ELTE TTK Doctoral School of Physics

Applying Complex Physical and Technological Inventions in Secondary School Physics Education

PhD thesis

Annamária Komáromi

Physics Education PhD Program

Thesis supervisor:

professor Imre Jánosi

Budapest, 2018.

Introduction

Interest in the engineering career and physics has been decreaseing by the beginning of the 21st century in Hungary and in other parts of the world, even though spectacular results in a number of areas of physics, for example material structure, particle physics, cosmology, or even space exploration arrive every day. A good deal of these, to a certain extent, reaches those not directly involved in science through the Internet. Therefore, it is not uncommon for a physics teacher or technical expert to be asked questions that are not at all simple to answer. So, in a sense, a duality has emerged in the last decade. Physics itself, as a teaching subject, is not very attractive to most students, on the other hand many adults frequently read current scientific developments on the Internet. It looks like there is curiosity about physics, or in the broad sense, about science by quite a few people. This doctoral dissertation does not intend to examine the possible reasons why physics is not popular among students sitting in the classroom, but one of the reasons may be that the textbook theory taught is not paired with sufficient amount of practical applications from everyday life. In my dissertation I present a tried and tested approach based on many years of experience to introduce technical developments, technical solutions based on scientific research into our teaching of nearly all elements of physics. Considering that space research has been of decisive importance in the twenty-first century, I would like to point out, more specifically through space engineering, that the dry textbook material can be brought to the students by means of practical examples, real technical solutions. Within space engineering my focus will be on satellites, because in recent years Hungary has made significant contribution to space exploration through the construction of the first Hungarian satellite Masat-1 and its successful mission, exceeding the planned three-month lifespan many times over. Secondary school students can be highly motivated by becoming familiar with some of the details of a spacecraft developed internally in Hungary, and what more, one that was designed and built mostly by university students. The deeper understanding of the working of the first Hungarian satellite is not only helpful in physics teaching but also brings students closer to high-technology tools and services that are becoming more and more commonplace in our daily environment, thus may make more students choose careers in engineering and sciences.

An important factor in my entire research was to come up with solutions that my colleagues in teaching can use in physics class not limited to the so-called elite secondary schools, but in classes of any high school in the country. Given the fact that previously I taught physics for a number of years in an art secondary school, the suggestions presented and tried for many years in the paper have been proven applicable in any high school. I am firmly convinced that time spent on some details of current technical achievements in space engineering is well worth it, since teaching physics with it as a whole will greatly benefit from it.

Objectives

My most important guideline is to utilize some complex physical and technical concepts in my thesis that are partly or almost entirely suitable for bringing the students closer to the laws of physics, students who will pass onto completely different fields in their life after finishing high school. Thus, I intend to present a new methodology of physics teaching by referring to, for example satellites, in every unit of the curriculum. I also wish to prove that the use of the complex physical systems I propose in teaching can foster students' grasp of the relationship between clarity of the laws of physics and the multitude of possible technical solutions, and that ultimately will lead to a reasonably correct view of our world based on theoretical and practical considerations.

THESES

Thesis 1

I demonstrate that appropriately chosen space-related complex physical and technical concepts can be used in the teaching of nearly all subjects of secondary school physics.

My publications related to the thesis: [1], [2], [3], [4]

The high school curriculum starts with mechanics. In my dissertation, I prove that space science and space technology references can be effectively applied in the field of high school kinematics and dynamics education.

- I demonstrate that teaching kinematics we can start to talk about satellites, discussing different types of orbits (geosynchronous, sun-synchronous). I show that it is a good idea to use appropriate sources from the Internet to examine orbits of some satellites. This way students will appreciate the relationship between theory and the real world. I demonstrate that the chapter on satellites of REALIKA digital collection of exercises - available for more than a decade for teachers and students - can be used effectively in the physics class to understand circular motion better.

- In the course of teaching gravity, I show that not only the work of Loránd Eötvös can be explained to students, but also the basic methods and results of modern space gravimetry can be taught at high school level physics. Consequently, by means of a modern spacecraft and measuring method, students will obtain a more illustrative picture of Earth's gravitational field and its examination.

- In my dissertation I show that teaching Kepler laws we can use relevant animation and visual material of space research on Internet sites to make class work more colourful. At the same time students inadvertently become familiarized with these web resources.

