

**Homo Metiens,
or the Student who Measures in Secondary School**

PhD thesis

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2017.

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1. Introduction: STEM in crisis

The definition of stem is: a central part of something from which other parts can develop or grow, or which forms a support [R1.1.].

In our case we will also consider STEM as an acronym. Our STEM is a collective field of these studies:

- S is for Science,
- T is for Technology,
- E is for Engineering, and
- M is for Mathematics.

A tree could represent the school subjects, and the disciplines of this field. The school subjects are the roots, since in public education the pupils and students meet these root stalks. These can grow and vitalize the STEM and its branches. I show these concepts in Figure 1.

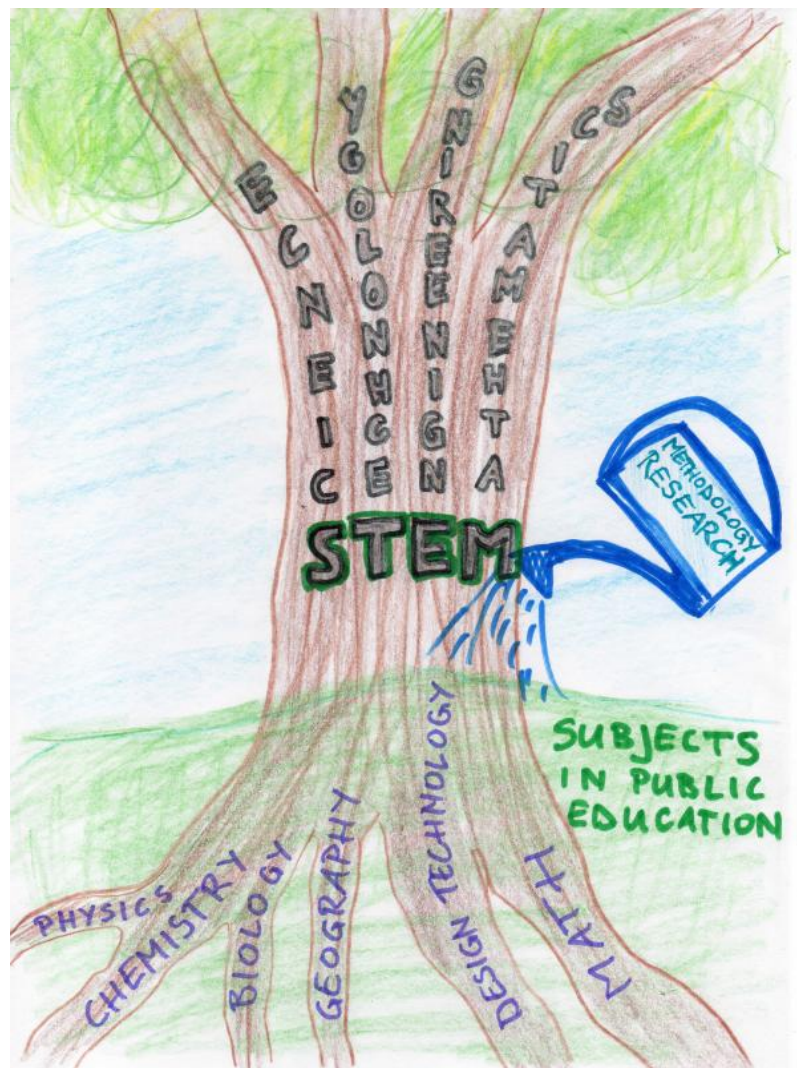


Figure 1: STEM and related areas

If we deal with STEM, we face serious problems worldwide. As an example, first I present flashes of the problems from the U.S.A.

The Bureau of Labor Statistics, (in United States Department of Labor) in May 2015 published an article from an economic point of view: “STEM in crisis or STEM surplus? Yes and yes.” [R1.2.]. We learn from the study about employment: the academic sector is generally oversupplied, while the government sector and private industry have shortages. Also, the geographic location and the discipline of the position affect ease or difficulty. Still, the in article, the researchers assert that “the vitality of the STEM workforce will continue to be a cause for concern”.

The U.S. Department of Education states [R1.3.]:

“In a world that’s becoming increasingly complex, where success is driven not only by what you know, but what you can do with what you know, it’s more important than ever for our youth to be equipped with the knowledge and skills to solve tough problems gather and evaluate evidence, and make sense of information. These are the types of skills that students learn by studying science, technology, engineering, and math—subjects collectively known as STEM.”

On 23rd March, 2015 President Obama ascertained the intent of science education like this:

“(Science) is more than a school subject, (.....). It is an approach to the world, a critical way to understand and explore and engage in the world, and then have the capacity to change that world....”

Linda Rosen, the Chief Executive Officer of “Change the Equation” points out the following [R1.4.]:

- The truth hurts: the STEM crisis is not a myth.
- In the U.S. even in the years between 2009 and 2012, there were nearly two STEM focused job postings for every unemployed STEM professional.
- Unemployment in STEM was over 4%, while the same value for non-STEM workers is 9.3%.
- STEM workers are paid more than non-STEM workers.
- She refers to estimates that STEM technicians get paid 10% more than non-STEM jobs with similar education requirements.
- She points out that the focus is on the need to make all young people STEM literate: STEM for all!

The Hungarian model: from triumph to trouble?

We, Hungarians are very proud of our world-famous scientists. Ling Siu Hing paid special attention to “The Hungarian Phenomenon” [R1.5.]. The author recognizes that at the turn of the 20th century the list of world famous STEM academics is surprising. According to Stanislaw Ulam: “Budapest (... at the time ...) proved to be an exceptionally fertile breeding ground for scientific talent.... [R1.7.]”.

