THESES OF DISSERTATION

MODELS IN PHYSICS EDUCATION

Mihály Hőmöstrei

Supervisor: Dr. Zoltán Rácz

ELTE-TTK.

Physics Education PhD Program
Head of the Program: Dr. Tamás Tél

2017.
THESES

1. High school application of dimensional analysis

Basic level application of dimensional analysis

I was investigating simple phenomena – such as height of free fall, period of mathematical pendulum, maximum of distance horizontal throw – using dimensional analysis in average high school classes. Using dimensional analysis on the level of the knowledge of high school students I was able to reach a deeper understanding of the students in the investigated topics. Combining dimensional analysis with controlling measurements my students were able to get a view into some physical cognition process.

The purpose of the dimensional analysis is to discover and find the correlation between many quantities that determines a given physical phenomenon. The requirement for the connection created for describing the underlying phenomenon is that it must be correct for the dimensions as well. In my research, I demonstrate that the advantage of having a proper high school application of the dimension analysis is that it is easy to implement the search for multiple variables. In my work, I applied dimension analysis to simple tasks, so the benefit was primarily that students could use the applied correlations as personal discoveries. In my experience, thanks to their own control measurements, the formulas and correlations obtained during the calculations were more firmly fixed and the dimension analysis was already voluntarily and effectively used by students to examine other phenomena.

Higher level application of dimensional analysis

Using dimensional analysis in the high school we were able to get a deeper understanding in topics – such as thermal radiation – which are because of the lacking mathematical knowledge too complicated to teach in average high school using other methods. Besides bearing in mind the gradual principle I was capable to create a teaching-learning-process which is useful for the students using higher level dimensional analysis in their further – university – studies.
If, through simpler phenomena, the method of dimension analysis has been introduced and understood, the scope of the phenomena that can be investigated significantly widened. According to my experience, the phenomena presented in the thesis – Kepler’s III law, thermal radiation – are suitable for more talented and more interested students, to significantly enlarge their image of physics. In the case of specialized or faculty groups, using the method of dimensional analysis, these topics can be well integrated into high school curricula. Thanks to my enthusiastic students, we are dealing with a number of biological phenomena with the help of our newly acquired dimensional analysis, which clearly showed the wide range of applicability of the dimensional analysis.
Publication related to this thesis: [1]

2. From dimensional analysis to similarity modeling

I show by using similarity modelling in practice that this method is an appropriate experimental technique to verify the theoretical results of the dimensional analysis. My investigations did show that my teaching-learning-process – based on similarity modelling – gives a full structure to improve the theoretical and experimental knowledge of the students.

The similarity modeling presented in my dissertation was a high schooling of an engineering task: selecting a suitable material for a mast for a prototype of a ship. An important part of the task was to make the selection at the lowest possible cost. For this, it is useful to design a small, similarity model. In my dissertation, I will show that similarity modeling, based on a comparison of dimensionless volumes, further increases the scope of dimensional analysis in secondary school and enhances students' abstraction skills. Through similarity modeling, a better understanding of geometrical and especially dynamic similarity helps my students to follow the non-dimensional numbers of hydrostatic and fluid dynamics – e.g.: Reynolds number. Using the method I examined, my students were able to develop the need for verifiability and actual control of theoretical considerations. The similarity modeling with dimensional analysis and the experimentally control helped me and my own students to personally experience a specific scientific cognition process.
Publication related to this thesis: [2]
3. Classical physics modelling for black-body radiation

To understand an important difference between classical and modern physics it is very useful to know the deduction of black-body radiation from Boltzmann. Boltzmann’s direct calculation has to be a bit simplified to use them in the high school. I show that with some necessary simplifications I used Boltzmann’s thread to offer a deeper understanding in black-body radiation for high school students. Using the appropriate level of high school mathematics – such as simple differential and integral calculations – I was able to give for my students a wide spectrum of physics – e.g.: electromagnetism, entropy – to consider. These considerations led my students to a better view of the limits of the classical physics.

Examination of black body radiation is an interesting topic only for students with the right interest and pre-qualification. Therefore, we only examined the Stefan-Boltzmann law and the detailed description of Boltzmann in study group. In addition to the knowledge of the black body radiation, the other result of my teaching-learning process was beside the new knowledge; my students had the opportunity to take part in a repetitive work process that includes a multiplicity of phenomena. This repetition workflow not only helped to prepare for maturity, but also put new insights into the phenomena studied to help students develop a wider physical vision.

Publication related to this thesis: [3]

4. Gradually refined models to get to know the Earth's greenhouse effect

Drawing on the interest in climatic questions that are increasingly influencing our everyday lives, I have developed a methodology in which a gradual, multifaceted atmospheric model allows students to understand the fundamental energetic contexts of the atmosphere. Meanwhile they are also learning about the gradual development of a physical model.

Climate change on Earth provides an actual theme for the scientists’ at the beginning of the XXI. Century. It seems to be a good idea to make this subject and the related interest into a helping hand of the physical cognition process. My examinations were conducted in Georg-Cantor-Gymnasium, located in Germany, under the astronomy lessons of the 10th grade students there. The astronomy lessons there primarily provide astronomical observation-oriented knowledge to students. Therefore, within the astronomy lessons, it seemed useful to examine a phenomenon -
the Earth's climatic energy balance - from which knowledge can be useful when examining other planets. My research shows that by using the knowledge of the students, we can get a better knowledge about the basics of the physical system of the atmosphere in a simple way by creating appropriate and continuously refining atmospheric models based on the balance of the energy balance.

