PhD Theses

THE “NEGLECTED” PARTS OF PHYSICS IN EDUCATION, TALENT CARE IN THE SECONDARY SCHOOL

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INTRODUCTION

In today's fast-paced world and in a constantly deteriorating educational system, with special emphasis on the education of Physics, I regard motivating students as well as talent care with up-to-date methods in a creative way crucially important. This is the attitude that I try to employ in my work as a Physics teacher. I consider my situation most fortune thanks to having taught in a talent-oriented secondary school named Berzsenyi Daniel Secondary school in Budapest for 13 years after graduating from the university as a teacher of mathematics and physics in 2009. Based on the local curriculum students can study in classes specializing in 4 different areas: Maths, Science (half of the class studies biology and chemistry, the other half does physics), Humanities and Languages. In contrast with the Maths classes, where students learn for 6 years, all the other classes start their secondary school studies after the 8th grade, having left 4 years of preparation for the school-leaving exams. Consequently, as a teacher I am subjected to the most diverse student community, which means a wide range of diverse interests and goals regarding students' physics studies. My PhD research paper focuses on my physics, maths and biology-chemistry groups, which serve as a specifically adequate field concerning talent care in teaching physics.

My theses are to be viewed as a "colorful bouquet" presenting the longer process of several school projects, their results as well as their manifold feasible long-term productivity. The "colorful bouquet" means a collection of research themes, which appear to be versatile in terms of methodology, thematics or the age groups they are meant for. Each of the projects were done in collaboration with my students.

I am under the impression that some explanation is necessary as to what regards the word *neglected* used in the title of my research paper. The word itself refers to the choice of the theses-themes. The projects were based on different themes, however, what is common about them is their focus on a theme that is to be left out in the framework of lessons given by the national curriculum due to their eccentric nature (uncharacteristic of traditional everyday physics lessons), as a consequence of the content and/or method they require to be dealt with. Or owing to their difficulty, complexity or the length of time these themes need. In addition, all these projects contain some unique professional or methodological novelty, which can help students prepare whether for everyday life, or for their higher education studies, not to mention situations and tasks arising in their further work.

For us teachers it means a constantly arising challenge and at the same time possibility of development to keep up with as well as provide students with the most up-to-date knowledge, which they also consider interesting. Not to mention the brand new research methods and approaches that might make it possible for us to motivate the next generation of students. The current reality and situation of education make it almost impossible to devote any time and energy to this crucially important aspect of our work. Still, I am showing that it proves to be useful to take a sideways track away from the official mandatory thematics and to acquire methods that give long-term applicability and help gain deeper understanding. I am demonstrating the possibilities through a few examples. It seems that this kind of project-based work forms focusing on unfamiliar territories in the secondary school context come with numerous diverse benefits for students.

The majority of the chosen themes is connected to the project work of the physics camp having been organized annually by my school since 2011, or to those that I did as part of my PhD course exam, not to mention those that I did as a result of my personal interest.

The final chapter of my research paper is devoted to the aforementioned physics camp organized in collaboration with all my colleagues in the physics department of Berzsenyi. I am elaborating on the programs, characteristic features, the process and method of organization as well as all the important circumstances meant. I am giving a short summary of the camp with special emphasis on and highlighting my own developments in the past years in the framework of a possible pedagogical project plan.

THESES

1. Pendulum wave - the common project of different age groups

I have demonstrated that acquainting students with the phenomenon of the pendulum wave is a useful tool to teach mechanical oscillation and waves in a more colorful way whichever specialization class is meant. With the intensified effect of the impressive spectacle its in-depth studying in the aforementioned classes also serves the purpose of deepening students' mathematical background knowledge. Furthermore, putting together the device specifically made for its demonstration as well as the simulation enriches and motivates them to acquire handcraft skills in addition to deepening their relevant IT knowledge, which also helps them learn and practice cooperation with students of different ages.