- With the example of the law of impulse conservation, I prove that it is possible to illustrate the law with specific space-related examples, even in practice. Therefore, we emphasize the universality of physical laws.

- When teaching Newton's laws, I show that it greatly helps learning if we look at the ESA video tutorial that demonstrates the validity of these laws both on Earth and on the International Space Station with the aid of students and astronauts.

- I prove that in the topic of "internal forces, external forces, conservative forces" it is also useful besides the traditional "earthly" references to mention "space" examples. When teaching density, I will show that we have opportunity to detect warning signs of an impending catastrophe by showing the satellite images of the Kolontár mud reservoir.

Up until now space research has not been mentioned in teaching of thermodynamics. I demonstrate that there is plenty of room for references of this kind:

- when discussing temperature, we can talk about temperature of satellites in space for a better understanding of the meaning of temperature;

- when discussing heat transfer methods, we can raise greater interest in the subject by discussing the heat effects of a near-Earth spacecraft (the role and history of development thermal shield is an excellent subject of research projects for students);

- we can point out the practical significance of the first law of thermodynamics, for example by having a class discussion on space junk problem.

I show that in the field of electricity it is expedient to teach about application in space research which is presently not covered in textbooks:

- When discussing the point effect, I can explain the phenomenon much more interestingly by mentioning and presenting ion propulsion.

- In the topic of semiconductors, I call attention to the opportunity of mentioning a specific Hungarian space industry success.

- I can explain the principle of the Seebeck effect through a practical example to show students the relationship between the power supply of spacecraft leaving the solar system and the Seebeck effect.

- In the field of magnetism, I present the elements of the complex physical and technical devices in space that can be included in our teaching at various levels (classroom, seminary): for example, in the field of electromagnetic waves, I will show that the ESA-developed Leoworks program enables our students to make colourful shots from "raw" shots.

In the field of nuclear physics, where anti-particles are now being discussed in almost all classes, I prove that the basic principle of the Pamela spacecraft can be understood with high school physics knowledge, so that we can tell students how this device senses anti-protons arriving to the atmosphere.

I show that it is advisable to apply space research aspects to the teaching of the general relativity theory. For example, we may refer to the science fiction film Space Odyssey 2001, in which artificial gravity is produced by a rotating space station.

Thesis 2

Only a few of the secondary school students have heard, regrettably, of the first, and the only independently designed and built Hungarian satellite, the Masat-1 and of its history. It is already a big thing if they know its name. Scanning the topics of physics, I show that in many fields in physics classes it is worth referring to this small satellite built by university students and professors who also controlled it while on orbit around the Earth.

My publications related to the thesis: [5], [6], [7]

I'm showing by the example of the 100mm cube-sized Masat-1 (or the 50mm cube-sized SMOG-1) how some simple computational examples, even at the level of primary school age group students, can be made on the satellite as a complex technical spacecraft.

In the course of teaching mechanics, I will show that on the basis of the secondary school curriculum, students can perform calculations to find the Masat-1 speeds at the various points of the orbit with the aid of Masat-1 orbit data. It is important for students to check their calculations with use of Internet to see if the various news portal reported values for the Masat-1 mission agree with their own results.

When teaching density, we can have the average density of the spacecraft calculated from Masat-1 data.

When teaching vibrations, I demonstrate that it is more interesting to present the material by showing the Masat-1 vibration test: here, resilience to extreme vibration is tested that the satellites (as payloads) will have to withstand during the VEGA spacecraft launch.

At the thermal expansion, I will show how to calculate the specific thermal expansion of the satellite using the technical data of Masat-1.

When teaching electrostatics, it is advisable to show the photograph of the Masat-1 control room during construction, which reveals that a Faraday cage was built. At the same time, I give illustrative explanation for the reasons for the Faraday cage. Teaching batteries, when the subject is Li-ion chemistry, I call the attention of students to the fact that the small satellite built by college students also had Li-ion batteries.

In the field of magnetism, I show that it is worth introducing interested students to the semi-active stabilization system built into the spacecraft consisting of a permanent magnet and two electromagnets.

When teaching electromagnetic waves, I draw attention to the diagram illustrating the Masat-1 communication system. It is useful to review it with students so that they see a practical example of a theory just learned. To make it more interesting, in class we talk about the OSCAR number marking radio amateur satellites that the first Hungarian satellite also received.