In the article the focus is on these factors:

- the Eötvös Contest
- the KÖMAL (Középiskolai Matematikai Lapok = Secondary School Mathematical Journal)
- good teachers, like László Rácz, Lipót Fejér
- high value on intellectual achievement

The conclusion is that this phenomenon is a useful reference, but can't and shouldn't be copied.

Nowadays, Hungarian STEM professionals (teachers included) are aware of a problem: "The Old Glory Has Gone".

Physics is not a compulsory subject for the School Leaving Exam since 1964. The number of lessons in public education is only a fraction of the ones even a few decades ago. In the senior year of public education there are only optional lessons for physics. In 1971 the number of applicants for physics was only 1.5 times the number of spaces. Today, for physics B.Sc. one can apply even without taking any type of examination in physics in secondary school. Organizers of most majors in higher education that rely on the students' knowledge of physics begin the course with a so called, criterion-test. If the student can't reach the predetermined level, they are to attend special courses organized for help to catch up. In 2009 in the physics criterion-test 1097 students out of the 2185 fell short. That is about (being punctual, more than) half of the freshmen.

The Hungarian Institute for Educational Research and Development (later OFI) have studies on the problems personas need to face in the Hungarian education system. One of this is the plight of physics.

Katalin Radnóti published an overview in this topic in 2009. In Hungary, physics is one of the most problematic subjects, as it is one of the least popular ones among Hungarian students (the other subject is chemistry). It is not particular. The results of TIMSS underpin that this phenomenon is international. The study shows that the logic of physics teaching is still of the inductive-empiricist scientific approach. According to the author there are five needs of development for the national methodological research. One of these is this: The task of education should be organizing the cognition of our pupils and students, based on adequately selected experiments considering the controlling role of theory [R1.8.].

It is obvious that methodological, didactical and pedagogical research is urgently needed. Marisa Michelini (Professor of Physics Education in the University of Italy, and also President of GIREP) declares that the main goal of science education is to bridge the gap between everyday experience and scientific knowledge. She also ascertains the areas of methodological research as:

- teaching and learning parts,
- tools' role in learning,
- DBR,
- curricular studies,
- conceptual profile,

- developing formal thinking,
- learning progression, and
- teacher education.

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- [R1.6.] Ulam, S. (1958). : "John von Neumann 1903-1957", Bulletin of the American Mathematical Society, 64, (2), pp 1 – 49.
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2. The Wonderful World of Measurements

My aim was to develop a series of Student's Measuring Projects (later SMPs) for secondary school students. However, I faced a problem. Every course book mentions the importance of measurements usually only in the introduction or in the first chapters; I could not find this content enough for preparing our work in SMP.

From my practice as a secondary school teacher I can conclude that despite some elements are usually in the curriculum, the first lessons are mainly dedicated to classroom management issues rather than making an overview of these notions.

2.1. The "Galilei-turn" in scientific cognition

The history of science often is parallel of the individuals' progression in knowledge. It is mainly so in the field of scientific notions.

The roots of science are told to be found in the culture of the ancient Greeks. But if we take a closer look from our perspective we find that Greek science should be considered more as scientific philosophy, than science based on objective cognition.

Galileo Galilei (1564-1642) is called "the father of science" as he recognised the need of validating the theory by experiments and measurements, and thus rethinking the key element in science, turning the focus of cognition on the scientific method. He set up standards for length and time. He made this in order to ensure that measurements done on different days or by different people can be compared in a reproducible way [R2.1].

2.2 A short introduction of Measurement Theory and some practical advice for teachers on how to teach the unit

In Hungary following the national curriculum is very important in secondary school education. Still, it gives a chance for the teacher to freely make the best use of 7 lessons (that is 10% of the course) each academic year on his or her discretion for the currently taught class. So the unit I developed is adapted to this frame.

2.2.1. The concept of measurement

First we need to define what measurement is. We can give a definition like this [R2.2.]:

“Measurement is the assignment of a number to a characteristic of an object or event, which can be compared with other objects or events. The science of measurements is called metrology.”

We can explain the methodology of measurements using simple figures, like Figure 2.

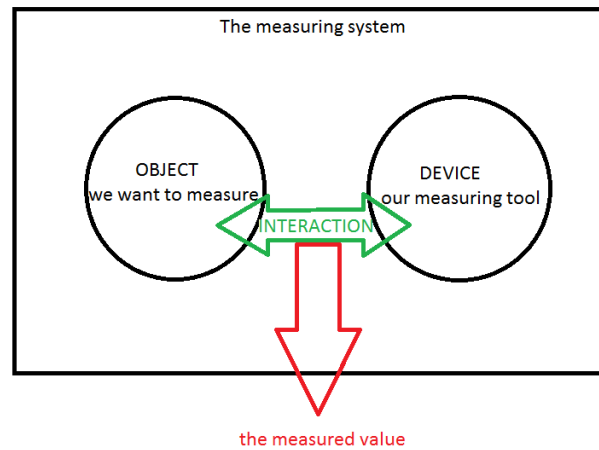


Figure 2: A simple model of the measurement

It symbolizes that a measurement is an operation of a system, the so called measuring system. It can be either simple or highly complicated. But the factors of it are these:

- object, something we want to get information about
- device or meter, that is a measuring instrument
- interaction between the object and the meter

The system will provide the result of the measurement. This information is of three elements:

- a magnitude, which is a numerical value of the characterization
- a unit, which is usually a standard, therefore the magnitude is the ratio of the measured quantity and this particular standard
- uncertainty, that inevitably comes from the operation of our measuring system.

