Ph. D. Thesis

Studying Non-linear Phenomena in High School Workshop

Jaloveczki József

Supervisor: Dr.Tél Tamás

Eötvös Loránd University

Faculty of Science

PhD School of Physics

Director: Dr. Palla László

Physics Education PhD Program

Program Director: Dr. Tél Tamás

2014

Introduction

The social appreciation of exact sciences and engineering – especially chemistry and physics – reached its bottom in the first decade of the 19^{th} century. It is a characteristic contradiction that in the meantime the development of technology has been accelerating rapidly, computers, automatic machines and electronics have been playing a more and more important role in everyday life. This kind of technology can only been used responsibly and can be improved by a generation who is susceptible enough to finding out how things work. Interest in exact science subjects, however, has decreased. In secondary education of physics there is less and less time for experiments and in connection with this for the profound comprehension of phenomena. In this paradoxical situation it is an important task for the teachers of science subjects to find new methods, new topics which can conduct the attention of elementary and secondary school students to the direction of natural science and engineering. In elementary school the majority of students are interested in experiments. In secondary school the spontaneous interest of students in information and digital technology can be helpful through which we can lead their attention to measures in physics, their explanation and by those to comprehending natural phenomena more thoroughly.

In my dissertation I give account of experiences of the researching and improving work I have been doing as a teacher of physics at Szent László Általános Művelődési Központ in Baja for almost ten years continuously arousing students' interest in physics as well as in the field of nurturing inquiring students.

At Szent László Általános Művelődési Központ in Baja in the elementary and secondary division beyond compulsory lessons we provide a number of interested students with study group activity as well as older students with organized workshop activity to enable them to improve their knowledge of the subject and their approach to physics. The primary aim of the study group created for students aged 12 to 16 held twice a week is to get them to like physics through experiments and phenomena. In motivating young students it is important that the best ones can take part in national competitions with their experiments as well as in the physics show organized by the school yearly to make physics popular. The latter can not only be visited by fellow students but by parents friends, acquaintances, or anybody interested from Baja. (The popularity of the event is growing year by year, so partaking in it is getting more and more motivating for the "performers".) The majority of the students succeeding in the study group and at competitions can do research work well beyond school curriculum in Mandelbrot Science Workshop from grade 10. (The workshop can be attended by inquiring grade 10-13 students irrespectively of the study group, even by students from other schools.) The workshop created in the autumn of 1999 is closely connected to the National Association of Researching Students. In the workshop we focus on the non-linear phenomena not included in school curriculum, especially on studying experiments on fractals and chaotic phenomena and modelling the results on the computer. During the sessions (4 hours once a week) students make measurements and do simulations with the help of computer by using mathematics and information technology effectively. The activity takes place in groups led by the teacher but with a great deal of student independence.

Objectives

In my dissertation I aimed to elaborate an effective programme which is suitable for me in the given urban circumstances to arouse the interest of gifted primary and secondary school students in physics and motivating them to study modern physics at a higher level to establish their future engineering and scientific carrier path.

In general secondary school practice the syllabus of workshops is hardly beyond the basic material of secondary school. There is hardly any workshop based on experimenting, most of the time they spend sessions working on rather difficult exercises. It is undoubtedly true that doing exercises is a trial of the physics way of thinking. The challenge of difficult exercises really motivates the best of “competing level” students with outstanding talents but it is not suitable for arousing and keeping up the interest of averagely gifted students. According to my experiences, contrary to doing sterile exercises it is more attractive to the averagely talented secondary school students to be led into a topic of modern physics, where they can do the job themselves to get the results. In secondary school a field like that can be studying non-linear phenomena. It is closely connected to computer applications and for students with interest in exact sciences most problems or activities related to computer means exciting challenge. In the field of applying information technology talented secondary school students are especially creative. During my doctorate work I aimed to do experiments and work out methods applicable also in secondary education by which the averagely talented, inquiring student can be led from experimental basics to some simple problems of non-linear phenomena. I found topics like that principally among mechanical phenomena which are researchable and perceptible well enough. I thought it important that the teacher’s job should only be to introduce the topic to the extent that will enable students to work on their own or in small groups. Then the teacher will only help and control them. The teacher’s job is to make sure they will meet success to motivate them in their job. For most of the students even the exclusivity of the topic is motivating itself, as it deals with things (fractals, chaos, etc.) that either their peers or average adults know very little about. Ensuring the reward for successful student achievements (student competitions, professional lecture and publication) is also the teacher's job.