The pendulum wave is a pendulum line made up of an arbitrary number of pendulums, in which the length of the pendulums is determined by the appropriate mathematical relation, and the pendulums can form special formations. The most important question is in what way they are to be arranged. I.e. How long should the strings be so that being displaced at the same time the pendulums make 'nice' formations?

I have pointed out that studying this phenomenon in the framework of project work well complements and deepens students' knowledge of the theme of harmonic oscillation including the theme of pendulum oscillation (properly and in a wider sense, period, string length frequency), its characteristic features provided by mathematical approximation as well as the less obvious logical background of the formation of this spectacular movement. This phenomenon can be applied concerning both its physics-concerned and mathematical implications, not to mention the IT background of the ready-made software, which provided both the user and the observer with applicable knowledge as far as solving follow-up exercises and their presentation are concerned.

The oldest age groups met the younger and youngest ones in our school to work together, via which they could develop each other while cooperating, including me as well. Further to a discussion clarifying the surprising for everybody physics and mathematical background, which proved to be less complicated for older students and almost incomprehensible for the younger ones, the 8th-graders from the maths specialization class made the device. It was followed by the 12th-graders (from maths specialization class) working on the computer-based simulation supporting and making more precise research possible. During the regular consultations the students came up with several ideas of their own overwriting the original plan to a considerable extent, thus very much enriching the project work. Among many other things we could gain an insight into several far-fetched extreme phenomena outside the realm of the validity of mathematical approximation. This way we made it possible for other specialization classes to recognize and see with their own eyes the essence and limitations of physics and mathematical approximation without doing any overcomplicated calculations.

Publications related to the thesis: [1], [2]

2. *The spread of infection in orchards - a so far unfamiliar, novel field in the education of physics*

Modelling the spread of an infection in the orchard was inspired by the project task based on the lecture series titled '*Cooperative Phenomena And Interdisciplinary Characteristics'* included in the program *Néda Zoltán's Teaching Physics*. The theme proved to be

adequate to demonstrate a field of physics rarely studied in secondary school context, i.e. statistical physics as well as a novel approach, which, out of the ordinary, makes it hard to produce mathematical proofs giving precise satisfactory solutions. Therefore I resorted to computer use with the help of my IT-savvy students. I have shown in what way it is possible to support the teaching of high-level complex and hardly comprehensible phenomena in non-science-specialization classes by means of a 'simple' computer-based model, which makes understanding and interpretation more accessible and effective.

A short summary of the task: There are evenly positioned fruit trees with arbitrary density in an orchard. An infection breaks out. In the beginning trees get infected with some probability. If a tree gets infected, then the infection might spread to other trees in a random fashion, the probability value of which, in the simplest case, shows linear decrease with the increase of distance from the given tree. In theory, each single infected tree might recover with some probability in a given time period, thus becoming immune to the infection. Provided an infected tree does not recover in the given time, unfortunately it leads to the death of the tree, meaning it will never grow fruit again. The subject material of our research is the spread of the infection dependent on certain parameters. The question is the following: How many trees should be planted in a given area in order to prevent an infection from spreading too fast in the orchard?

Studying this problem makes it possible to demonstrate the surprising and eccentric features of statistical physics, which is a far cry from classical mechanics students are used to in their high school studies. The exercise in its original KöMaL version is not too detailed. Consequently, it already meant a huge challenge for my team of students to come up with an adequate and precise description, which also meant the solvability of the exercise. Taking several aspects into account, we rewrote the exercise to a huge extent by adding several new parameters, like the so called *order parameter*, which is used to describe the rate of the infection spread. This way it helped acquaint students with a new concept, which is left out of there high school studies.

The demonstration of the model proves to be useful when revising phase transition, behavior at the critical point and when discussing its order parameter. At the same time one of its greatest merits lies in its potential to speak about several similar surprising and exciting phenomena like the spread of rumors, herd procession, the synchronization of scintillation of East-Asian fire beetles, the formation of stormy applause, how nerve cells work, modeling chemical reactions, the research of social systems (e.g. panic situations), earthquakes, financial situations and so on. I firmly believe that bringing up these phenomena in the lesson, depending on the depth and level they are dealt with, makes any student interested in physics. These areas are still not considered everyday ones in teaching physics, however, due to their nature bordering on the extreme they offer the possibility of recognizing how much different scientific disciplines are interlinked, which, in turn, might help students form a new way of thinking about and approach towards physics with wider horizons.