In present days it is important to find and help our students to be good users of the information on the internet. A series of three videos are more than worthy to offer for students and teachers to learn about uncertainty: “Precision: measure of all things” [R2.3.]

2.2.2. Errors

I find that simple existence of uncertainty is hard to accept for secondary students. They find it easy to understand the result is the duo of a magnitude and a unit. They meet this phenomenon in everyday life (e.g. half a kilo of bread, 10 meters of fabric, 80 cm-long shoelaces, etc.) and in their studies in primary education. My colleagues often need to use the phrase “puppy or kitten” when pupils give an answer focusing only on the magnitude and omitting the unit after their work on a problem or an example that uses units also in mathematics or science class.

When explaining the importance of the interaction as the crucial component of the operation of the system, uncertainty can come clear as an important factor in the result. Uncertainty indicates the confidence level of the measurement. Random and systematic errors are represented in it. We need to emphasize that errors are not mistakes.

Random error

If we measure a constant quantity a number of times we are likely to gain slightly different values. We call this type of error random, because it can't be predicted from the previous values. We should not use our instruments in their extremes of their operating limits to reduce this error. Multiple measurements help us to estimate this type of error: making more measurements and calculating the average can give us a more accurate result.

We can demonstrate simply this type of error by using a digital tool, like a kitchen scale. We can place a light or heavy (compared to the operating limit) object on it. The last digit varies; still, the students can see that we measure the very same object. You can see on the photos in Figure 3 how it goes. We performed 5 measurements. The reading is 19g (2 times) and 18g (3 times) for the same scone. It is in the lower extreme span of our tool, since it measures to 5000g.



Figure 3: Demonstrating random error

Systematic error

The measured value contains an offset. It is an error that remains constant in a measurement setting. The measuring instrument determines the range of this type of error. The goal is to minimize this sort of error in the measuring procedure. We can use standardised protocols and instruments to minimize this type of error. It is also known as measurement or statistical bias. The sources of systematic error are: problematic calibration, the related manner of the measured quantity and drift.

We can also demonstrate this type of error with simple tools. The task is to measure the length of a rod with one provided tool. We can provide a meter rod, a ruler, a Vernier calliper and a micrometer screw. For our student our point will be obvious.

When discussing errors two notions arise. These are the process of authentication and calibration.

Authentication is an official analysis to prove that our device measures according to its protocol. In Hungary it is performed exclusively in OMH (Országos Mérésügyi Hivatal) and its branches. Devices that are used in commerce (scales, weights, utility meter gauges, etc.) must be subjects to the procedure regularly.

Calibration is a method to determine measuring characteristics of a given device. It a check to see if our measuring instrument is accurate.

We have discussed the two natures of error. What are the sources of error?

- the method of the procedure,
- the target of the measurement,

- the measuring device,
- the person implementing the measurement and
- effects from the environment.

Significant figures and error propagation

We can consider the accuracy of our data in secondary education by introducing the concept called significant figures [R.2.4.]. Now, our students can understand that using devices of greater sensitivity means that the result of the measurement is more accurate.

In mathematics we consider the values equal if there is only placeholder zero-s in a number. Like there is no use of writing 1.54 in the form of 1.5400.

Let us see what the digits mean in the last number. 1 – One integer, 5 – five tenths, 4 – four hundredths, and

-- in mathematics it is useless to emphasise 0 as it means none of the thousandths, and ten thousandths, but

-- in physics, it means that we could measure to ten thousandths accuracy, and the last digits are measured to be zero.

To see if the students can understand the idea we can ask them to make a group discussion and as a result of it to give a short reasoning on the following task (data should vary for the groups):

Your task is to interpret and show the difference in a practical example between these two results:

Peter: "The result is 3 decimetres."

David: "The result is 30.0 centimetres."

The answer is not a problem for our students. They come up with great examples rooting in their everyday life, like this reasoning:

"Both lads are gardening. Peter is a farmer; he is talking to his friends in a pub, explaining how his corps is growing. David is a student at Agricultural Secondary School; he is working

on his project. He is talking to his teacher about how his crops are growing with the fertilizer he is studying.”

The number of significant figures can be counted by a simple method: from the left we count the non-zero digits in the magnitude. If we use digital device, the display determines it. At analogue device we estimate the last digit, and consider this as significant figure.

In metrology the propagation of error is a great chapter. We use our results in formulae; therefore we need to talk about how the uncertainty of quantities influences the final result of a measuring project. I find that for our students working with the relative error is simple enough to work with. These are the rules we can teach them:

1. When two quantities are added (or subtracted) their determinate errors add (or subtract).
2. When two quantities are multiplied (are divided: a/b) their relative determinate errors add (subtract: e(a)-e(b)).

If we work with significant numbers, the rules are also easy:

1. When we add (or subtract) we take the minimum of the significant figures.
2. When we multiply (or divide) we add the number of significant figures.

In the calculations we use the rules of rounding.

We can show how it goes on an example, see Figure 4.

How does accuracy of data influence the results of calculations?

a) $0,03\text{ m} + 0,03\text{ m} = 0,06\text{ m}$
 $0,003\text{ m} + 2\text{ m} = 2\text{ m}$

b) $\frac{2\text{ kg}}{3\text{ m}^3} = 0,67\frac{\text{kg}}{\text{m}^3}$
 $\frac{2,00\text{ kg}}{3,0\text{ m}^3} = 0,66667\frac{\text{kg}}{\text{m}^3}$

Figure 4: A student's notes in class

2.2.3. The International System of Units (SI)

First, I find it important to show that a need emerged for this system in history. In literature we often meet the measure of capacity. Therefore our students have some units in their passive vocabulary from their reading experience. The first task I give is to investigate what we mean by “akó” and “icce”. They can use the internet to find the answer.