I consider an important part of my doctorate work to prove that the system of nurturing talents worked out myself starting from performing experiments by young secondary school students to researches done in student workshop is effective. It can be showed by detailed description of the work in the dissertation. I illustrate with examples how students use computers in examining different phenomena either for measurements or analysing the received data as well as for simulation.

An important aim of my nurturing talent job is that through particular research projects students should become familiar and acquire the steps of scientific work in practice (observation, experiment, measurement, modelling and simulation). It is important to make clear that the real standard of the comprehension of the phenomena is the correspondence of the data measured experimentally with the computer modelling.

1. Studying non-linear and chaotic phenomena by measuring angle with potentiometer

I elaborated a method suitable for student workshop, with the help of which students are able to study difficult even chaotic movements based on physics and information technology taught in secondary education. I showed that studying measuring angles with a potentiometer well-known from special literature can be effectively applied in student workshop to studying non-linear even chaotic phenomena. In my dissertation I demonstrate how students can be led to understanding the point in chaotic movements starting from a specific experiment then expanding it. Applying the elaborate method we showed by experiments that the movements of the pendulum stimulated horizontally by different pushing frequencies are chaotic.

Mechanics in secondary school curriculum deals with linear motions. It is a narrow field in real life. It can be illustrated rather well with the motion of the pendulum. At school we discuss mathematic pendulum moving harmoniously with low digression. Most of the time we do not even mention that real pendulums do not move that way, moreover their movements are so difficult that no matter we know the effects of the environs or the initial conditions of the motion the movements of the pendulum seem to be completely random, *chaotic*. We do not teach chaos-phenomenon in secondary school physics at all, although most of our students know the expression in everyday respect. Via the example of pendulum with chaotic, non-periodic motion it is easy to discuss the meaning of physical chaos, which will give us a clue to the extension of the notion either to other sciences or to relations of everyday phenomena.

Chaotic motions arouse the interest of the students. I based the work in the topic of studying physical pendulum on the method of measuring angle with potentiometer well known from special literature. In the workshop students succeeded in using potentiometer for measuring. To study non-linear phenomena they made a double physical pendulum with rotating potentiometer more suitable for the job. Comprehending the principle of voltage division they calibrated the tool on angles. I regard as a success that students can use what they know about electricity in their job inventing a tool when they are studying difficult mechanical motions. During the work through experiments done with their own tools students really understand how the double pendulum moves. In the study describing the job [12] the double pendulum was damped by friction significantly, so its motion was transiently chaotic.

Related publications: [6], [12].

2. Measuring non-linear and chaotic phenomena by web camera measuring system

I worked out a method for studying the performance of two-dimensional non-linear movements by applying the programme of the Hungarian innovation "Webcam Laboratory" computer measurement software package called "Kinematic". I used the method with my study group students successfully for studying the movements of double pendulums, being the first to prove that the programme designed for demonstrative measurements at school is suitable for studying non-linear movements in student workshop as well.

In the last few years our school also took part in the workshop test of the measuring programme developed by Hungarian specialists. Our students know, like and during the workshop activities they use this programme regularly. Part of the package is the measuring programme called "Kinematika" suitable for the quantitative examination of planar motions. The substance of the method is that we can follow the motion of the coloured object by a web camera attached to the computer. The computer senses and follows the varied position of the coloured object on its digital picture; it saves the space-time coordinates of the motion into the programme file as well as maps it graphically. As part of my ph. D work I broadened the range of the measurements described and suggested by the inventors by studying non-linear phenomena. I showed that this measuring system is also suitable for displaying phenomena as well as for student research. During the work with students at first we studied oscillating motions where outward drive and frictional subsidence were in effect. The data of the software WebCamLaboratory were processed with Excel programme.