The project started as joint work based on two math specialization 12th-graders' expert IT knowledge, which later developed into and finished with an equal collegial professional relationship years later. After consulting IT teachers, we developed a programming model for the level of talented high-schoolers in order to support the research of this problem. Every single detail of the necessary Monte Carlo type computer simulation was written by my students, which in the end turned out to exceed the expected requirements regarding both appearance and technology. In addition to the spectacular simulation, which could also be run by changing the parameters in the most diverse spectrum, the students also produced an assessment program. The not in the least easy description of the exercise, the challenge of the IT background as well as the beauty of the model lie in the fact that thanks to the program it turned out that the order parameter produces some transition similar to the phase transitions included in the theme of magnetic substances, which is part of the curriculum in the specialization classes. We can also account for a few interesting sums with analytical calculations. Elaborating on these themes is part of talent care education. Furthermore, the newly acquired IT knowledge thanks to the programming part of the project proved to be useful in other areas later on.

Publications related to the thesis: [3]

3. Building a windtube - with high school students

I have shown that designing and building a windtube in collaboration with students (even if it means our free time and summer holidays) proves to be successful as a tool of demonstrating essential phenomena of aerodynamics, which has been unjustifiably left out from the curriculum as a final exam requirement in the past few years, and as such may become an important tool of teaching physics. Not only is it useful as an experiment tool, but it also comes with benefits regarding the planning phase of the project.

We designed the windtube with all kinds of equipment in order to study different flow phenomena: the straws providing laminar flow are connected to a smoke generating device by means of copper tubes. There is a built-in line of led bulbs for better lighting as well as a wind speedometer. The windtube can be applied when studying the flow image (aerodynamics and turbulence) generated by the flow medium around the fixed objects in the flow field, also, when getting the wing profile laser-cut from polystyrene lifted (in a vertical motion direction by means of knitting pins under the influence of buoyant force), when measuring formal factor, when lifting the the roof of a model house generated by the flow medium (based on the Bernoulli-law), and when studying the drag resistant to the wind impacting the matchbox car attached by a spiral and so on.

I have shown that one is capable of producing extraordinary experiment devices in a cost-saving way. Besides, in the meantime talented and creative students acquire countless knowledge and skills like planning, cooperation, precise cutting technique, welding, painting, creative technological solutions, taking financial means into consideration and so on. It has been proved several times that this project work, our private summer endeavor created the basis for preparation for similarly high-level (even international) competitions requiring similarly advanced-level qualities on the part of the students. This way all this project proves its relevance and usefulness in education.

4. Bridge-physics models - accessibility in secondary education

I am demonstrating that the secrets of bridge-building, regarded by university teachers and practical constructors as a diverse, complex and complicated field, can be studied via simpler models (focusing on one or two particular examples, highlighting important parts without in-depth detailed elaboration) in the framework of a study circle. My aim was to produce both qualitative and quantitative results.

Based on the background theoretical research data, we studied the construction of lattice bridges on a deeper level by means of theoretical methods, which means studying the force impact generated in certain elements of the bridge during the process of self-weight loading. The magnitude order and symmetry of the generated impact forces show interesting results. Basically, the acquisition of the method is arbitrary and similar, yet it can be utilized in the theme of differently designed bridge constructions or other themes of building construction.

Next, based on an article published in the English language magazine named Quantum, regarding the architectural wonders, the so called hanging bridges hanging in the air held by almost invisible forces, we defined what curve the upper ends of the thin metal straps holding the bridge in even distances should adjust to, if we would like each single strap of the unloaded (by cars or pedestrians) bridge to be loaded to the exact same extent by the weight of the bridge of its own. In addition to the mathematical calculations published in the article, we could account for the given results with experiments by means of Arduino-controlled generator cells built in a simple bridge model.