Thesis 3

I demonstrate how to incorporate into the teaching of physics one of the new concepts of the twenty-first century, space weather.

My publications related to the thesis: [8], [9]

First of all, I describe the concept of space weather. Space weather primarily means solar activity and its various effects that reach our planet. I demonstrate how to use the diagrams available on the Internet to analyse the diversity of entities impacted by space weather.

I show that in relation to space weather we can talk about solar physics, as one of the dynamically advancing areas of physics today. We can familiarize students with the various solar activities and the methods examining solar activities. I certify that here again we have the opportunity to motivate students, since quite a few Hungarian solar physicists work in this area and carry out research in research institutes in various parts of the world. I show that through a deeper teaching of the subject, we can create more intense "space awareness" in the students, which can stimulate interest in space research in them. I show that when discussing space weather observation, it is worth talking about the latest space weather observation spacecraft, and to familiarize students with the news sites where they can follow solar activity online themselves.

By way of examples, I prove that it is essential to use English-language websites in physics classes since when orienting to the technical field, we must also make students aware that the language of international scientific life is English. I show that it is worth talking about the Faraday Cup plasma sensor since by describing the operation of the device, we have the opportunity to assign a practical example to the concept of thermal velocity. The description of the DSCOVR satellite magnetometer is such a practical example. In the course of my doctoral activity, I analyse a lesser known adverse effect of unfavourable space weather; the corrosion of pipe networks. I mention the biological effects of space weather, which offers interesting research work to students with an interest in biology.

Thesis 4

With actual examples, I support that through the continuous familiarization of complex physical and technical objects, students can be motivated to more frequent participation in competitions.

My publications related to the thesis: [10]

I show that the Fizika Mindenkinek (Physics for Everyone) contest is great for students, who do not chose to participate in traditional, classical problem-solving competitions, to experience a sense of accomplishment in the field of physics. The nature of the competition places great emphasis on good choice of subject. Introducing some of the topics of my students successful in competitions, I demonstrate that the instructor plays a significant role in providing a suitable, well-processable topic for students, if necessary. These topics include: the presentation of Masat-1; introduction to the connection between NASA and origami; the similarities and differences between the operating principles of the Eötvös pendulum and the GOCE satellite; the physical background of the lie detector operation; the production of satellite imagery using the LEOWORKS program developed by ESA; Lagrange points and ideas of space researchers to utilize Lagrange points; expanding universe experimental demonstration; acoustic levitation, and synchronization of metronomes.

Thesis 5

I show that in order to assist our students in their development and to achieve successes with them, it is not essential that we ourselves be proficient in a new technical solution and its application.

My publication related to the thesis: [11]

Two years ago after I arrived to teach in my present school I took on leading the robotics study group without any previous training in robotics. The enthusiasm and results of students show that there is no need for the teacher to worry if students are more experienced in a subject. In the "Road to Science" competition, my students built a space excavator robot, and in the course of the design, they researched the subject of space mining. They became acquainted with the pitfalls of space exploration, participated BME Space Forum and Hungarian Astronautics Society events, thus gaining insight into current ideas specifically in the field of space mining and, in a broader sense, space research.

In recent years, the use of the ARDUINO microcontroller has become increasingly popular. In our school, several students use this tool. I demonstrate that there are students who need only guidance and opportunity to present, since they already gained the necessary level of expertise through own diligence, with the aid of the Internet. Through presenting the expansion of a page turning robot with a smart bookmark, I show how to combine the LEGO Mindstorms EV3 robot with ARDUINO. I show that an older student - who is already confident using microcontrollers - is able to steer younger ones towards physics by introducing new, modern tools. In the case of an acoustic levitator handmade by one of my students, I show an example of how useful ARDUINO can be in the successful solution to an IYPT (International Young Physicists' Tournament) problem.

Thesis 6

I demonstrate the "flipped classroom" methodology, which essentially means that the teacher does not give a lecture in the classroom so students study it further at home, instead following proper instructions, the students will process the subject independently ahead of the class, and then present what they researched in relation to that material in class. Within a specific theme, related to an experiment, the application of the "flipped classroom" method will be introduced.

