hoped to answer was how much mechanics Aristotle had known, how much he had left for people such as Galileo and Newton to discover. Given that formulation, I rapidly discovered that Aristotle had known almost no mechanics at all (…) [T]hat conclusion was standard and it might in principle have been right. But I found it bothersome because, as I was reading him, Aristotle appeared not only ignorant of mechanics, but a dreadfully bad physical scientist as well. About motion, in particular, his writings seemed to me full of egregious errors, both of logic and of observation." [13].

Later he recognized that Aristotelian physics is not a wrong (premature) mechanics, but a different philosophy of nature, a different paradigm. Kuhn used the term paradigm to refer to a collection of procedures or ideas that instruct scientists, implicitly, what to believe and how to work. Most scientists never question the paradigm. "Different paradigms have no common standard for comparison; they are 'incommensurable', to use Kuhn's term. Proponents of different paradigms can argue forever without resolving their basic differences because they invest basic terms – motion, particle, space, and time – with different meanings. The conversion of scientists is thus both a subjective and political process. It may involve sudden, intuitive understanding – like that finally achieved by Kuhn as he pondered Aristotle. Yet scientists often adopt a paradigm simply because it is backed by others with strong reputations or by a majority of the community." [14].

If Aristotelian physics is a physical paradigm then it must be commensurable with a modern physical discipline, which is, on the other hand, incommensurable with Newtonian physics, or it must be an alternative approach to be rediscovered. In modern physics relativity theory, quantum mechanics, complex system theory are considered to be incommensurable with Newtonian physics, but the problems they discuss were not present in Aristotle's era. Nevertheless, there is an almost forgotten modern discipline which is also incommensurable with Newtonian physics – phenomenological thermodynamics.

Representation of Aristotelian physics as ancient thermodynamics was proposed already [15, 16]. In the next chapter, arguments will be listed that Aristotelian physics is a qualitative, ancient formulation of phenomenological thermodynamics, and so they establish the same paradigm. Thus, a science education starting with phenomenological thermodynamics does not demand a paradigm change; the learning process will be a cumulative process. Newton's laws will be introduced later, as very effective approximations of the real world processes. This type of introduction eliminates the learning of Newtonian physics as a paradigm, so there will be no paradigm change when quantum mechanics and relativity appears as they do not contradict to phenomenological thermodynamics.

ARISTOTELIAN PHYSICS AS ANCIENT PHENOMENOLOGICAL THERMODYNAMICS

In the paper "What Are Scientific Revolutions?" Kuhn listed the main differences between Aristotelian physics and Newtonian physics, which are as follows:

1. The role of locomotion is different. "The exclusive subject of mechanics for Galileo and Newton is one of a number of subcategories of motion for Aristotle. Others include growth (the transformation of an acorn to an oak), alterations of intensity (the heating of an iron bar), and a number of more general qualitative changes (the transition from sickness to health)."

2. The world is inherently complex in Aristotelian approach, while it is simple in the Newtonian one. "A second aspect of Aristotle's physics – harder to recognize and even more important – is the centrality of qualities to its conceptual structure. By that I do not mean simply that it aims to explain quality and change of quality, for other sorts of physics have done that. Rather I have in mind that Aristotelian physics inverts the ontological hierarchy of matter and quality that has been standard since the middle of the seventeenth century. In

Newtonian physics a body is constituted of particles of matter, and its qualities are a consequence of the way those particles are arranged, move, and interact. In Aristotle's physics, on the other hand, matter is very nearly dispensable. It is a neutral substrate, present wherever a body could be – which means wherever there's space or place. A particular body, a substance, exists in whatever place this neutral substrate, a sort of sponge, is sufficiently impregnated with qualities like heat, wetness, color, and so on to give it individual identity. Change occurs by changing qualities, not matter, by removing some qualities from some given matter and replacing them with others."

3. Time arrow: "Another aspect of Aristotle's physics – one that regularly seems ridiculous in isolation – begins to make sense as well. Most changes of quality, especially in the organic realm, are asymmetric, at least when left to themselves. An acorn naturally develops into an oak, not vice versa. A sick man often grows healthy by himself, but an external agent is needed, or believed to be needed, to make him sick. One set of qualities, one end point of change, represents a body's natural state, the one that it realizes voluntarily and thereafter rests. The same asymmetry should be [in Aristotle's thinking] characteristic of local motion, change of position, and indeed it is. [For Aristotle,] the quality that a stone or other heavy body strives to realize is position at the center of the universe; the natural position of fire is at the periphery. That is why stones fall toward the center until blocked by an obstacle and why fire flies to the heavens. They are realizing their natural properties just as the acorn does through its growth. Another initially strange part of Aristotelian doctrine begins to fall into place."