Furthermore, we also used a different generator cell, though, very similar to the previous one, to study the loading of a bridge made up of simple homogenous planks supported at its two ends by means of Lego robot cars of different masses moving with different speeds. First, we theoretically defined the forces generated at the supported ends dependent on time, which then we accounted for by measuring them. The software program used for graph illustration and function matching was written by one of the participant students out of curiosity.

The studied themes also make it possible to demonstrate the useful practical applicability of balance, vector resolution/summing of forces, torque, graph illustration, mathematical skills (series, complicated functions, analysis).

5. *The Bermuda Triangle of piano tuning - or why do we not teach tuning in high schools on a deeper level?*

The answer is very simple: Because it can be extremely complicated!

It was a huge challenge to find the part and depth of acoustics that was presumably comprehensible and digestible in secondary school context as well. Finally I managed to have my students get a grasp of its essence by focusing on relevant details, which appeared to be still digestible even for classes interested in music in the framework of non-specialization curriculum. All this was supported by project work, which turned out to be highly integral and detailed enough. We dug into the physics of the discipline of tuning. I am showing the possible relevance of a historical overview based on basic concepts of physics, what reasons (physics-based or other) lie behind past and current tuning techniques, elaborating on their advantages/disadvantage and difficulties.

The expression “Bermuda Triangle” is perfect to express that the pillars of tuning (the vertices of the triangle) are determined by clarity (equal temperament) and inharmonicity, whose beauty lies in that if one works, then the other surely does not, meaning they ruin each other. The tuner’s task is to find the balance in this Bermuda Triangle, which we tried to reach in our “physics-triangle”.

Watching out for continuous reactions I believe I found students’ limitations concerning the digestibility of the theme. We came up with a structural build-up of the theme that created contextual harmony of the numerous information they had learnt in their previous studies, research, lectures and consultations. Further to some introductory talk on some basic physics background knowledge, we went through the history of tuning in chronological order, which contained plenty of interesting facts.

The explanations were based on the piano, a musical instrument having closed strings at both ends. Since many students are familiar with its keyboard, the piano appeared to be the obvious choice to base most of the explanations on by means of some tables. The necessary concepts required by the theme are relevant in the high school curriculum: oscillation, resonance, levitation, waves, standing waves, system of overtones, which complement themes that are only touched upon in the curriculum, like intervals (their addition or subtraction), scales, tuning types (clean intervals, diatonic scale, Pythagorean tuning and other historical temperaments, chromatic scale, well-tempered tuning, tuning in perfect fifths) pythagorean comma, wolf quint, the comparison of the tuning in perfect fifths and Pythagorean tuning a la Lissajous, "the elimination of problems", clarity, inharmonicity and so on.

One of the biggest difficulties was the lack of background music knowledge. I regarded it as one of my major tasks to teach the thematics so that students could make sense of it without a deeper understanding of solfege, music notes, signs and terminology. I developed an adequate method to make it possible. It truly is delightful to experience when the world of music becomes more understandable via physics… and vica versa.

6. The pedagogical and professional plan of my physics camp projects

I am giving a short summary of the build-up of the physics camp of Berzsenyi Daniel Secondary School, which has provided the background for my projects done in collaboration with my students in the past ten years. Based on my experience I can firmly state that the methodology I worked out has proved to be adequate to do bigger projects including a great deal of smaller details, which anyone can utilize when thinking in terms of similar exercises for students.

I am presenting a way using my own experience and projects, how it is possible to carry out almost an academic-year-long program, which appears to be truly motivating and delightful, not to mention its benefits of providing students with long-term applicable knowledge. A project is made up of three parts. The first part is a longer process of preparation: brainstorming, choosing the theme, creating a schedule, research, collecting material, understanding, calculation, measuring, realization, making tools, devices/software, making presentations and preparation for the presentations. The next phase is about the preparation for the presentation of projects in front of a bigger audience. Finally comes the evaluation session. I am sharing ready-made, freely and easily transformable materials intended for all the three processes: a schedule table, technical information: “the rules of making a presentation”, “how to build up and give a presentation”, assessment sheets and so on. In addition, I am attaching a table of theme ideas, recommended age-groups, sources and accomplished student materials based on my camp projects.