My publication related to the thesis: [12]

I show that when applying "flipped classroom", the teacher has a mentor role in the classroom. Students discuss and synthesize the self-developed curricula in groups. I demonstrate that this approach fits closely with the PER (Physics Education Research) international program, where one of the main components - instead of the simple transfer of knowledge - is the preliminary research work of students. I show that another important element in the experiments based on PER is that students fill a pre-questionnaire before the discussion of the topic, and a post-questionnaire afterwards.

In the thesis, I present a PER application in an actual example. In the subject of heat conduction the experiment I present was set up in relation to the accident of the first US space station, Skylab. In the experiment, students examined the heat-insulating properties of the various materials. With the experiment, which was presented at the Science on Stage International Festival in 2017, I also show an example of how to design a physics experiment together with students. In this experiment, data evaluation criteria were also designed jointly with students, so they could have a taste of the researcher work.

Publications:

[1] A.Komáromi (2015): *Space Science in Thermodynamics*, In: Kovács, K. (ed.) Proceedings of H-Space 2015, 1st International Conference on Research, Technology and Education of Space, 13 Feb 2015, Budapest. MANT, Budapest, 2015, pp 47-48.

[2] Komáromi Annamária (2015): *Űrtan a hőtanban,* ***Űrtan Évkönyv 2014*** (Frey Sándor ed.), MANT, Budapest, 2015, pp 76-85 (MANT = Magyar Asztronautikai Társaság). http://www.mant.hu/kiadvanyok/urtan_evkonyv_2014.pdf

[3] A.Komáromi (2016): *Space Science in Thermodynamics,* In: Proceedings of International Conference GIREP EPEC 2015 July 6-10, Wrocław, 2016 Poland, pp 207-211 (ISBN: 978-83-913497-1-7). http://girep2015.ifd.uni.wroc.pl/files/GIREP_EPEC_2015_Proceedings.pdf

[4] Komáromi Annamária (2017): *Űrkutatással a szerethetőbb fizikáért,* ***FIZIKAI SZEMLE*** (LXVII. évf.) 2017/1 (745.) szám, pp 27-31. http://fizikaiszemle.hu/szemle/tartalom/23

[5] Komáromi Annamária (2017): *Öt éve állították pályára a Masat-1-et,* ***FIZIKAI SZEMLE*** (LXVII. évf.) 2017/9 (753.) szám, pp 324-327. http://fizikaiszemle.hu/szemle/30

[6] A.Komáromi (2016): *With space research for more lovable physics classes*, In: A. Király, T. Tél (eds.): Teaching Physics Innovatively – New Learning Environments and Methods in Physics Education, „e-book", Graduate School for Physics, Faculty of Science, Eötvös Loránd University, Budapest, 2016, ISBN 978-963-284-815-0, pp. 157-162. http://parrise.elte.hu/tpi-15/papers/Proceedings_of_TPI_15.pdf

[7] A.Komáromi (2016): *Rendere piu piacevole lo studio della fisica con la ricerca nello spazio,* ***LA FISICA NELLA SCUOLA*** Anno XLIX (2016) Supplemento n.2, pp 13-16 (ISSN: 1120-6527) (as a Proceedings of 54° Congresso Nazionale A.I.F. Associazione per l'insegnamento della Fisica, 21-24 Oct 2015, Trento, Italy).

[8] A.Komáromi (2017): *About Space Weather in High School*, In: Bacsárdi, L., Kovács, K. (ed.) Proceedings of H-Space 2017, 3rd International Conference on Research, Technology and Education of Space, 9-10 Feb 2017, Budapest. MANT, Budapest, 2017, pp 59-60 (ISBN 978-963-7367-12-0).

[9] Komáromi Annamária (2017): *Időjárás és annak előrejelzése a Földön kívül,* In: Bacsárdi L, Kovács K (szerk.) Selected papers of the 3rd International Conference on Research, Technology and Education of Space (H-SPACE2017). Konferencia helye, ideje: Budapest, Magyarország, 2017.02.09-2017.02.10. Budapest: Magyar Asztronautikai Társaság, 2017. pp. 16-19. (ISBN 9789637367168)

[10] Komáromi Annamária (2016): *Űrkutatásról a multimédia segítségével,* In: XXII. „Multimédia az Oktatásban" nemzetközi konferencia, Keszthely, 2016. június 3-4. Konferenciakiadvány, Balatoni Múzeum, Keszthely 2016, pp. 5-8. ISBN 978-615-80204-3-5 *http://www.mmo.njszt.hu/Kiadvanyok/2016/MMO2016_Proceedings.pdf*

[11] Komáromi Annamária és Nagy Dániel (2018) *Akusztikus lebegtetés és más kísérletek Arduino felhasználásával, avagy ne féljünk attól, ha a tanár tanul a diáktól,* ***FIZIKAI SZEMLE*** (LXVIII. évf.) 2018/10 (766.) szám, pp 356-360.