Publication related to this thesis: [4]

5. Concrete educational application of open-ended tasks

Use of an open-ended task to better understand some thermal concepts

I demonstrate that by studying the temperature changes during the flexible deformation of different types of rubber bodies, I have managed to further develop and apply the measurement method and the measurement method for better understanding of various thermal processes. Using this method, we can improve the image that is often misunderstood for students, so that thermal phenomena or concepts – e.g.: entropy – can only be used to describe the behavior of ideal gases

Due to its complexity and the abstract quantities of the thermodynamics, in the normal education, of course, the most appropriate model with which thermodynamics can be effectively taught is the ideal gas model. However, in my experience, the validity of thermodynamics is often limited to the phenomenon of ideal gases even for the most talented students too. One of the problems set for 2014 in the International Young Physicists’ Tournament (IYPT) gave me a good opportunity for my research to avoid this narrowing down in student thinking. The task was to investigate the temperature of an inflated and then rapidly lowered balloon. By examining this phenomenon and my experience with my deeper understanding of my students, I can say that the student's image of the thermodynamics can be easily improved and expanded through a simple rubber band. The specialty of this teaching-learning process I performed in this case was the steps of the process formed together with my student. Appropriate modeling has, of course, played an important role in this case as well, and important, but not tangible, difficult-to-measure quantities – e.g.: entropy – was also a great help. By choosing the right model, students of high school can also understandably and correctly describe the direction of thermal processes associated with entropy
and estimate the magnitude of stretching and contraction of the rubber band. Our theoretical results were verified by specific measurements.

**Computer modeling to discuss holograms at high school**

A special kind of Benton's rainbow holograms called scratched hologram. I show that this easy-to-produce hologram type can be helpful and interesting in the teaching of optical phenomena even in physics lessons. I worked with two of my students on a method based on computerized design and implementation of scratched holograms. My students could actively, through creative work, know the holograms' operating principle, model them with computers, and create their own holograms. In my experience, the curiosity and novelty of the holograms increase student motivation. With scratched holograms, interested students can easily immerse into the physics of holograms and acquire new or deepen previously acquired optical and geometric optical knowledge - even beyond the curriculum.

The problem of 2014 IYPT called “Scratched holograms” meant to create holograms on a plastic sheet with scratches. The problem showed how interesting the holograms could be. It is very useful and interesting to learn about the theory of holograms if students can make their own themselves: the so called scratched holograms. Since making these holograms is time-consuming, it is advisable to plan ahead more complex holograms using a computer, more precisely the GeoGebra program. During our work, only the real holograms were made after the proper computer model was made. Based on our work, I claim that the production of scratched holograms is suitable for the teaching of the physics of holograms in high schools and the development of students' ability to model physical phenomena with a computer.

Publications related to this thesis: [5], [6], [8].

6. Open-ended problems in talent management and everyday physical education

Successful work or learning requires interest, persistence and diligence, and is not merely a talent. I am convinced that in physics education not only with exceptional talented students can be beautiful achievements achieved, but also on a broader spectrum of students. I will show that the study of open-ended problems – the physical exercise based on their
examination, and the simpler open-ended problems within the school framework – is a productive educational medium and a strong motivation not only for the most talented, but for all the diligent students interested in physics.

One of the answers to the challenges of presenting physics education may be that we do not give up the goal of teaching physics, and we place great emphasis on developing a motivating learning environment and developing the skills needed to learn. My experiences show that it is an excellent way to motivate learning and to develop useful skills for learning - for example, examining the open-ended tasks of the IYPT and participating in preparation. Hungary has been participating in this competition since 1989, as several colleagues for several decades from the Department of Materials Physics have recognized the benefit and the innovative power of physics education based on open-ended tasks. The essence of the preparation program developed with my colleagues since 2013, using the circumstances and results created by the colleagues working in front of us so, that adapting to the challenges of the 20th century, students should be able to solve individually or working in teams physical problems as much as possible. As a result of our work, our students have been able to learn outside of the school, to discover and test new knowledge and to synthesize their existing knowledge.

Solving open-ended problems is useful not just for the competition, but also for physical cognition process within a classroom framework. During the competition preparation or school work, the physics teacher has a new role as a teacher, as during the research not only the teaching material that he already has to teach. Exiting and different from the classical teaching role, while studying open-ended tasks, physics teachers can also learn a lot about the phenomena studied. Physics teachers will find new results often with their student - whether it's competitive preparation or even baseline work. In my experience, I can say that students are not only accustomed to physical knowledge, but developed their observation and measurement skills and learned how to create, analyze, and evaluate appropriate, often self-based, models. In addition to the development of important skills and abilities, the ability to talk and lecture greatly improved by the work we have done. Competition and classroom problems naturally require varying quality and quantity of work from students and teachers, but in both cases the key to success is the opened, cooperative and physically enthusiastic attitude.

Publication related to the thesis: [5], [7].