Basically, the camera attached to the computer with a wire is in a fixed position so we study the motions in a static system. I elaborated the method to enable WebCAmLaboratory measuring programme to be used for working in moving systems too with the help of a wireless web camera (transmitting data by radio frequency).

3. Measuring non-linear and chaotic movements by Wiifiz system

I demonstrated that the computer technique applied by Károly Piláth (ELTE, Trefort Ágoston Gyakorlógimnázium) to studying movements – based on the widely-known computer game (Nintendo) can effectively be applied to studying chaotic planar movements.

The substance of the experimental method is that an infra LED operated by a coin-cell battery is attached to a moving object, the radiation of which is sensed by the remote control of the Nintendo game placed on the table as a receiver and it records the coordinate and time data of the moving object. The data recorded by the wiifiz programme is assessed with the Excel programme. The computer records the sign of the remote control by Bluetooth connection.

The special feature of the computer game system is that it has a wireless remote control operator called WiiMote. It is a one-handed control panel equipped with a speedometer and an infrared sensor. This function is originally for monitoring the player’s physical movements during the game. The control panel is in touch with the console by Bluetooth connection. The WiiMote console can be used hung on a spring or fixed on a pendulum too. Using the infrared sensor the route-time graphs can be illustrated. As a speedometer it is suitable for measuring g and also indicating the graphs of pendulums, vibrations, collisions and speed-time graphs as well. We have studied pendulum motions in rotating system and also the motions of the pushed pendulum with this method.

4. Numeric simulating of non-linear and chaotic movements

I elaborated a method for teaching how to solve equations of motions numerically in secondary school. Solving differential equations numerically is unteachably difficult, that is why it is not included in the curriculum. However, for senior students talented and interested in computer technology numerical solution is intelligible and can be applied successfully. After interpreting the conceptual way of calculation at first we use the programmes used in scientific work to solve differential equations for solving equations of motions appearing in school curriculum. The method is verified by the result obtained numerically and its correspondence with the well-known function in the curriculum. This correspondence encourages students after stating the equation of more difficult movements to try solving them on the computer as well. According to my observation, stating equations of motions based on physical consideration, their numerical solution and their comparison with experimental observations are significant in shaping their way of thinking, it results in comprehending the basic principles of dynamics.

Natural phenomena can usually be described with differential equations. In secondary school practice the use of differential equations is not possible because of the students' level of abstraction and their deficient mathematical knowledge, so instead of stating and solving differential equations in general we come down to discussing simplified cases and using algebraic contexts giving rather good approximate description of them. If we want to interpret real problems with our talented students beyond the simplest idealised cases stating and solving differential equations cannot be avoided.

At the beginning of the 1980s the 10^{th} grade grammar school physics book by Miklós Dede and Sándor Isza tried to discuss motions in this kind of approach. According to observations, without computers it proved to be too difficult for average 15 to 16 year-old students as a compulsory material. During my doctorate work I could confirm that a few years older interested and talented grade 11-12 students equipped with modern computers can be taught this kind of approach to motions. Nearing the end of secondary grammar school after learning the basics of differential-integral calculation students have enough mathematic and information technology command to comprehend it and so they are able to solve differential equations applying numeric methods describing real motions with the help of computer. For the incompleteness of mathematical background it is useful to start the work with simple but still real motions (e.g. the effect of drag in the case of freefall, ballistic throwing, etc.)

