Doctoral Thesis - Arguments

Research on the Complex Phenomena and Implementation of New Methods in The Teaching Process of Optics

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Introduction

Nowadays, the perception that education of natural sciences may be facing a crisis has already become a cliché. However, we are witnessing with distress the ever decreasing interest of the students in subject matters pertaining to natural sciences – such as Physics, for example. Furthermore, there are problems encountered in the implementation of the acquired information, in connecting the laws of Physics to daily life, and last but not least, in identifying motivated students. All of the aforementioned shortages and difficulties have already been long revealed and global attempts have been made to modernize the education of sciences. (Implementation of new methods, competence-based curricula, new handbooks, conferences supporting the transfer of any related best practices etc.).[1] As possible solutions, we may first of all consider to enhance the role of experiments and to prioritize independent student activity (inquiry-based, as well as project-based learning), however, we may, just as well, consider the other options at hand, such as follow-up activities for the students lagging behind and special talent support classes for the best and most outstanding ones.[2]

As taught in schools, Optics is highly suitable to shape the students' rather complex view on natural sciences. Light, as a phenomenon, is well-known to students because humans perceive most of the surronding information through sight. Although our eyes make a great instrument to perceive light, in order to be able to reveal the nature of light, we need more than our eyesight. To gain full comprehension on the nature of light as it is, we need to perform awareness-guided observation and experiments. Despite of the fact that the study of light is facilitated by a wide range of possibilities during class – including demos, as well as experiments - achieving acceptance among the students viewing the wave-like nature of light is a rather difficult didactical task. However, the problem can, by all means, be solved if we ground our case on the issue of mechanic waves, which we can, of course, tackle only if prior insight on the periodic motion has already been provided - special focus being herewith given to the harmonic vibrations, as well as to the basic vocabulary required to describe such phemomena. (Quite obviously, the study of vibrations has its own immanent importance, as vibrations make one of the most frequent types of motions in nature.) By treating mechanic

[1] OECD: *Measuring Student Knowledge and Skills: A New Framework for Assessment*. OECD, Paris, 1999.

[2] Nagy Lászlóné (2010): A kutatásalapú tanulás/tanítás ('inquirybased learning/teaching', IBL) és a természettudományok tanítása. Iskolakultúra, 12. sz. 31–51

waves, we provide our students a visual experience which enables us to proceed and to introduce the notion of the wave to them. Then, during the study of the visible light, we may conclude by stating that light bears exactly the same features as the waves. With no intention whatsoever to attempt a fully comprehensive approach, my treatise aims to introduce new and modern means that facilitate the knowledge transfer of certain areas of Optics, and to present complex student projects, which I have successfully implemented in order to enhance the students' motivation towards learning Physics. The backbone of my research consists of a four-year period which I have spent teaching Physics – also as the class teacher of a bunch of Math students. I can call myself lucky as 15 out of the 33 students in the group applied to be part of the talent support activities at the very being of the 9th grade, meanwhile 17 students chose Physics as their optional subject matter at the end of the 10th grade. Therefore, quite a large number of enthusiastic students were eager to become parts of various projects, to perform measurements during our extra-curricular activities – our common work bringing about many results and lots of experience.

I have aimed to inflict my students the aspiration and the willingness to regard the world in its wholeness, and to try to interconnect the different areas of science which at a first approach do not seem to share a common root.

Targets and Methods

In the course of working on my PhD dissertation, I have focused on elaborating and implementing new teaching materials in Optics. While drafting the educational material, I have been striving to use new methods and up-to-date technology during the experiments in Optics. Furthermore, I have aimed to trigger a coherent scientific viewpoint in my students' approach via the complex learning material, as well as through the well-prepared measurements that I have provided. I have thoroughly studied the learning/teaching strategies, such as the IBL *(inquiry based learning)*, the PBL *(project based learning)*, and the DBR *(design based research)*, as well as the impact and the efficiency of the information communication tools (ICT), which I used during the Physics classes and talent support activities. I have been seeking the opportunity to prove that the aforementioned methods not only have the potential to increase the students' level of motivation but that they also aid the involvement of the students into the educational process.