“akó”: <https://hu.wikipedia.org/wiki/Ak%C3%B3>

“icce”: <https://hu.wikipedia.org/wiki/Icce>

They can find that there were different measures of “akó”. “Akó” in German is Eimer, meaning 58 litres until 1762, and 56.589 litres later. The Hungarian “akó” widens the picture as a great example to show how complicated the system of unit used to be:

- the Pest akó meant 53.72 litres until 1700, then 54.94 litres, and 58.6 litres
- the Buda akó meant 53.72 litres

The unit called icce is a suitable unit for further study: the Hungarian icce means 0.848 litres; the Pozsony icce means 0.839 litres, the Transylvanian icce 0.707 litres.

In these chapters we can read about a number of other units for, like: pint, meszely, cseber(more types!), kanta, veder, köböl, barii.

For students with a background in the English culture I would give a similar task concerning barrel and gallon.

We can use old units for mass, area, volume length, etc.. Exciting items of information will enchant our students, and brings interest for them in topic. Some items I found most motivating for my students are:

- St. Steven, the first Hungarian king had a shoe-size of 48. We know it as the Hungarian foot is 31.26 cm (, whilst the English foot is 30.48 cm).
- Some Indian tribes had different units for length and distance.
- In the Hungarian Great Plain a unit of the area was “sheep”, referring to the area a sheep can graze in one day.
- The unit “mile” is the distance one can walk without a halt. Depending on the individual’s fitness it means different distances. The variations of this unit worldwide are 1.7 - 11.3 kilometres.

I find that most of our students are familiar with the units used either in Great Britain or in the USA. Still, for some classes it is of worth to analyse this topic.

The need of a consequent and coherent system for measures and units is obvious. There are some that we know of, like the MKS and CGS.

The early history of SI dates the French Revolution (1790s).

The basic requirements of the system were laid in 1860s in the British Association for the Advancement of Science: the system should contain base units and derived units. Base units are to be taken from nature. There are 7 mutually independent quantities and their units in SI. All other units are to be derived from these. The base units are materialized in the forms of standards. A set of standards were made and one of those were selected by random to be appointed as the international standard or prototype. These are kept in Sevres, in France. The rest of the standards were raffled among the nations that joined this system, they are the national standards. The Hungarian standards are in the OMH, an institution we have talked about already. Interestingly, the only western nation that has not adopted this system is the USA.

The seven base quantities and their units are shown in Table 1. I inserted some quantities in green to the corresponding base quantities, since these are of great help in the teaching process; partly because they are in the curriculum, partly because they are in everyday use.

quantity	symbol	unit	symbol
length	l	metre	m
mass	m	kilogram	kg
time	t	second	s
electric current	I	amp	A
electric charge	Q	coulomb	C
temperature	T	Kelvin	K
		degree Celsius	°C

amount of substance	n	mole	mol
amount	N	piece/bit/---	--
luminous intensity	I	candela	cd

Table 1: SI base quantities with extras

We need to understand what each of these units and their standards are.

Metre, the measure of length:

- 1793: 10^{-7} of the quadrant along the meridian through Paris, that is between the North Pole and the Equator

Teacher's note:

- Our students are familiar with this definition. They have learned about it most likely in geography. But, if we take a closer look at the circumference of the Earth we can find it slightly different from what we expect: not $4 \cdot 10^7$ m, but 40 075 km. By showing the details to our students like on the site (figure 5.): https://en.wikipedia.org/wiki/History_of_the_metre we can refer to what we have learned about errors.

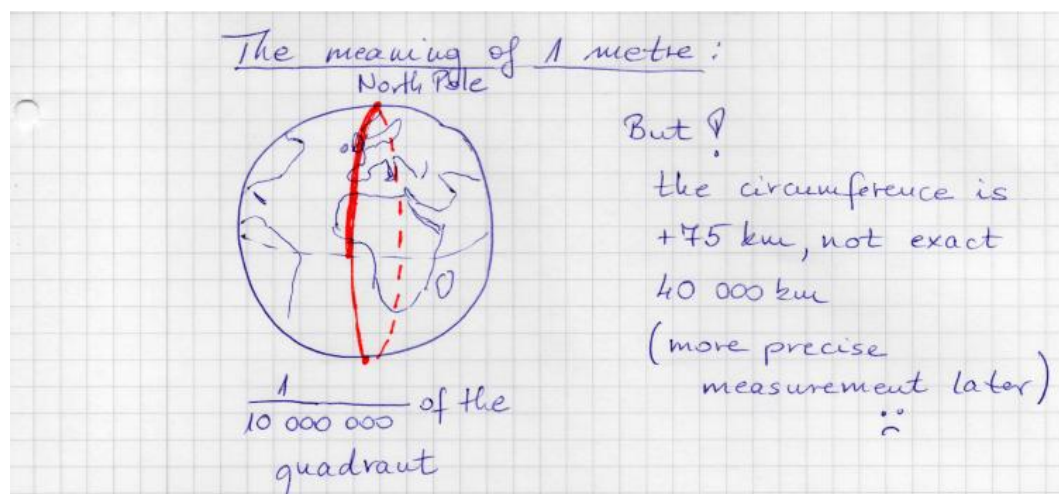


Figure 5: Student's notes on the definition of 1 metre

- The International Prototype Metre is an alloy (90% platinum and 10% iridium) bar, and 1 exact metre is the distance between two lines on it, when the bar is at the melting point of ice. We use this unit; we can confirm the link to everyday life also with showing a meter rod or Figure 6 [P2.1].



