Homo Metiens,

or the Student who Measures in Secondary School

PhD theses

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Introduction

The attentiveness towards physics, the prestige of the subject is diminishing in the past decades. It can be best characterised by a nose-dive. This is a worldwide phenomenon; scientists, researchers work on escape routes from this situation. The most well-known problem is the crisis of STEM (S for Science, T for Technology, E for Engineering, M for mathematics); the search for the possible solutions is an international task.

In Hungary, the level of the knowledge even of those junior students who enter the physics-specialized higher education appoints new tasks for those who work with these students. All freshmen attending technical and scientific higher education are to sit for a test that measures their scientific competence. It is the so-called criterion test. Those who can't reach the pre-determined level (, which is 50%+ of the freshmen) must attend special courses organized for them to help to catch up. This course contains mainly the secondary level requirements of the subject. The successful completion of the course is a chief requirement for the further studies.

In our country a few decades ago, the focus of physics teaching was on tasks using calculations. The teachers of mainly mathematics and physics majors paid special attention to develop this skill, thus drawing back on other skills. This is in line with the fact, that the most well-known, highest valued, so called talent-hunter competitions (Mikola, OKTV) concentrate also on this skill. This is an important segment of scientific competence, for sure. But is this it? Can we draw equal scientific skills and calculations?

Besides, secondary school students who are not exceptionally talented in calculations are facing a fiasco, they continuously get discouraged. Some surveys underline this: physics is one of the least liked subjects in public education.

In the beginning of the XXI. century the goal of the public teaching of physics is forming a scientific point of view and getting the students familiar with the methodology of scientific cognition, rather than memorising the curriculum and making calculations.

In the beginning of the XX. century, in the field of active pedagogy, some institutions were outlined. The purpose of their existence is to make science popular. These are the science centres. Their pursuit is in the "hands-on" principle. The realization and the operation of these places is quintessential for making science and thus physics more popular. Our colleagues are delighted and enthusiastic to organise field trips to such institutions. But there is obviously a vast gap between classroom events and the experience science centres offer. In my work (as a teacher and as a researcher) these questions employed my interest:

- Can we bridge this gap?

- Can we engage our students with adventure and experience in class, thus exclude the humdrum classroom events?

I found my answer: yes, and this bridge is called “hands-on, minds-on” didactics.

Based on this, I developed the Student’s Measuring Project (SMP) method with the classes and sets I worked with as a teacher. In SMPs the students gain personal experience after their aided preparation: they get their own readings in their measurements that are referring to the studied law or phenomenon. They analyse these data and report on their result. I studied this method and worked out excipients for the teachers focusing on the new methodology and renewing their background knowledge in the topics, each selected to best fit the secondary curriculum. I used this method with 4 sets and tested it. It enabled me to compare the competence of the experimental and control groups.

Finding ways of teaching new content and finding new, motivating solutions for classroom use pry open the palette of methodology research. My work is pointing to the latter.

1st thesis: The Wonderful World of Measurements

I have worked out a chapter for my colleagues to revisit or widen their scientific knowledge in metrology. This chapter reinforces the bases of the theme, includes some announcements and pinkies of curiosity. I give proposals also for everyday teaching practice. The knowledge and skills equip our students they need to use the SMP method to understand the basic laws of nature and their cognition.

The steps of scientific cognition traditionally are defined in public education by Galilei. When studying a phenomenon, it is necessary to make the step of objectivity, to “quantify”: measuring means comparing something that is changing with a well-defined constant.

The theory of measurements is not one of the foci in the training of physics teachers. Metrology is the science, or a theoretical study of measuring, considered as a basic element of cognition in a practice-oriented way. I made a chapter to refresh or broaden the knowledge of the science teachers on this slice of scientific cognition.

Based on my practice over the years I propose a topic structure that can introduce this interesting theme for secondary school students. This topic is feasible in physics or science classes. I also involve examples of SMPs.

This chapter is fulfilling a dearth.

Publication reposing the thesis: [A5]

2nd thesis: Defining the Students Measuring Project (SMP) and its study in a few didactical aspects

I define the Students Measuring Project (SMP) as a possible element of science methodology for public education. I study it in some aspects of pedagogy and didactics. Related to the secondary school curriculum I make proposals for classroom use.

Professor Öveges wrote a book titled "Let's make experiments. And let's think." This book focuses on the notions of physics in an adventurous, experience-based way of learning, which is an exceptionally effective method. The book was first published in 1960, and is ever since a great success. It has created a new tenet in Hungarian physics teaching. Its approach is a great example of "hands-on, minds-on" didactics, which is in the cutting edge of our present-day didactical research: the steps of scientific cognition are collaborated with active pedagogy.