It is, nevertheless, worthwhile acknowledging that every student has some pertinent prior knowledge viewing waves and/or light – some of it accurate, however, some of it entirely erroneous. Hence, in order to map the students' information pool, and to have their misconceptions and failed patterns revealed, I consider it important to perfom previous knowledge level, as well as diagnostic capacity evaluation tests. The efficiency or, as the case may be, the shortages of the applied methods and/or the planned developments may thus be instantly revealed once the new learning material has been delivered and the students' profficiency level assessment has been subsequently reiterated. However, it is also worthwhile analyzing, whether the applied methods have really supported the learning process – herewith, I have drafted questionnaires for my students and I have submitted them to comparative testing.

In my doctoral treatise, I have studied the possibilities to integrate the chosen methods, along with the processed phenomena, into the syllabus, but also into talent support activities and students' lectures. During the time spent together with my class, we had various accomplishments, such as taking part in several projects during the first years of high-school – the projects pertaining mostly to periodic motions and the qualitative description of solar irradiance. Meanwhile the students' Mathematical tool-kit got richer and richer, we got ouselves deeper and deeper into the world of waves – especially in terms of the light-related phenomena. In this paper hereby, I will demonstrate how the students' vocabulary, as well as their knowledge has developed during the four years. We have come to process phenomena, which are not at all (or merely to a very restricted extent) included into the related curriculum, but which, however, are highly adequate to make the object of individual projects and/or extra-curricular activities.

In order to conclude, I have grounded my results on the experiences gained through singular acts of teaching and on the analyses following my small group-based research. Therefore, my conclusions fail to bear the power of absolute proof. Nevertheless, I feel that the materials that I have elaborated, as well as the experiences that I have gained through teaching are worthwhile publishing as they can provide further food for thought, and they can also serve as ground for a possible start-up to my colleagues who have also ventured into practising teaching.

Arguments

1. Argument No. 1
Android Application-Supported Study of Periodic Motion [1], [3], [5], [8], [12]

Grounding of the Wave Theory takes place by studying periodic motion. As a first step, I have elaborated a talent support activity material for 9th graders, which requires an Android Application and which comprises of different kinds of tasks for the students, such as experiments, as well as calculation-based exercises on the various types of periodic motion (damped oscillation, pendulum, circular motion), with regard to the students' prior Mathematical knowledge.

At an early stage of their high-school years, the students do not have the Mathematical knowledge that is required for a detailed approach of the periodic motion, however, thanks to the application, the necessary Physics parameters can be measured and graphically represented with ease. Not to mention that the students' creativity, their problem-solving skills, as well as their approach to Physics may also significantly evolve during the small-group free-style experimenting activities. I have proven that the acceptance and understanding of certain abstract notions such as acceleration in simple harmonic motion becomes a lot easier if visualized via smartphone simulations.

Kinematics is of defining importance in the process of Physics education as it grounds the introduction of the students into a quantifiable level of Physics by having them first acquinted with the overlapping structures of observation, experimenting, measurements, notion and theory. Providing data pertaining to the position, velocity and acceleration of a body in motion dependant on time within a given frame of reference is not an easy task to deal with while making an experiment, especially in the case of more complicated types of motion, where all of the three physical parameters undergo continuous alteration. Therefore, according to my experiences, it is, by all means, not accidental that the students find it most difficult to cope with understanding curviliniar motion.

The tool-kit of usable procedures has constantly expanded and developed, to finally reach the stage of using smartphones during extra-curricular class activity, where we have executed the measurements with the triaxial acceleration sensor of a smartphone, asssisted by a free Android Application, the Accelerometer Monitor, which can display and analyze the measured data. We have started the anaylsis of periodic motions by examining the uniform circular motion as this motion type represents the students' first encounter with the idea of curviliniar motion. However, once having acquired some knowledge viewing the featues and characteristics of the aforementioned motion type, we can switch on to the basically phenomenon-centered examination of damped oscillation and pendulum.

2. Argument No. 2
Photometry Education via the BYOD (Bring Your Own Device) Method [4], [9]

I have proven that in the course of teaching Optics, the project-based method can be successfully and efficiently implemented if combined with the BOYD technique (Bring Your Own Device) as it has an increasingly positive impact on the students' attitude viewing their approach to Physics by motivating them to aim for a more profound understanding of the notions used in Optics. The applied methods tend to trigger the students' interests, meanwhile the possibility of autonomous experimenting makes it easier for them to understand the novel pieces of knowledge, followed by a more facile process that leads to a whole range of individual discoveries viewing the laws of Physics and their possible connections to certain phenomena. In the project, we have given priority to Photometry, which is a rather neglected subject in the high-school curriculum.