Figure 6 [P2.1.]: A monument of the world standard

- Since 1983: The distance travelled by light in vacuum in $1/299\,792\,458$ seconds.

Teacher's note: It is important to present one of the most famous Hungarian scientists in this field to our students. We, Hungarians are proud of Zoltán Bay (1900-1992), who insisted on the new definition. Also, we can find great information for public education on the internet [R2.5.]

Kilogram, the measure of mass:

- 1795: The mass of one cubic decimetre of pure water at its freezing point.
- 1875: The mass of one cubic decimetre of pure water at its maximum density.
- Since 1889: The mass of the International Prototype Kilogram, called "the Grand K".

Notes:

- The "Grand K" is a cylinder made of 90%platinum and 10% iridium kept in a protective double glass bell in Saint-Cloud, France. See Figure 7 [P2.2.]



Figure 7 [P2.2.]: The "Grand K"

- As by definition the unit of mass is the mass of the "Grand K", comparing it to the mass of other official copies (these happened in 1948 and 1989) we know that its mass changed. Now there is attempt to redefine the unit. The Watt Balance project

(US) and the Avogadro Project are the forefronts. We can learn more about it from the internet [R2.3. or R2.6.]

Second, the measure of time

- The unit of time comes from periodic phenomena.
- In medieval times: $1/86400$ of a day.
- Since 1967: The duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the caesium -133 atom.

Notes:

- The number in the definition can be interpreted easily to the students: We take midday and the consecutive one. We divide it to 24 hours, each hour to 60 minutes and each minute to 60 seconds. And $24 \cdot 60 \cdot 60 = 86400$.
- There is a need to talk about the “seconds-pendulum” [R2.7.]. One second is swinging from one direction and one more second to return. The time period is therefore 2 seconds. The name is misleading, we should discuss this.
- We also must bear in mind that a day can be obtained from the Sun or from the stationary stars and these two are different. [R2.8.]

Amp, the measure of electric current:

- 1881: The electric current flowing in an arc of 10^{-2} m of a circle of 10^{-2} m in radius that creates a field of one oersted at the centre.
- Since 1946: The constant current in wires that are placed parallel 1 m apart in vacuum, would attract or repel each other with a $2 \cdot 10^{-7}$ N for each meter. The wires are to be maintained in two straight, infinitely long conductors, of negligible cross-section.

Notes:

- The unit is named after Andre-Marie Ampere (1775-1836), we can meet the name of the unit in the form ampere as well.
- Both definitions refer to the magnetic field induced by electric current. Both involve units our students are not necessarily familiar with, like oersted and newtons-per-metre [R2.9.]. This is confusing for them. We discuss the definitions above, but a more illustrative definition is welcome by the students.

- Although the definition I use is not the official one, it shows the basic concept of SI. I use the definition with elementary charge:

“If in one second $6.242 \cdot 10^{18}$ electrons flow through the cross section of a conductor, we call it 1 amp.”

Kelvin(, and degree Celsius), the measures of temperature

- 1743: The centigrade scale is obtained by assigning 0°C to the freezing point of water and 100°C to the boiling point of water.
- Since 1967: $1/273.16$ of the thermodynamic temperature of the triple point of water.

Notes:

- Kelvin is named after William Thomson, 1st Baron Kelvin (1824-1907), the Scots-Irish scientist. Very often my students ask the question how it is that he is called Thomson, and also Kelvin. He was the first British scientist who was elevated to the House of Lords. Kelvin is a river that flows close to his laboratory in Glasgow. He became Baron Kelvin of Largs in Ayrshire. [R2.10.]
- The original definition is familiar to the students. Still, our task is to introduce Kelvin as the official unit. At this point of the course I often choose a simple figure to demonstrate the connection between degree Celsius and Kelvin. See Figure 8.

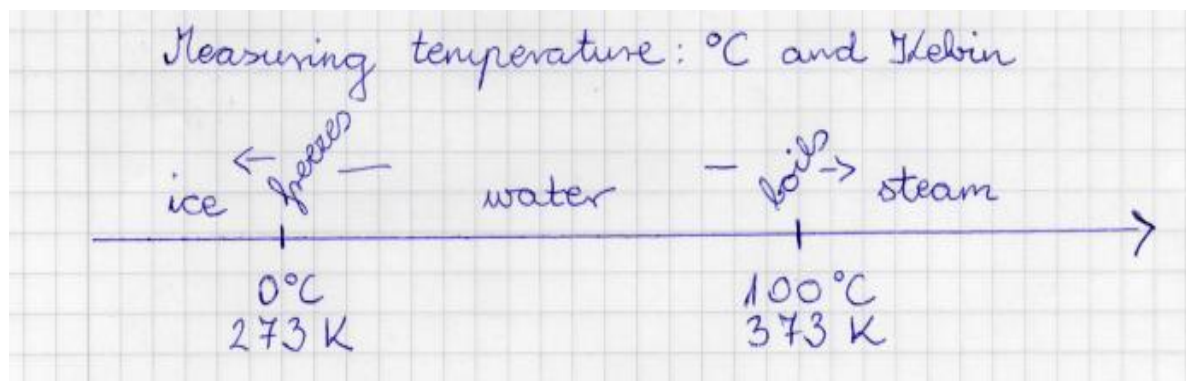


Figure 8: Degree Celsius, Kelvin and changes of state of water

A deeper study is can revisit this question when studying thermodynamics. When ideal gases are studied for the Gay-Lussac laws in both isobar and isochoric manners, both laws can be written in the simple form of direct proportion if we work in $\text{K} = ^{\circ}\text{C} + 273$ units.