We use numeric proceedings to solve motion equations stated applying force principles. To succeed it is enough for the students to understand the meaning of computational algorithm, they will write the programme themselves. The utility of the computer use is proved when the numeric solution of the motion equation results in giving the characteristics of the real motion in case of setting the initial parameters (initial place, velocity) properly. It is rather instructive to apply more and more precise methods, analyse their faults and draw the graph.

To solve the simplest motion equations at workshops we used either the Euler method or in case of drag the modified Euler method. To solve driven motions with friction numerically more precise methods are needed. Students in workshop rather familiar with programming try to use each of Runge-Kutta methods. It is considered a challenge how much the occurring chaotic motion can be predicted that is what parameters and initial conditions are needed for the chaotic motion to evolve.

Connected publications: [2],[3],[11]

5. Comparing computer simulation with the experiment

"Experiments are the sole judge of scientific truth."

R. P. Feynman

I elaborated a method to get talented secondary school students to experience the role of computer simulations becoming more and more important in scientific research today in finding out about and understanding phenomena through their own activities. I demonstrated that even among the limited opportunities of secondary school it is possible to simulate simple movements on the computer where the result obtained show a good correspondence with the experimental analysis of the given movement. Basically, the correspondence of the simulation and the measurement results verify that the physical considerations made while stating the equation of motion are right. The results of simulations with changing parameters draw attention to interesting cases worth analysing and verifying in a direct experiment afterwards.

Computer simulation is an accepted research method in physics. Monitoring an interesting phenomenon thoroughly considering all details and outward conditions through real experiments and measurements is really expensive and time consuming. Simulating it on the computer the long and costly procedure can be spared. Results of the computer simulation can draw the attention to the interesting cases, which have to be checked with real experiments and measurements. Correspondence between the computer simulation and the real measurements indicates that our background physical conceptions describing the substance of the phenomenon by the differential equation are right. In case that there is no good correspondence it is advisable to try modifying the differential equation, especially refining the interactions influencing the phenomenon. If the correspondence of the repeated simulation and the measurements gets better it indicates that the modified motion equation suits reality in a better way, so the substance of the phenomena could be made understood rather successfully.

Getting the students to understand the method described above is based on experimental examination of selected phenomena and parallel computer simulation taking the principle of gradation into consideration. In practice studying the phenomena of vibrations worked well. After testing the harmonic movements of a vibrating object hung on a spring, which can be considered ideal, we start the examinations with damped harmonic vibration. Having recorded the motion with a web camera and drawn the proper graphs (space-time, speed-time, space-speed) we state the differential equation taking the drag proportionate with the speed into account. Workshop students observe surprised that even the relatively simple (modified Euler) method has a rather good correspondence with the measurement graphs. Then the examination of the physical pendulum suspended to move horizontally follows. Here experimenting the phenomenon and solving the motion equation numerically is done by the workshop students almost on their own.

During the job it can be seen quite well that the expectations to make the results of the simulations match to the experiments better are working out gradually. They understand clearly that during the job it is the simulations they have to suit to the experiments. As part of the workshop activity the best ones examined the motions of the driven double pendulum successfully (with real experiments and computer simulations). My students performed the latter at the Science Workshop Conference effectively.

Connected publications: [6]

6. Propagating physics, nurturing talents based on experiments

I worked out a programme for nurturing talents based on phenomena, experiments and computer use built up on the discipline of gradation, with the help of which the interested student can be led from simple demonstrative experiments to independent student research with results worth of international publication. I showed that solving well-chosen problems stretching beyond secondary school curriculum means a challenge for secondary

school students encouraging them to do persisting, creative work. A special goal with a given deadline can motivate them effectively, for instance preparing for the demonstration of an experiment or an experiment contest, taking part in national or international tenders. Working in small groups informally there is a crucial role of cooperation with the group members besides the instructions of the teacher. During the job their approach to physics, their ability to solve problems and their creativity improves almost undetected still remarkably. On the basis of almost a decade's experiences it can be stated that students taking part in workshops nurturing talent go on to higher education in science and engineering fields.