By using the Smartphone light sensor during extra-curricular activity, we examined different optical phenomena. We started off with a classical Photometry-related measurement (comparison between the relative illumination value of a traditional light bulb and a CFL), which had already emerged in the high-school graduation upper-level exam Physics test, followed by a Smartphone assissted measurement, after which we proceeded to the comparison of the due results. Subsequently, we made further measurements on light reflection by using a home-made device built by the students, and we also examined the connection between illumination and the light source output dependant on the network power transfer.

According to the BOYD (Bring Your Own Device) concept, the students can individually set up their own working environment, by using their own devices (mobile phones, tablets etc.), the familiar setting thus facilitating a faster and a more efficient accomplishment of the task itself. By the quality-centred study of the light-related phenomena, one of the major goals of our project has aimed to ground the understanding and to facilitate a swifter processing of any knowledge on the nature of light, as well as to reach a more quantity-based interpretation of the optical phenomena.

3. Argument No. 3
Classical and Modern Methods in Optics-related Experiment Education [9]

On using diagnostic and summative evaluation tests on Optics, I have shown that experiments performed with modern devices may improve the process of acquiring quantitative optical knowledge, and, moreover, supported by devices, we may also have the opportunity to examine certain phenomena that have been left outside of the curriculum, not to mention the possibility of triggering the focus of the students otherwise quite short of interest in terms of mathematical calculations.

In my research carried out with a class of 11th graders, I split the 33 students into two groups and while doing the selection I paid attention to have allocated students of fairly equal levels of knowldedge and skills, as well as mathematical competencies into the groups. One of the groups consisted of 15 students, all of them being familiar with Smartphones used in the learning process, meanwhile the other group – the control group – was made up of 18 students. Physics classes took place frontally, in a traditional way, without having the students split up, and I always took care to perform a diagnostic evaluation prior to conveying my students new knowledge, and only afterwards, subsequent to the test results, I started teaching them the phenomena of reflection, refraction, interference, deflection, meanwhile we performed the due measurements applying classical methods (laser-beam, plane mirror, optical grid etc.). Afterwards, the control group was given the possibility to reiterate the tests within smaller groups, meanwhile the test group had to repeat the classical tests by using Smartphones. Thus, both of the groups spent a similar amount of time processing the new knowledge, the test group being also given the opportunity to gain awareness on the traditional experiments. I studied the efficiency of this method via summative evaluation tests, the contents of which were similar to the performed diagnostic assessment.

Experience shows that besides motivating the students, the use of modern devices has a positive impact on the absorbtion rate of the new knowledge, meanwhile the students also reach a better understanding related to the operating principles of their own devices, thus gaining a complex, overlapping set of knowledge hitting multidisciplinarity.

However, it is worthwhile mentioning that the above methods also provide the possibility to study certain phenomena and to perform certain measurements that would otherwise be rather difficult to look into by using traditional instruments. For instance, today we can already define the light distribution intensity of the optical grid, as well as the transmission coefficient of the Fresnel equation. Viewing any further benefits of the above method, besides its appropriateness to help validating certain laws, I must mention its utmost adequacy to provide numerical data in a rather natural way, the processing of which leads to a quantitative description of the phenomena, thus boosting the mathematical competencies of the students, as well. It has been unequivocally proven that the appearance of the modern technical devices in the classroom has significantly enhanced Optics education.

4. Argument No. 4
Inquiry-Based Education During the Study of the Solar Eclipse in 2015 [2], [6], [7]

On studying the solar eclipse in 2015, the students took the steps of physical awareness taking them to research, and it also become a certainty that measurement of scientific value was possible in classroom. Furthermore, inquiry-based education was also shown to be capable of motivating the students to a very significant extent in terms of acquiring and consolidating new konwledge.