Mole(,or piece), the measure of substance(,or amount)

- 1890: The molecular weight of substance in mass grams.
- Since 1967: The amount of substance of a system which contains as many elementary entities as there are in 0.012 kilogram of carbon-12.

Notes:

- Although we find the first definition also in literature, I find it problematic.

When studying mechanics we must keep in mind that weight and mass are different notions. This definition is very confusing, since weight is a type of force, and mass is a scalar quantity.

- When discussing the second definition we should appoint that number of atoms in the carbon-12 is $6.022 \cdot 10^{23}$, and we call it the Avogadro constant [R2.11.] or in the German literature the Loschmidt constant.
- In our studies we usually use a quantity similar that is why I mention it here. This quantity is called amount. The symbol in literature is N, and it is the answer to the question: "How many?". It has no unit, since this later is a ratio of one single entity.

Candela, the measure of luminous intensity

- 1946: The brightness of the full radiator at the temperature of solidification of platinum is $6 \cdot 10^5 \text{cd}$ every m^2 .
- Since 1979: In a given direction of a source that emits monochromatic radiation of $5.4 \cdot 10^{14} \text{ Hz}$ and that has a radiant intensity in that direction of $1/683 \text{ W/sr}$.

Notes:

- The wavelength of the radiation mentioned in the first definition is $555 \cdot 10^{-9} \text{m}$.
- I find it enough to demonstrate it for our students with a common candle, since its intensity is roughly 1cd. Or to show that a 100W light bulb has an intensity of 120cd.
- We should also mention that lumen and lux are photometric quantities, as these are normally written on the box of the light source, and therefore our students can make the connection between their everyday life and the content we cover in class.
- This quantity is very rarely used in physics, especially in public education. It is not in the syllabus, but light bulbs are of everyday use, therefore it is a great opportunity to strengthen the link between everyday experience and scientific knowledge.

Prefixes

Once we have an agreement on the base unit we may find that these are either far too big or far too small for our project. Prefixes are used to solve this issue. We can find the prefixes in the table below (Table 2, [P2.3.]).

Standard prefixes for the SI units of measure

Multiples	Prefix name		deca	hecto	kilo	mega	giga	tera	peta	exa	zetta	yotta
	Prefix symbol		da	h	k	M	G	T	P	E	Z	Y
	Factor	10^0	10^1	10^2	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}
Fractions	Prefix name		deci	centi	milli	micro	nano	pico	femto	atto	zepto	yocto
	Prefix symbol		d	c	m	μ	n	p	f	a	z	y
	Factor	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

Table 2 [P2.3.]: Prefixes of SI

Some further remarks on orthography

Values can be adjectives. We can use like “an 80 cm shoelace” or “an 80-centimetre shoelace”.

The name of the units are common nouns, we use lowercase letters to start. It is so also if a unit is named after a scientist, like newton after Sir Isaac Newton. The name of the unit is newton, the symbol is N. In the case of degree Celsius degree is the unit.

The value of a quantity is written as a number followed by a space and the symbol of the unit. Symbols are not abbreviations, no full stop is needed. Prefixes come before the symbol of the unit without a space. Symbols do not have plural form. So we write 4m not 4ms. (This later would mean 4 milliseconds).

Extra motivating possibilities for Hungarians

For some classes, if time allows I show at least some minutes from a video. This is a series of 6 cartoons; each episode is 10 minutes long. Tamás Szabó Sipos made this series to advertise the introduction of the SI in Hungary for the public. It has an excellent sense of humour and every piece of the information it uses is correct. Often I show a few minutes only from one of the episodes, and I find the students have watched it at home, and they use the jokes or the melody in class. <https://www.youtube.com/watch?v=JyJBy24MIGw>

The most common old Hungarian units are available for study on this link: <http://gyorkos.uw.hu/mertekegysegek.htm>

2.2.4. The Record of Measurement

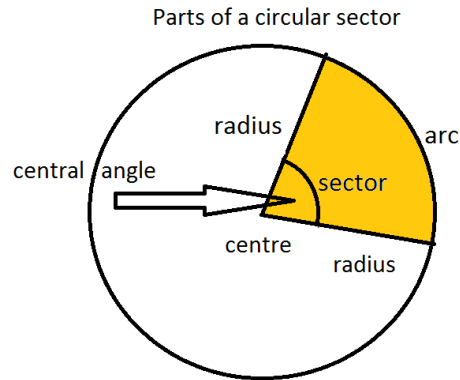
In engineering and also in research it is important to make the documentation of our work. I worked out a type of documentation that helps our student most to understand the steps of scientific cognition, and the analyzed problem itself also. In this part of the physics course I use two projects (and therefore work on two RoMs) to help my students to get familiar with the scientific method.

A project done together: Specifying angular measure

I find it important to strengthen the connection between school subjects. This first project is dedicated to this idea: being also a teacher of mathematics, I have experienced that our students find it difficult to understand and work with it, although it emerges nearly every year in the Hungarian National Curriculum.

As we progress in cognition we also understand what each part of the Record of Measurement stands for. Table 3 shows how the students get familiar with the method on an example. I do it as an outdoor activity if the weather allows.