I gave a definition to the SMP method, which works the "hands-on, minds-on" way. I present only the aspects from its analysis that are picturesque and are considered of highest value from the point of view of classroom use. Therefore, the aspects I mention are only excerpts from a pedagogical analysis. I concentrate on Dale's pyramid of cognition (as a demonstrative tool of the pedagogy of active learning).

Related to the secondary school curriculum I set six SMP proposals for each grade. These all are easy to accomplish, cheap and safe for classroom use. I put emphasis on strengthening interdisciplinary connections in each of the 18 proposals.

Publication reposing the thesis: [M4]

3rd thesis: Grouping the natural laws of the secondary education of physics from the point of view of Similarity Theory, introducing the linear and exponential types

The main idea of Similarity Theory is that two phenomena are similar if the same type of differential equation can describe them. This means that the mathematical solutions are of the same type. I specify the types of natural laws of secondary school physics based on their mathematical form, then examine the linear and exponential types.

The mathematical context between measurable quantities are called natural laws. The analysis of the readings in a measurement can serve two goals. On one hand to recognise the context, that is the task for scientific research. On the other hand, the analysis or use of the stated laws, which gives a great opportunity to renew public education.

After studying Similarity Theory in a nutshell, I checked its feasibility in methodology research. I grouped the laws of secondary school physics from the perspective of their mathematical form. I distinguished five types.

I deeper studied the linear and exponential laws. These are two momentous units of methodology. I looked for everyday examples from the classical grouping of physics for both types.

Publication reposing the thesis: [M3]

4th thesis: The cooling law in public education with SMP method

I studied how cooling can be discussed with SMP method in different platforms of public education. The original wording of Newton's law of cooling provided the scientific background. Based on this wording I prove that the law is necessarily an exponential nexus.

Cooling is a well-known phenomenon of thermo-physics. An object of different temperature from its surroundings cools to the temperature of the surroundings. The temperature of the object versus time gives an exponential nexus. According to Newton's law of cooling: "The rate of change in temperature is directly proportional to the corresponding ambient temperature, where the last means the temperature difference of the object and its surroundings." I prove (revisiting advanced level physics) that the two wordings are equivalent.

I expound what content and what purport of the law is most applicable in different platforms of public education: at primary school level, at secondary level and in mentoring secondary school students.

Publication reposing the thesis: [A1]

5th thesis: Theoretical and practical issues of teaching the law of radioactive decay

5./A Teaching the law of radioactive decay in the Hungarian classrooms in the beginning of the XXI. century

I made and evaluated a survey to study how the law of radioactivity is taught in the classrooms. I explore what struggles, needs and problems our colleagues face, what help they are looking for to better cope with the task in their practice.

Teaching the law of radioactive decay and introducing half-life is one of the “Christmas tree”-s in the secondary education of physics. The main goal of my work was to see at what extent some issues correspond: the standpoints of methodological research and the standpoints of the colleagues who are in the classrooms facing the task.

I mapped the problems our colleagues have, the possibilities they know and use in their practice. I did this work based a survey: there were problems they were to rate and others they named.

The result gives us a snapshot (relying on our colleagues’ opinion) what is really happening in physics classes that are to be dedicated to teaching the radioactive decay law. There were 35 colleagues who supported the research with their expertise.

Publication reposing the thesis: [A3]

5./B A tentative curriculum for teaching the law of radioactive decay

I elaborated an alternative method based on SMPs to teach the topic. It a systematic and tendentious block of teaching exponential laws

„Problems can’t be solved by the same mindset that created them.” This saying is dedicated to Albert Einstein. Probably it is rather a paraphrase of his words that were published in the New York Times. The gist is that studying the problem from a brand-new point of view has a potential to find the solution for the methodological query.

My aim is to do this task with using SMPs built into a systematic setup. In line with the framework given in public education I attempt to help our students to understand half-life and apprehend the averment of the decay law. I invoke two exponential laws from classical physics: the law of cooling and the law describing the discharging of a capacitor. We get gradually to the radioactive decay law of modern physics. I pay special attention to the methodology of making the difference between inverse proportionality and exponential decay. Each law is proposed in SMP method and contains “in-situ” measurements. I build on the analytic thinking of our students. Thus, it can help them to cope with the complex questions of a model experiment and abstract notions.

Publication reposing the thesis: [M4]

5./C Studying the effectiveness of the tentative curriculum

I had a chance to test the SMP method in a teaching experiment of 4+4 sets. The SMP insertions typified the three-year old course for the experimental groups. I measured the effectiveness of teaching and learning the law of radioactive decay as an episode. I did it

by a delayed questionnaire. I proved that the SMP method is worthy to be present on the methodological palette of the recommended solutions.