4. Horror vacui – Nature abhors vacuum. Interestingly, Aristotelian objection is more the refutation of the inertial system. "In a void a body could not be aware of the location of its natural place." Here we cite one of Aristotle's arguments against the vacuum: "The second reason is this: all movement is either compulsory or according to nature, and if there is compulsory movement there must also be natural (for compulsory movement is contrary to nature, and movement contrary to nature is posterior to that according to nature, so that if each of the natural bodies has not a natural movement, none of the other movements can exist); but how can there be natural movement if there is no difference throughout the void or the infinite? For in so far as it is infinite, there will be no up or down or middle, and in so far as it is a void, up differs no whit from down; for as there is no difference in what is nothing, there is none in the void (for the void seems to be a non-existent and a privation of being), but natural locomotion seems to be differentiated, so that the things that exist by nature must be differentiated. Either, then, nothing has a natural locomotion, or else there is no void" [17].

These comments illustrate the way in which Aristotelian physics describes the phenomenal world. Kuhn also emphasized the fact that elements of description lock together to form an integral whole, one that had to be broken and reformed on the road to Newtonian mechanics.

Kuhn's argumentation holds for Aristotle's Physics. However, nowadays Aristotelian physics is often interpreted through the medieval (scholastic) interpretation. Medieval scholars rejected Aristotle's interpretations on numerous issues, as it contradicted to theology. In the year 1210, the Condemnation was issued by the provincial synod of Sens, which stated: "Neither the books of Aristotle on natural philosophy nor their commentaries are to be read at Paris in public or secret, and this we forbid under penalty of excommunication." [18]. There was a forgotten paradigm change done by Saint Thomas Aquinas [19]. He made Aristotle consistent with the official doctrines of the Church. He changed many concepts, replacing them with his own views. A detalied description of the differences can be found in the lecture of Edward Grant on Natural Sciences [20].

Irreversibility appears in two levels in Aristotle's Physics. The natural movement is an irreversible process, as the natural position conceptually corresponds to the equilibrium state of thermodynamics. The natural movement is such a process, where the body tends to occupy its natural position, i.e. without external effects this process must not go from the final state to the initial state. The law of natural movement is the same as the Second Law of thermodynamics. In fact, Aristotle meets the problem of 'heat death' (in a closed world after infinite time equilibrium state develops). In a closed Aristotelian sublunar world everything would occupy its natural position, and no further movement would be possible. The Aristotelian solution for the 'heat death' problem is the 'unmoved mover', who moves the outermost sphere, while each sphere moves the next inner sphere. The heat produced by the friction of spheres is focused and transferred to the Earth through the Sun rays, continuously 'kicking out' the water from its natural position, leading to the formation of clouds. The weather then prevents the sublunar world from its final stopping [21]. Further discussion of 'heat death' in the framework of modern cosmology can be found in the paper of Kutrovácz [22].

The other appearance of irreversibility, closely related to the first, is in his dynamics. It is evident, that formally the Aristotelian dynamics is the same as that of thermodynamics. In both cases the change of the state characterizing quantities are proportional to the force.

Nevertheless, the analogy is deeper. The thermodynamic interpretation of the terms appearing in his dynamics leads to a more concise reconstruction, with the disappearance of lot of well-known paradoxes. Basic factor of the Aristotelian `physics' is the recognition of the contradiction of the eternal (reversible) processes in the lunar world, and the `irreversibility' of the sublunar world. Because of the irreversibility of natural motion the only possible interpretation of Aristotelian physics can be found in the framework of phenomenological thermodynamics.

In modern physics there are two distinct approaches to thermodynamics, namely the statistical and the phenomenological ones. In the statistical model the basic laws are derived from basic principles, and it can be discussed naturally in the Newtonian framework. It is a part of Newtonian paradigm.

Phenomenological thermodynamics on the other hand arrives to the fundamental laws of nature as the generalization of the experiences. In short, phenomenological thermodynamics is built on the First Law and the Second Law. The First Law in the restricted form states the conservation of energy, but in the generalized form it is for the conservation laws. The basic conservation laws are the conservation of mass, energy, momentum, and angular momentum. Sometimes, in the Newtonian paradigm, these are stated as principles of mechanics, implying that they are irrelevant to thermodynamics. As a matter of fact, traditionally momentum and angular momentum did not appear in thermodynamics, and instead of energy the internal energy was used. Nevertheless, they are already present in modern irreversible thermodynamics.