RECORD OF MEASUREMENT	
Name (+mates):	
Venue:	
Date:	
Investigation:	<i>Measuring Angles Project</i> <i>Learn how angles can be measured by measuring length only</i>
The scientific background of the project:	
<ul style="list-style-type: none"> • Roger Cotes in 1714 described this nature-based measure of angles. The term, radian first appeared in Belfast, at Queen's Collage in an exam paper, in 1873. • Till 1995 it was an SI supplementary unit, now it is considered as a derived unit. • In a figure basic notions of a circular sector are shown. 	



- We define the measure of the central angle by the ratio of the length of the corresponding arc and the length of the radius in a circular sector.

$$\hat{\alpha} = \frac{\text{length of the arc}}{\text{length of the radius of the circle}} = \frac{a}{r}$$

- Another well-known measure of angles is degree. We measure it with a protractor. The full angle measures 360° .
- It is used in the study of circular motions.

Steps:

1. We draw circular sectors of different angles and radii. We will investigate 0° , 30° , 45° , 60° , 90° , 180° , 270° and 360° . The radii can vary from 10 to 100 cm.
2. We measure the length of the arc using yarns, and the length of the radius using a tape measure.
3. We divide the readings to get the angle in radian.

$$\hat{\alpha} = \frac{\text{arc}}{\text{radius}}$$

4. We repeat steps 2 and 3 for each sector

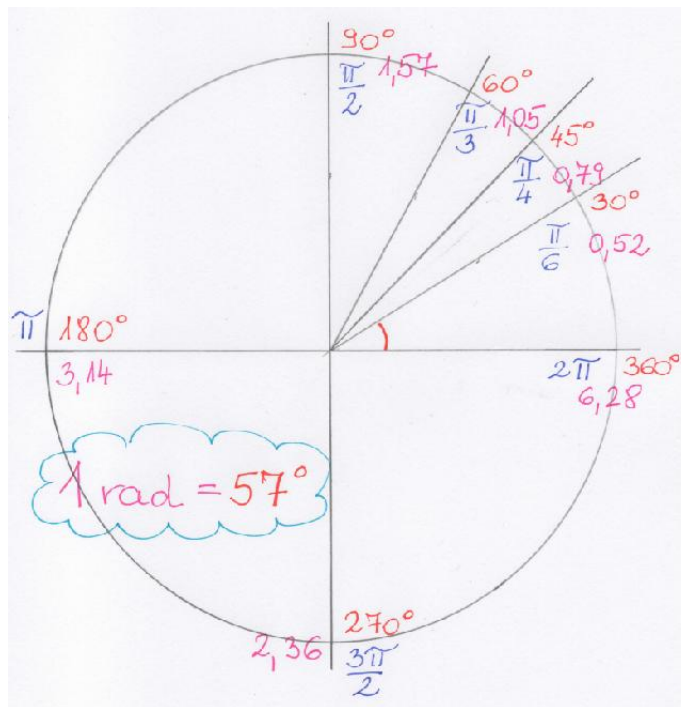
Tools:

yarn, choke, tape measure

Readings and analysis:

angle	30°	45°	60°	90°	180°	270°	360°
arc							
radius							
angle in SI							

Conclusion:



Notes:

We used the <https://en.wikipedia.org/wiki/Radian> site for our studies.

The thickness of the choke's trace made it difficult to measure the length of the arc and radius precisely.

Also, we made our readings from the tape measure to cm accuracy.

Table 3: A RoM on angular measures

I have experienced in my practice that months later, when my students learn about this topic in math class, my colleagues are happy to hear about our project from the students. They regularly give the feedback that this project helped their work in the study of circles.

This project is usually carried out in the yard of the school, and is of very low cost.

The Cinderella project

Cinderella or The Little Glass Slipper is a fairy tale very popular all around the world. We know the story mostly in its version told in the Brothers Grimm in 1812. In the story she needs to pick lentils out of ashes. In our project the manual activity is very similar: we count pepper-grains.

The investigation is “How many pepper grains does a package contain?”

The project is a variation of the SI base quantity, the amount of substance. The students are encouraged to look back on what we have covered in the topic when focusing on the theory.

In this project the students count how many grains they have in a package using different methods. These methods may be

- a) counting one-by-one
- b) making groups of 10, counting the groups, and adding the rest
- c) making groups of 50, counting the groups, and adding the rest.

Very often they face the problem of not having exactly the same number of grains with the same method. This gives an excellent opportunity for the teacher to revisit what they have already discussed about errors. As the studied theory comes alive in a practical situation it consolidates the knowledge and also demonstrates the duo of theory and its application. This knowledge goes to a thorough level of cognition, gets a deeper understanding.

As the groups are working they realize that their results are different. The difference of the groups’ results is worthy of a study. Counting how many grains are there in one particular package does not give the best answer to the question. Making simple statistics of the results of different packages is evidently a feasible solution. Thus they also understand the need of cooperation in scientific research.

The class also needs to work out a table setting to logically show the results. In my practice I found two appropriate solutions.

Solution 1.(with details) is demonstrated in Table 4.

Groups					
method a)					
method b)					
method c)					
grains in the package					
average					

Table 4: Number of grains in packages, a possible table

Solution 2. (of two tables) is as follows in table 5.

Our package	method a)	method b)	method c)	our average

for more packages

Group							eventual average
average							

Table 5: Number of grains in packages, another possibility

The students make a note on their average as the element of the set of averages, like: “Seemingly in our package we had just about as many grains as all the other groups had.”