In terms of education, we distinguish two types of learning, such as *PBL – problem based learning* and *IBL - inquiry based learning*. Meanwhile the first approach means that the learning material is integrated into relevant topics where due answers have already been provided, the latter operates on open-ended questions. However, it is important that the students are engaged into research-like activities and that they become active participants of the teaching/learning process. The IBL, actually, consist of three major parts: identification of the issue in question, data collection, analysis and conclusions.[3]

Associated with the solar eclipse in 2015, the students were able to perform the study of a rare phenomenon, while they had the opportunity to experience the earthly effects of the solar radiation, as well as any of its subsequent changes. Furthermore, they were also strongly motivated by the thought that the output of their activity could be well-used in a real scientific research. Supported by the measurements performed together with the students, we were able to reproduce the results obtained following the analysis of the data collected during the total solar eclipse in 2006. Although in 2006 there was a total solar eclipse, meanwhile the one in 2015 was only a partial one, it did not make any difference for us because we were not necessarily interested in comparing the two solar eclipses but to study the effects of the phenomenon (imminent decrease of radiation) on the environment. As we chose the best possible approach in this respect, we successfully demonstrated that the temperature values measured prior and subsequent to the phenomenon could time-wise be integrated into a linear function, along which changes of temperature would have been recorded anyway, even without the eclipse. Also, we studied the differences in the temperature drops dependant on

[3] Heather Banchi, Randy Bell: The many levels of inquiry, Science and Children, 2008/12, 26. o

soil types, as well as the phase delays dependant on the correlation between the value of Sun-disc surface and the decreases in temperature. However, we were very happy to have reached results which were fairly similar to the ones encountered in our scientific references.

5. Argument No. 5
Creating a Solar Eclipse Model and Comparing the Data with the Experiences Gained in 2015 [11]

Supported by a student-designed device, we created a model of the solar eclipse during extra-curricular activity. The work done showed that - based on their existing knowledge, the students were capable of modelling the newly-acquinted phenomenon. They found it very exciting to have designed their own tool in order to inquire about a complex phenomenon. Our measurements validated the accuracy of the referred results, as well as the correctness of any due correlations.

The research tool consisted of a 2 m high wooden rack on which we placed digital thermometers every 10 cm. We chose to do so because we needed high sensitivity thermometers, capable of swift reactions in order to show the differences in temperature produced at such a small scale. The Sun was replaced by an infrared lamp. Various albedo surfaces were placed at the bottom of the rack. Making good use of the ICT devices at hand, we integrated the light sensor of a Smartphone, which made it possible for us follow the light as reflected by the different surfaces.

Although building the model did not require any special knowledge in Physics, the mathematical skills of the students allowed us to have a more detailed insight of the solar eclipse even prior to designing the model. The solar eclipse was accomplished by changing the output of the infrared lamp, which we increased/decreased dependant on the changes produced in the Sun-disc surface value. (Calculation of the Sun-disc surface was possible via trigonomeric correlations – first introduced to the students in the 10th grade).

Subsequent to the evaluation and the due conclusions, we performed the comparison of the results to the ones of previous measurement values. However, we were happy to see that our model was fully convincing and capable to reproduce the output obtained in 2015.

6. Argument No. 6
Interactive, Thematic Experimental Demo, Lead by Talent Support Class Students [5], [10]

Our school launched a high-level, complex science course two years ago. Occasioned by open school days and other events – and also in order to advertise the course, my students organized thematic experimental demos for anyone interested. Making good use of my experiences, I have proven that by presenting interesting experiments –

especially if the presentations are held by the students themselves - the interest for Physics can also be triggered in other students, too.

I have shown that „peer instruction" is very efficient when it comes to motivating younger students or even the role players. The program, therefore, unequivocally develops the self-confidence, as well as the lecturing skills of the students performing the demos. While exhibiting their knowledge in front of their younger peers, they are also given the opportunity to see how it feels to be a teacher. On seeing their enthusiasm, there is a notable increase in the number of youngsters applying for admission to talent support classes, optional Physics classes and science courses.

During student demos, the experiments are performed by the students themselves – individually or in smaller groups. Speaking about student activities, this structure is obviously the best one as the students are not only observers but also stakeholders of the process. Moreover, such activities enhance curricular and/or extra-curricular student activity, meanwhile the subjects gain a lot more self-confidence and they are also willing and eager to try new experiments, thus having a beneficial influence on their peers.