Major differences between phenomenological thermodynamics (PT) and the Newtonian paradigm are as follows:

1) In PT changes are not restricted to locomotion; they include all type of processes.
2) In PT systems are characterized by state variables and constitutive equations. The latter defines the dependent variables as functions of independent ones.
3) Dynamics is defined by the differences of intensive parameters (e.g. temperature, pressure).
4) Equilibrium is a distinguished state. Every isolated system, every natural process tends to the equilibrium state.
5) PT considers the systems as complex systems, and it is well aware of the fact that in thermodynamics only a model of the real system can be discussed.

The comparison of differences between Aristotelian and Newtonian paradigms, and on the other hand the thermodynamic and mechanic description, reveals the fact that differences are the same. Therefore, phenomenological thermodynamics and Aristotelian physics are akin, they are commensurable paradigms.

TEACHING IN THERMODYNAMIC FRAMEWORK

Piaget demonstrated that every child independently rediscovers a number of conservation laws analogous to but different from the more formal conservation laws that have played such an important role in physical science. There are many researches which demonstrate that conservation of the quantity, mass, number and area is already present in pre-school age. Also, the majority of children entering elementary school are able to distinguish between 'natural' and 'unnatural' processes. They can formulate the Second Law in the form: Heavy bodies do not rise spontaneously. The heat does not go from a cold body to a hot body. They are amazed with the operation of the refrigerator and ask for explanation. Nevertheless, the quantification of these naive concepts is missing.

Students in industrialized countries rarely have the opportunity to learn and practice measurements outside of school, so they lack the knowledge of the numerical values of the physical characteristics of the surrounding environment [23]. However, without data, physics simply remains an abstract applied mathematics.

Developing the instinct of estimating the values of measurable quantities in students is the first step to the science of physics. It is something that cannot be taught but only obtained through learning by doing. In the first part students measure the surrounding environment, in the second part they collect data about the characteristic sizes in the Universe. The aim is to achieve a skillful knowledge of the different scales of length, volume, time, velocity and weight.

Then, observing the regularities of impact can lead to the discovery of the conservation of momentum. It assumes the repetition of the measurements of Buridan, Huygens and Wallis.

Recently C. M. Graney published a paper on Buridan's work, in which he wrote [24]: "Buridan's story is a fun tale to tell to students. Moreover, Buridan's discussions are so insightful that they suggest innovative ways of presenting the concept of momentum to students who may resist the idea that 'an object in motion remains in motion'. Buridan was writing in a time before modern algebra had come into use. If his descriptions seem vivid, perhaps that is because in his day verbal description of ideas in physics was more common. Moreover, he is expressing ideas without the benefit of a training in Newtonian physics, something he shares in common with the introductory physics student!"

The next step is the introduction of mechanical exergy. Exergy defines the maximum amount of work that can be extracted from a physical system [25, 26]. While energy is conserved, exergy can be destroyed. The Second Law formulated by exergy is the principle of exergy dissipation. Mechanical exergy is the quantity which decreases in inelastic impacts. Collecting data on the exergy flows forms a sound basis for the problem of sustainable development.

Last part is the experimental exploration of the properties of heat and temperature, and the introduction of the conserved energy (the First Law). This way students will discover the energy concept, which was given by the Nobel Prize winning physicist Richard Feynman, who wrote [27]: "There is a fact, or if you wish a law, governing all natural phenomena that are known to date. There is no exception to this law – it is exact so far as is known. The law is called the conservation of energy. It says that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes. That is a most abstract idea because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same."

On this basis the problem of planetary motion will lead to Newton's laws. Absolute space, time, vacuum and point mass will be introduced as necessary axioms for the mathematical formalism of Newtonian physics.

CONCLUSIONS

Teaching of physics could be made more efficient by reducing the number of paradigm changes. This can be achieved by substituting the Newtonian approach by the Aristotelian approach when introducing physics. In that way students could go through a natural process of gaining more understanding about the world and establishing for themselves the rules, laws of physics, instead of just obeying the teacher and learning (often without understanding) the taught formulas. This change could lead to better understanding of physics in the population and to a better skilled upcoming generation of scientists.

ACKNOWLEDGMENTS

We should like to express our gratitude for the comments to É. Déli, V. Poór, K. Radnóti and B. Sas.

APPENDIX: ENERGY PROBLEM

Present physics curriculum does not apply exergy. That is a source of problems. "One hundred and sixty years after its advent energy has become an indispensable concept for describing and explaining our world scientifically. Therefore it is now ubiquitous in school science curricula worldwide and regarded as of first importance universally by scientists and educators alike. Nonetheless, energy is not well understood by our students. Students graduating from secondary schools generally cannot use energy to describe or explain even basic, everyday phenomena" [28].