The participants of the nurturing talents programme are students from grade 7 to 12. Students of younger age groups (13-15-year-olds) do not have enough knowledge in the subject or definite ideas but their school achievements and interest can indicate that their talent in the subject can be improved. These grade 7-12 students are generally good at all subjects.

In study group and workshop activities the instrument has to be made, the experiment and the measurement done and the results assessed. It is crucial how talents can be found and improved. The most important features are accuracy, patience, perceptibility, concentration, disciplined thinking, straightforwardness, having manual skills, creativity, multitasking ability, curiosity. At student group it is a treat for the students to carry out an experiment themselves, but many of them delivers experiments seen or read somewhere else.

Students outstanding at workshops usually come from grade 11 to 12. Working out a problem they make good use of their IT and mathematic knowledge. During measurements they improve each other's creativity as well. I analyse the procedure through examples in which students interested and diligent at lessons become seriously experimenting workshop students with competency in research.

7. Making physics popular and arousing the interest of young students (Physics Show)

In Baja during my "Physics-show" organized with the active assistance of my students I proved that physics can be made attractive by experimenting even for students who can deal with academic and calculation problems with difficulties. Experiments made publicly arouses the attention of fellow students as well as of younger or older visitors, which influences the appreciation of physics as a subject positively and widely, and by that it helps

continue the job of nurturing talents at school at a high level significantly. It ensures the interest of a good proportion of students and raises the prestige of the study group and the workshop.

Through the experiences of "Physics Show" having been organized publicly with the active contribution of my students in Baja for years I proved that physics can be made attractive by experimenting even for students who have difficulties in tackling with academic and calculation problems. Student experiments carried out publicly arouse the interest of both fellow students and the youngest and older visitors, which affects the attitude to physics widely and by that it helps the job of nurturing talents at a high standard significantly while it ensures the query of a great number of students raising the rank of the student study group and the workshop.

A lot of attempts have been made nationally at stirring up the interest in physics. Among these the most successful ones have been the exhibitions demonstrating phenomena and the interactive scientific game stations (e.g. Csodák Palotája – Budapest, Mobilis - Győr, Varázstorony - Eger, Futura – Mosonmagyaróvár) opened in major cities. In most towns like Baja there is no opportunity for demonstrations like these. I have made up for the shortage organizing the occasional "Physics Show" programmes held annually. In our school students having been prepared for the job beforehand have been demonstrating and explaining phenomena and experiments for seven years now during a whole day event. The stress is on observing and through this understanding the particular phenomenon. It is an essential aim to get the students from our school and also the visitors to perform the experiments themselves and understand the phenomena. That is why it is important that the experiments are carried out by students and the explanations are given by them as well.

The preparations for the events take place in the physics study group at school by students taking quite a long time. During this period the students do not only get familiar with the experiments but they also learn how to demonstrate them professionally and explain them to the curious visitors. Through this procedure their competence in experimenting, their ability to focus on something, their communicative skills and their creativity are all improving. Students having difficulties in tackling with the academic tasks can perform successfully at demonstrating experiments. In practice, attending the show almost always makes a positive impact on the attitude towards the subject.

After an impressive demonstration their interest in experiments improves significantly (they often make suggestions on modifications on their own, they bring hand-made experiments to classes, their willingness to take part in experimenting physics competitions and projects increase). The success of experimenting generally affects their performance in classes positively, their self-confidence and activity at lessons thrive, their interest grows and all these appear in better marks traceably. I found out in personal conversations later that the experience of the “Physics Show” influenced many of them in their future carrier path.

To help the preparations for students I put down and publish the most popular experiments demonstrated at the events and their professional explanations as well.

Publications related to the thesis are: [1],[4],[5],[10].

Exploitation of the results, plans for the future

The efficiency of the job of nurturing talents summarised in the dissertation is confirmed by the success of the students. The popularity of the “Physics Show” organized annually is growing among the students and the residents in the town. Students working in the study group and workshop participate in regional and national competitions and in student conferences with their work regularly, where they got into the finals many times and won several prizes. However, what even more important is that there are more and more students of mine who found their profession in science and engineering.