The demo held by my students was more than a traditionally playful experiment – actually, it was an interactive Physics class, where the students lectured on their peers. Our purpose was not to organize an interesting Physics show – as the activity looked more like an interactive Physics presentation among peers. In the past four years, the group comprised of 2 constant members – this number having always been completed by 4-5 younger/older students. The demo repertoire consisted of a wide range of presentations, starting from the simplest ones up to measurements performed with the most up-to-date devices. Adjusted to the syllabus, the experiments have been grouped around the subject matters (Mechanics, Thermodynamics, Electromagnetics), never failing to rely on the younger members' already existing knowledge. Beside the syllabus, we have always acted on the latest project of the talent support class, as well.

7. **Argument No. 7**

A New Approach to the Wave Theory via Design Based Research (DBR) [12]

Within the Experimental Handbook working group of the Education Pedagogy Research Group set up jointly by the Hungarian Academy of Sciences together with the Eötwös Lóránd University, my colleagues and myself have been working on the development of a new Physics handbook since 2016. We have developed an experimental website (https://www.kiserletitankonyv.hu/), that should be appealing enough for high-school students so as to raise their interest in Physics. Grounded on my experiences, inasmuch as on the students' feedback, I could state that the students received the new learning style with a warm welcome – the online contents (videos, simulations) enjoying the greatest amount of success.

We have been experiencing for a long time that the traditional Physics handbooks do not really meet the ever increasing challenges and expectations of the past decades. However, in the long run, radical changes are yet to be triggered by the complex education support materials available in downloadable formats.

Demo-wise, we chose the chapter entitled „Vibrations and Waves" as we aimed to reach out primarily to those students, who had already decided during high-school that they would like to take the path of physical sciences, and for that they would have to pass a graduation exam in Physics, too. While going through the teaching material, we gave up on the traditionl approach even as far as the structure of the chapter was being concerned. We presented the features via surface waves – as mechanic waves – and then we opted for a parallel structure instead of a linear one. The first round of testing – actually, the demo of the e-handbook – took place within a rather small group, as we wanted to evaluate the feasibility of the website and then, subsequent to having the student feedback, we performed the necessary fine-tuning. Now, once having the final version of the website, we would like to organize wider range trials of the e-material.

Utilization of results

I always performed the above experiments with my own talent support class and/or project students first, only a few of the experiments being run during regular class activity. As a general rule, the students did greatly enjoye the experiments done with Smartphones and, therefore, they could be drawn into the process of active learning with ease. The success of my research-based work has been confirmed by the fact that many of my former students have chosen a scientific and/or technical career.

Besides taking the floor on the open school days, my students were also present on different events, performing experiments and demos – The Mobile Experiment Fair in Győr (2014, 2015, 2016), The 2nd Science Education Exhibition in Kecskemét, The Researchers' Night and The Science Fair Contest in Szombathely, The International Science on Stage Festival in Debrecenben (2017), meanwhile they never failed to promote Physics among the younger student generations. Their work brough them fame and reconnaissance and also several awards (The 1st Prize at the Science Fair Contest in 2015 and the 2nd Prize in 2016, The Award of the Public in 2015 and 1029, and the Marvel Palace Award/Csodák Palotája Díj in 2015.).

My own publications:

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2. Finta Zs., Mitre Z. (2015): A Kutatás alapú tanulás alkalmazása a 2015. március 20-i napfogyatkozás során végzett hőmérséklet mérésre, *Proceedings of the 14th International Conference on Applications of Natural, Technological and Economic Sciences, Editors: Szőcs H., Mesterházy B., Szombathely, Nyugat-magyarországi Egyetem, pp. 57-64.* ISBN: 978-963-359-053-9

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5. Finta Zs. (2015): Mozgások nyomkövetésének módszerei – Okostelefonok alkalmazása a fizika órákon, *A tudományért és a tehetségekért – Tudományos diákköri munkák a Természettudományi és Műszaki Karon, Szerkesztette: Nagy Tóth E., Szombathely, Nyugat-magyarországi Egyetem*
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   ISSN 1335-4981
10. Finta Zs. (2019): Interaktív tematikus kísérletbemutató tehetséggondozó szakkörön résztvevő diákok vezetésével
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