Teaching the concept of energy is still unsolved [29-31]. The problem of the different connotations was already mentioned in 1914 by a Hungarian writer Ferenc Móra (1879 – 1934). Móra wrote a short article in a newspaper about Robert Mayer, with a good, sound explanation of the First Law of Thermodynamics. He described the grave conceptual problem as: "If I say that I do not believe in the conservation of energy then the Professors of Physics will say that I am asinine, as I am a layman. If I say that I do believe in the conservation of energy then the Reader of this Journal will say that I am asinine, as I am a scientist." In his article, Móra finally arrived to the point that he does not believe in the conservation of energy as his energy disappeared: "Where is that Robert Mayer who can tell me where my childhood's energy is?" [32].

The problem of understanding the concept of energy is not only a problem of schools. After the secondary school, the majority's education in natural sciences comes to an end.

There are at least six different energy concepts, used in different areas of sciences and human activity [33].

E1) colloquial "power and ability to be physically and mentally active"

E2) metaphysical energy

E3) the conserved energy of physics

E4) a capacity to perform work

E5) useful energy of ecology and economics

E6) pseudoscientific energy

The majority of non-natural scientists do not feel the energy concept, and the only understandable version for them is the E6).

REFERENCES

[1] IUPAP: *The Importance of Physics to Society*.
http://www.triumf.info/hosted/iupap/C12/IUPAP_AIMS.html,

[2] Azuma, T. and Nagao, K.: *An inquiry into the reproduction of physics-phobic children by physics-phobic teachers*.
preprint arXiv:0803.3167, 2008,

[3] Kim, E. and Pak, S.-J.: *Students do not overcome conceptual difficulties after solving 1000 traditional problems*.
American Journal of Physics **70**(7), 759-765, 2002,
http://dx.doi.org/10.1119/1.1484151,

[4] Radnóti, K. and Király, B.: *Physics knowledge of students entering to the university*. In Hugarian.
A Fizika Tanítása. MOZAIK Oktatási Stúdió, Szeged, 2011,

[5] Zirbel, E.L.: *Framework for Conceptual Change*.
The Astronomy Education Review **3**(1), 62-76, 2004,
http://dx.doi.org/10.3847/AER2004007,

[6] Disessa, A.A.: *Unlearning Aristotelian Physics: A Study of Knowledge-Based Learning*.
Cognitive Science **6**(1), 37-75, 1982,
http://dx.doi.org/10.1207/s15516709cog0601_2,

[7] Wieman, C.: *Transforming Physics Education*.
Physics Today **58**(11), 36-41, 2005,
http://dx.doi.org/10.1063/1.2155756,

[8] Vosniadou, S.: *On the Nature of Naive Physics*.
In Limón, M. and Mason, L., eds.: Reconsidering Conceptual Change: Issues in Theory and Practice. Springer, Dordrecht, pp. 61-76, 2002,
http://dx.doi.org/10.1007/0-306-47637-1_3,

[9] Smith, B. and Casati, R.: *Naive Physics: An Essay in Ontology*.
Philosophical Psychology **7**(2), 225-244, 1994,
http://dx.doi.org/10.1080/09515089408573121,

[10] Shanon, B.: *Aristotelianism, Newtonianism, and the physics of the layman*.
Perception **5**(2), 241-243, 1976,
http://dx.doi.org/10.1068/p050241,

[11] Delbrück, M.: *How Aristotle Discovered DNA*.
In Huang, K., ed.: Physics and Our World. A Symposium in Honor of Victor F. Weisskopf. American Institute of Physics, New York, pp. 123-130, 1976,

[12] Horgan, J.: *What Thomas Kuhn Really Thought about Scientific "Truth"*.
http://blogs.scientificamerican.com/cross-check/2012/05/23/what-thomas-kuhn-really-thought-about-scientific-truth,

[13] Kuhn, T.: *What Are Scientific Revolutions*?
In Kruger, L; Daston, L.J. and Heidelberger, M.: The Probabilistic Revolution. Volume I: Ideas in History. MIT Press, Cambridge, pp. 7-22, 1987,

[14] Horgan, J.: *Profile: Reluctant Revolutionary: Thomas S. Kuhn Unleashed 'Paradigm' on the World*.
Scientific American **264**(5) 40-49, 1991,
http://dx.doi.org/10.1038/scientificamerican0591-40,