[12] A.Komáromi (2018): *Space mishap as a stimulus context for thermal conduction exploration in secondary school,* (megjelenésre váró elfogadott, lektorált cikk) In: e-Proceedings of International Conference GIREP-ICPE- EPEC 2017 July 3-7, Dublin, Ireland.

Hungarian language publication published during the PhD course, not expressly based on the theses:

[13] Komáromi Annamária (2015): *Kézzel fogható részecskék nem csak a részecskefizika oktatásához,* ***FIZIKAI SZEMLE*** (LXV. évf.) 2015/12, pp 425-432 http://fizikaiszemle.hu/archivum/fsz1512/FizSzem-201512.pdf

Italian language publication published during the PhD course, not expressly based on the theses:

[14] Komáromi, Annamária (2016): *Particelle - per essere toccate con le mani e non soltanto per l'insegnamento della fisica delle particelle elementari,* ***LA FISICA NELLA SCUOLA*** Anno XLIX (2016) Supplemento n.2, pp 129-133. (as a Proceedings of 54° Congresso Nazionale A.I.F. Associazione per l'insegnamento della Fisica, 21-24 Oct 2015, Trento, Italy)

Conference presentations:

Komáromi, Annamária (2015): *Űrtan a hőtanban (Space Science in Thermodynamics),* H-Space 2015, 1st International Conference on Research, Technology and Education of Space, 13 February 2015, BME, Budapest, Hungary.

Komáromi, Annamária (2015): *With space research for more lovable physics classes,*International Conference on Teaching Physics Innovatively – New Learning Environments and Methods in Physics Education (TPI-15), 17-19 Aug 2015, ELTE, Budapest, Hungary.

Komáromi, Annamária (2015): *Rendere piu piacevole lo studio della fisica con la ricerca nello spazio,* 54° Congresso Nazionale A.I.F Associazione per l'insegnamento della Fisica, 21-24 Oct 2015, Trento, Italy

Komáromi Annamária (2016): *Űrkutatásról a multimédia segítségével,* 22nd Multimedia in Education Conference – 22. Multimédia az oktatásban konferencia, 3-4 Jun 2016, Keszthely, Hungary.

Komáromi, Annamária (2016): *Lo Space Weather nel Liceo,* 55° Congresso Nazionale A.I.F. Associazione per l'insegnamento della Fisica, 12-15 Oct 2016, Gran Sasso, Italy

Komáromi Annamária (2017): *Űridőjárásról a középiskolában,* H-Space 2017 3st International Conference on Research, Technology and Education of Space, 9-10 February 2017, BME, Budapest, Hungary.

Komáromi Annamária (2017): *Space mishap as a stimulus context for thermal conduction exploration in secondary school*, International Conference GIREP ICPE EPEC 2017, 3-7 July 2017, Dublin, Ireland. http://www.girep2017.org/ehome/girep2017/568547/

Komáromi Annamária (2018): *L'utilizzo di Arduino e di LEGO MINDSTORM EV3 nel liceo* 57º Congresso Nazionale A.I.F. Associazione per l'insegnamento della Fisica, 24-27 Oct 2018, Giardini Naxos, Italy

Conference posters:

Komáromi, Annamária (2015): *Space Science in Thermodynamics,* International Conference GIREP EPEC 2015, 6-10 July 2015, Wroclaw, Poland

Komáromi, Annamária (2015): *Particelle - per essere toccate con le mani e non soltanto per l'insegnamento della fisica delle particelle elementari,* 54º Congresso Nazionale A.I.F. Associazione per l'insegnamento della Fisica, 21-24 Oct 2015, Trento, Italy

Komáromi, Annamária (2016): *La ripetizione di un esperimento spaziale nel liceo,* 55º Congresso Nazionale A.I.F. Associazione per l'insegnamento della Fisica, 12-15 Oct 2016, Gran Sasso, Italy