The projects have no predetermined form. They might mean one or more experiments, measuring processes, presentation of the evaluation, building an experiment device, the use or making of computer simulation or measuring program, theory, calculation or even historical background.

I am also presenting the experiential results of a fictional project irrespective of any theme, though, including specific optional examples, which might be used when teaching a given theme, which I can only recommend for use in any educational context. Colleagues can successfully utilize them.

As a teacher I find it of utmost importance to efficiently prepare students not only to be professional, but also to learn what it means to be a lecturer. A child does not know what it means to stand in the limelight in front of 50 people. It is worth writing a “script” of who speaks about what and when, where they stand so that the board can be seen, how they demonstrate an experiment, how to hold the audience’s attention till the end, how they should communicate, how important it is to write down their thoughts professionally and then to proofread them. It is also a good idea to practice in front of classmates, teachers and parents at home. It is also part of quality work to be competent users of presentation tools (formula-editor, graphs, colors, text), which appears to be a huge challenge not only for younger students, just like the instinctive understanding of how much their presentation might be understood by the audience when hearing it for the first time. Having no previous experience students find it hard to notice and realize these things.

Students acquire mathematical and IT skills, experimental and measuring methods closely connected to the physics content. Besides the subject-related material students learn cooperation skills, time management, physics lab knowledge and cleaning, precision, selectiveness, foreign language knowledge when collecting background material, adaptation skills indispensable for teamwork, tolerance, willingness to help when teaching one another, individual research work, purchasing skills, manual dexterity, all forms of DIY, creativity and problem-solving.

Certain projects of mine done in collaboration with students, whether as a whole or partly, are also “utilized” in other events (year-end presentations, conferences organized abroad and in Hungary, poster presentations, in articles, competitions, physics lab applications, lessons).

I can only recommend trying out similar programs specifically organized in local context. Non-specialization schools or those with less physics teachers on the staff might find their own goals, motivation, methods, styles of tasks or themes for their own students.

Publications related to the thesis: [4], [1], [2]

SUMMARY - RESULTS and EXPERIENCE, GOALS and FURTHER PLANS

I worked out a colorful bouquet of themes neglected in high school context in my research paper, which provides numerous ideas concerning students’ diverse development. Not only does it mean knowledge useful in mathematics, physics and IT, but also competencies enriching their everyday life and personality development.

Based on my experience I firmly believe that any child, irrespective of their scope of interest, might easily be motivated with well-designed and structured individual or team projects. One should find the right exercises matching students’ level, depth of knowledge of the theme, with which we can make the lessons more colorful and can widen their horizons, not to mention our own horizons. The PhD course as well as the relationship with the new colleagues I met during the course have enriched my methodology with several new ideas.

I would like to work on similar projects in the future, not only in the framework of the physics camp, but also with specialization classes. I also find it important to take non-specialization classes’ interests (those of humanities and language classes) into account, to arouse and maintain their interests on their own level by means of themes and projects matching their level and interest. Even though my theses do not concern these projects, I have always used them in lessons. However, I do feel I lack in the necessary competencies regarding them, thus I clearly see I have much to improve so that I can support my students’ development.

Furthermore, naturally I have the intention of continuing working with students talented in physics, which, obviously, requires more creativity and is filled with challenges both professionally and concerning methodology. This is a crucially important field of both my students’ and my own development. Based on students’ reaction and despite the huge extra work it appears to be worthwhile. Thanks to my age I am aware and firmly believe that I have much to learn and do in this profession. Until I can work with students and colleagues I am lucky to work with and until the system lets me do so, I am positive I will always have the chance to work the way I like to work.

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II. Lendvai Dorottya: Beteges Kertecske, Erdélyi Magyar Fizikatanári Ankét, 2018