[15] Martinás, K. and Ropolyi, L.: *On the Hidden Aristotelian Thermodynamics*.
Doxa **9**, 113-128, 1987,
[16] Martinás, K. and Ropolyi, L.: *Analogies: Aristotelian and Modern Physics*.
International Studies in the Philosophy of Science **2**(1), 1-9, 1987,
http://dx.doi.org/10.1080/02698598708573299,
[17] Aristotle: *Physics*. Book 4.
Translated by Hardie, R.P. and Gaye, R.K.,
http://classics.mit.edu/Aristotle/physics.4.iv.html,
[18] Grant, E.: *A Source Book in Medieval Science*.
Harvard University Press, Cambridge, 1974,
[19] McInerny, R. and O'Callaghan, J.: *Saint Thomas Aquinas*.
In Zalta, E.N., ed.: The Stanford Encyclopedia of Philosophy. Winter 2013 Edition.
http://plato.stanford.edu/entries/aquinas , accessed 30.03.2014,
[20] Grant, E.: *Natural Science Lessons*.
http://bartholomew.stanford.edu/naturaltext.html accessed 30.03.2014,
[21] Martinás, K.: *Aristotelian Thermodynamics*.
In Martinás, K.; Ropolyi, L.; Ropolyi, K. and Szegedi, P., eds.: Proceedings of the Conference on the History of Thermodynamics. World Scientific, Singapore, pp. 285-303, 1991,
[22] Kutrovátz, G.: *Why Is There Motion In Our World*?
Periodica Polytechnica Social and Management Sciences **10**(1), 151-161, 2002,
[23] Addington, S.; Dennis, D. and Jetter, M.: *Measurement and Multiplicative Thinking in Prospective Elementary Teachers*.
International Congress of Math Education, Monterrey, 2008,
[24] Graney, C.M.: *Mass, Speed, Direction:John Buridan's 14th century concept of momentum*.
The Physics Teacher **51**(7), 411-414, 2013,
http://dx.doi.org/10.1119/1.4820853,
[25] Rant, Z.: *Exergie, Ein neues Wort für "technische Arbeitsfähigkeit"*.
Forschung auf dem Gebiete des Ingenieurswesens **22**, 36-37, 1956,
[26] Ayres, R.U.; Ayres, L. and Martinás, K.: *Eco-thermodynamics: Exergy and Life cycle analysis*.
Energy **23**(5), 355-363, 1998,
http://dx.doi.org/10.1016/S0360-5442(97)00076-5,
[27] Feynman, R.; Leighton, R. and Sands, M.: *The Feynman Lectures on Physics*.
Addison-Wesley, p. 4-1, 1963,
[28] Swackhamer, G.: *Cognitive resources for understanding energy*.
http://modeling.asu.edu/modeling/CognitiveResourcesEnergy.pdf,
[29] Frankowicz, M.; Maciejowska, I.; Martinas, K.; Radnóti, K. and Rimai, A.: *Energy In School Textbooks: A Comparative Study*.
Gamtamokslinis Ugdymas **3**, 33-41, 2008,
[30] Kurnaza, M.A. and Arslaí, A.S.: *Effectiveness of Multiple Representations for Learning Energy Concepts: Case of Turkey*.
Procedia – Social and Behavioral Sciences **116**, 627-632, 2014,
[31] Kurnaza, M.A. and Arslaí, A.S.: *Praxeological analysis of the teaching conditions of the energy concept*.
Cypriot Journal of Educational Sciences **5**, 233-242, 2010,
[32] Móra, F.: *The conservation of energy*. In Hungarian.
Szegedi Napló, 1914,
[33] Martinas, K.: *Energy in Physics and in Economy*.
Interdisciplinary Description of Complex Systems **3**(2), 44-58, 2005,
http://indecs.eu/index.php?s=x&y=2005&p=44-58.

KURIKULUM NASTAVE FIZIKE ZA XXI. STOLJEĆE

K. Martinás and B. Tremmel

Sveučilište Eötvös Loránd
Budimpešta, Madžarska

SAŽETAK

U radu argumentiramo, sljedeći Kuhna, kako su fenomenološka termodinamika i Newtonova fizika nekomenzurabilne, dok su fenomenološka termodinmika, naivna fizika i Aristotelovska fizika komenzurabilne paradigme. Poučavanje temeljeno na fenomenološkoj termodinamici uklanja problem nekomenzurabilnosti.

Također, naznačen je kurikulum nastave fizike temeljen na fenomenološkoj termodinamici. U njemu se Newtonove jednadžbe uvode u kasnijoj fazi, kao model koji dobro opisuje svijet.

KLJUČNE RIJEČI

poučavanje fizike, paradigme, Aristotel, fenomenološka termodinamika, eksergija