In my school I had a chance to teach in all four parallel classes for the entire three years period of the course. We had sets of the classes: in the experimental sets I introduced the Wonderful World of Measurements and taught the most fundamental laws using the SMP method. I did this work mainly in the account of the guaranteed 10% class-time dedicated to the teachers arbitrament. I worked with my colleagues in the department in close cooperation.

Teaching radioactivity happened in the end of the course in all eight groups. I decided to measure the effectiveness of this episode exclusively. Filling the anonymous questionnaire happened 5 weeks after the implementation of the topic. I measured the added value in the three aspects of scientific competence.

I analysed the data using descriptive statistics. According to its result the method is promising, gained its right in the practice of physics teaching.

Publications reposing the thesis: [M4], [M2]

6th thesis: The Sledge Project

"Why is it easier to pull a sledge on level ground than on a slope upwards?" Referring to this problem that turned up in a science competition I proved with a small research group (using IT) that the traditionally given qualitative answers are not necessarily correct. Later, we provided two correct answers incorporating our theoretical studies and the results of our "in-situ" measurements.

The expectable qualitative answers give only a skin-deep solution to the problem. We did the Newtonian analysis for the components of the forces. The result is a function of two variables: $\mathrm{sgn}\Psi(\alpha,\mu)$. Its analysis is not in the secondary curriculum. Using IT we made an analysis of the function. Considering this, the statement is not necessarily true. We gained data for the tilt angle of a sledging slope and friction constant with "in-situ" measurements. Having incorporated the results of our theoretical and practical work we provided answers.

Publications reposing the thesis: [A2], [A4]

7th thesis: Excerpts from mentor projects

Mentoring the talented and motivated is "the icing on the cake" task for all teachers. I present a selection from the projects that I made in the past few years with secondary technical students.

The peripatetic method is one of the best fits for the age characteristics of the teenagers, that is why I chose this method. With one of my students I built a Tesla coil of the size of a man. We set up a presentation based on the equipment to advertise physics and related areas. This proved to be highly motivating for the mates. With another student we drew attention to the fact that in extreme circumstances the materials show odd properties. We lit a match with H_2O. This project also had “afterlife” projects, each was an outreach program. Introducing voltage is not an easy task. Drawing parallel with altitude, a notion known from geography helps to create a picturesque notion. With another student I built a tool that can make voltage (between two outlets of a capacitor) visible.

These projects give us proof that our students can be motivated and can reach high level work when taking part in mentoring. Thoroughness and the need for scientific work become their personality traits when they participate in a project. They can experience joy and success. Their social and scientific competence, creativity and scientific literacy improves.

Publication reposing the thesis: [M1]

Summary, plans:

I am one of the lucky persons who met and learned from the outstanding professor, George Marx in my university studies. I attended his lectures and seminars, sat in exams that turned to conversations, and could catch a glimpse of the heart of an educator when meeting the scientist. He negotiated in many of his articles how it could be possible to prepare the later generation for the future. For me the most determinate of his articles is entitled “Educate for the unknown future”, in which he is redefining scientific tuition to scientific education.

The SMP method created tangible value with all the sets I used and developed it: in special courses for scientific specialisation, in a special school for the imperilled students, in a bilingual technical high school and in an elite art secondary grammar school.

The success of the work I unfolded in my thesis can be demonstrated in several different ways. Many of my students chose scientific or technical career. Many have PhD degree. A research fellow of the Wigner Institute, Budapest was eager to share his results in particle physics with me in CERN in 2009. He recalled with shining eyes the SMPs we did in his school years. Meeting a mum 4 kids, who fights very hard to make ends meet from temporary jobs in Budapest can be a joy for me also, because she was happy to introduce me to her kids, and narrated on the measurements she enjoyed doing in physics class in her years. Many of my students participated and scored well in local, regional and national science competitions. The outreach projects, night classes on science, mentoring projects, funny contests have always been great success.

The “farewell” presents of the school-leavers are providing heart-warming feedback:

- a T-shirt saying: “good-better-physics”,
- a report of measurement with this conclusion: “13d <3 physics” *(<3= love*s),
- or the pencil-case with this quote engraved: “Working in physics means contemplating God’s creation” W. H. Nernst.

It is important to give a chance for my colleagues to give this method a try. I have attended the annual meetings of the Hungarian physics teachers, other conferences on methodology and have seeked the opportunity to report on my achievements and teaching aids. My plan is to make a website to broaden the attainability. I would be happy to share my work with would be teachers too, (for this work I have already had opportunity).

SMPs are feasible not only for classroom use in secondary school physics, but also for mentoring projects, for presenting new content in physics and in other branches of science or STEM.