In our school called Szent László Általános Művelődési Központ in Baja there is an emphasized role of science subjects and nurturing talents. The work of the physics study group and the workshop is supported by the institution morally and financially as well, which hopefully can ensure the continuity of the job.

Beyond carrying on long standing topics and methods parallel to mechanical motions I plan to expand the syllabus to studying non-linear phenomena in magnetism and thermodynamics as well as building and examining non-linear circuits [14]. I also plan to acquire new instruments and find out about new methods beside the ones having been used so far [15].

I regard as important that the methods of nurturing talents proved to be successful in Baja should be utilized by other schools too. Previously I already gave lectures demonstrated with measurements together with my students in teachers’ forums. Based on my experience I plan to summarise the programme of Mandelbrot Science Workshop in the form of curriculum recommendation and teachers’ guide. In the methodical specialization for teachers I would describe in details how students worked processing the materials not included in secondary school curriculum. Beyond reviewing the experiments and the measurements the background knowledge will also be presented (e.g. the mathematics-information technology session on fractals, learning and practising numeric methods, the ways how different sensors work, etc.)

Publications

1. *Jaloveczki J.* : 2008, Kétnapos "fizika-show" az iskolában, Fizikai Szemle, No. 9, 309-311.

2. *Eichhardt I., Jaloveczki J.*: 2008. „Fizikázzunk egyszerűen, számítógéppel", Fizikai Szemle, No.9, 311-315.

3. *Eichhardt I., Jaloveczki J.* : 2009, Numerikus módszerek a diákköri munkában, Fizikai Szemle, No.10, 348-351.

4. *Jaloveczki J.*: 2010, Fizika kísérleti bemutató ,Fizikai Szemle, No.6**,** 215-218.

5. *Jaloveczki J.*: 2012, „Fizikashow", a fizika népszerűsítésének eszköze, Fizikai Szemle, No.11, 388 -391.

6. *J. Jaloveczki*., 2011, Studying Non-linear And Chaotic Phenomena in High School, Physics Competitions 13, p.29-37, No.1.

7. *Jaloveczki J.* : 2010, Témazáró feladatlapok - Fizika 7. [R00788], Panoráma sorozat, Nemzedékek Tudása Kiadó, Budapest

8. *Jaloveczki J.* : 2010, Fizika 7. Feladatgyűjtemény [00788/F], Panoráma sorozat, Nemzedékek Tudása Kiadó, Budapest

9. *Jaloveczki J.* : 2011, Fizika 8. Feladatgyűjtemény [00888/F], Panoráma sorozat, Nemzedékek Tudása Kiadó, Budapest

10. *Jaloveczki J.:* 2011, „Fizikashow", mint a fizika népszerűsítésének eszköze, in**:** Természettudomány tanítása korszerűen és vonzóan, szerk.: Tasnádi P., ELTE, TTK, Budapest, 409 - 413.

11. *Jaloveczki J.:* 2010, Numerikus módszerek a diákköri munkában, in: Fizikatanítás tartalmasan és érdekesen, szerk.: Juhász A, Tél T., ELTE, TTK, Budapest, 303-309.

Other related publications

12. *Békéssy L.I., Bustya Á*: 2005, A fizikai kettősinga vizsgálata, Fizikai Szemle, No.5,185-191.
13. *Dede M., Isza S.*: Fizika II., Tankönyvkiadó Vállalat, Budapest, 1983
14. *Juhász A.(szerk.)*: 1996., Fizikai kísérletek gyűjteménye 3., Arkhimédész Bt.-Typotex Kiadó, Budapest, 186-220.
15. *Bérces Gy., Főzy I.*.: 1991, Fizikai kísérletek számítógéppel, ELTE Továbbképzési Csoportjának kiadványa, Budapest, 161-165.