For me, it has surely been only “that first mile” of a long marvellous run.

Own publications reposing the theses

<u>List of publications in Hungarian</u>

1. Fülöp Csilla, Paál D. “Tesla tekercs a Trefortban”
   In: Természettudomány tanítása korszerűen és vonzóan, ELTE, 2011
   (the same title) eds.: A. Juhász, T. Tél, ELTE TTK, Budapest, 2011, pp 419-423
   ISBN: 978-963-284-224-0
2. Fülöp Csilla: “Fizika a matematikai kompetencia fejlesztésében”
   In: A fizika, matematika és művészet találkozása az oktatásban, kutatásban, ELTE-EMT, 2012
   (the same title), eds.: A juhász, T. Tél, Tirgu Mures (Marosvásárhely), 2013. pp 329-334 ISBN: 978-963-284-346-9
3. Fülöp Csilla: “Fizikai kísérletek más nézőpontból, avagy azonos matematikai összefüggésekkel leírható fizika összefüggések rendszere”
   In: A fizika, matematika és művészet találkozása az oktatásban, kutatásban, ELTE-EMT, 2012
   eds.: A. Juhász, T. Tél, Tirgu Mures (Marosvásárhely), 2013. pp 291-296 ISBN: 978-963-284-346-9
4. Fülöp Csilla, Kiss É. Cs.: “A tanulói mérőprojektek módszere a radioaktív bomlástörvény tanítása során”
   In: Matematikát, fizikát és informatikát oktatók XL. Országos Konferenciája, Óbudai Egyetem, Alba Regia Műszaki Kar, 2016

Conference MAFIOK XL eds.: É. Hajnal, T.G. Orosz, Székesfehérvár, 2016. pp154-159 ISBN: 978-615-5460-83-8

List of publications in English:

1. Cs. Fülöp: "Teaching Newton's law of cooling in hands-on measurement approaches"
   In: The International Conference of Physics Education, ICPE-EPEC, Aug. 2013
   ICPE EPEC 2013 Proceedings, eds.: L. Dvorak, V. Koudelkova, Prague, 2014, pp 1137-1144, ISBN: 978-80-7378-266-5
2. Cs. Fülöp(, R. Szabó, T Berényi, B. Simó): "The sledge project"
   In: International Conference on Teaching Physics Innovatively, ELTE, 2015
   Teaching Physics Innovatively, eds.: A Király, T. Tél, Graduate School for Physics, Budapest, 2016, pp 255-260, ISBN: 978-632-2848-15-0
3. Cs. Fülöp, Cs. É. Kiss: "Teachers on Teaching the law of radioactive decay"
   In: International Conference on Teaching Physics Innovatively, ELTE, 2015
   Teaching Physics Innovatively, eds.: A Király, T. Tél, Graduate School for Physics, Budapest, 2016, pp 403-408, ISBN: 978-632-2848-15-0
4. Cs. Fülöp: " IT promoting physics projects"
   In: AIS 2015, 10th International Symposium on Applied Informatics and Related Areas, "Jubilee Conference without Borders", Székesfehérvár, 2015.
   AIS 2015, ed: T. G. Orosz, Óbuda University, Alba Regia Kar, Székesfehérvár, pp 89-92, ISBN: 978-615-5460-49-4
5. Cs. Fülöp: "Information Society supporting an optional chapter (the Wonderful World of Measurements) in secondary school physics"
   In: AIS 2017, 12th International Symposium on Applied Informatics and Related Areas, Székesfehérvár, 2017, (accepted for publishing, due on 9th Nov. 2017.)

List of other scientific presentations:

1. Cs. Fülöp: "Homo Metiens, avagy a Mérő Ember középiskolában"
   DOFFI 2014., Balatonfenyves, http://doffi.elte.hu/2014/abstract.php
2. Cs. Fülöp: "Physics Education the peripatetic way in Trefort Bilingual Technical High School", DOFFI 2015., Balatonfenyves, http://doffi.elte.hu/2015/abstract.php
3. Cs. Fülöp "A radioaktivitás aktív tanulása"
   DOFFI 2016., Balatonfenyves, http://doffi.elte.hu/2016/abstract.php
4. Fülöp Csilla: "A fizika mindenkié 2.0"
   135 éves a Madách Imre Gimnázium, Almanac, ed.: A. Németh, K. V. Hadikné, VII. kerületi Madách Imre Gimnázium, Budapest, 2015, p 27, ISBN: 978-963-12-6146-5
5. Fülöp Csilla: "Tűz és Víz!"
   Öveges Tanár Úr utódai, ELFT-Ericsson, 2017. p 15, ISBN: 978-963-12-6672-6