When finishing the project the issue of errors often occurs again. Namely some grains happen to “disappear” somehow: either some youngsters tend to eat them, or I find a few on the ground after collecting the equipment. The irreducible presence of error in a measurement turns into the focus again, thus vouching the previously so strange idea.

Using these data also gives an opportunity to practice statistical notions (like modus, median, mean, extent, etc.) for the math class.

A program for the unit

In teaching having the feedback from our students is a very important issue. It may also convince us that changes are necessary in our plan. Still, it is important to have a plan that we can use as a guideline in our work. Based on my experience this is how I plan the unit for my classes. See the plan I work with for 7 classes in the Appendix.

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3. What is the Student's Measuring Project?

We can experience a huge gap between experience based or active learning and the learning possibilities in real classrooms. Teachers are eager to see examples how to make the best use of a field trip or a visit. They are seeking for proposals how to implement the experience in their everyday teaching and how to best prepare a group for an informal event (Figure 9, [P3.1.]). There are excellent teachers who do their best. But some would need support and proof to give new solutions a try.



Figure 9 [P3.1.]: Great tries to bridge the gap

One of the sharp edges of methodological research is where science centre pedagogy meets the didactical and methodological research of hands-on, minds-on didactics. The same question is in the focus: "How can we build a bridge to fill the gap?" (Figure 10,[P3.2.]).



Figure 10 [P3.2.]: New results can offer solutions

3.1. Active pedagogy; “hands-on, minds-on” didactics

Teaching methods are different in terms of retention. In case one can’t remember what one learned, the time spent learning is wasted.

The learning pyramid model of pedagogy (Figure 11.) helps to explore how different teaching methods affect retention rates. Dale’s cone of experience highlights the difference between passive and active ways of learning. It is a very popular model, but very often misunderstood. “...the Cone of Experience is visual model, a pictorial device that may help you to think critically about the ways in which concepts are developed.” [R3.1.]

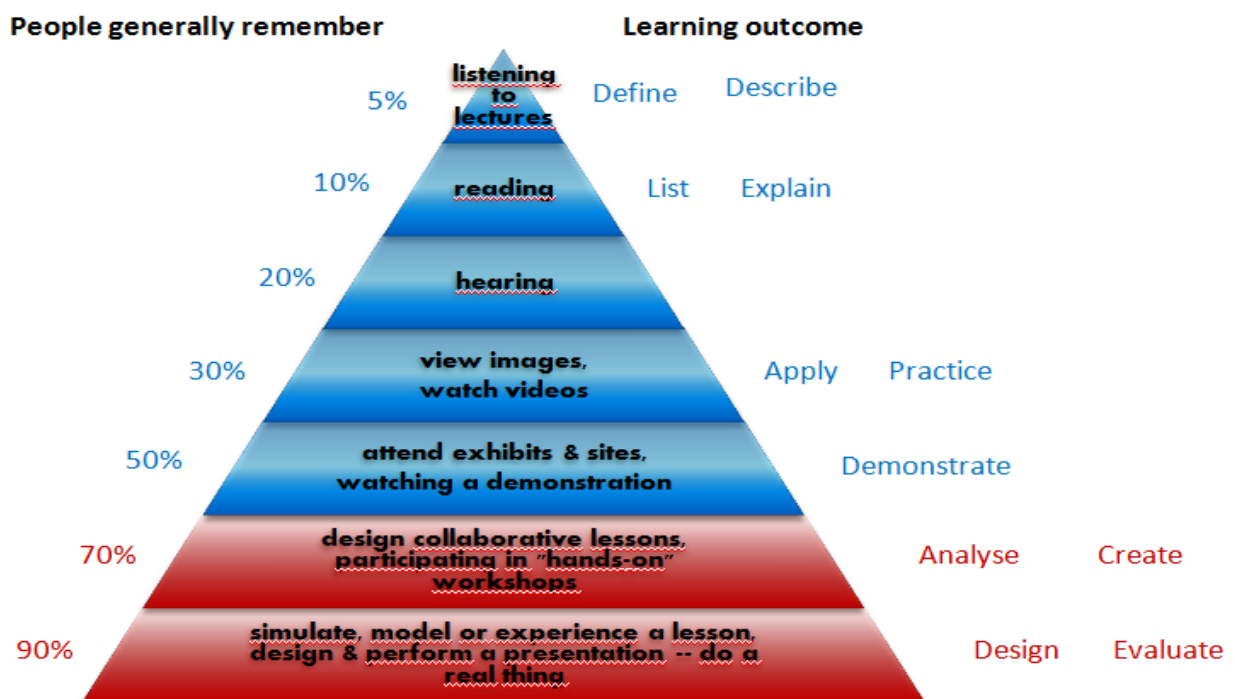


Figure 11: Dale’s cone of experience making a difference between passive and active ways of learning

The idea of active learning can be dated to the beginning of the 20th century. Science centres were invented, elaborated and implemented in this milieu. „Hands-on” experiments are of multi-purpose, and are worthily called active way of learning. As we can see from the model above “hands-on” experiments are not used only for working with notions, introducing and measuring quantities, understanding interdependence, defining notions, practice the use of literature, finding explanation, use of graphs or formulae, being aware of

applications, listing influences, apply phenomena, etc.. They also include even more means, like: checking interdependence, summing up the gist in a study, discussing ideas, working in team, informing others, preparing for projects, evaluating a study, solving problems, planning an investigation, carrying out a study, verifying a law, and many more active ways of learning. Surely, we can state that “hands-on” didactics show a lot in common with IBL (Inquiry Based Learning). In IBL research is regarded as a theme which underpins teaching. „Hands-on” measurements are widely used in IBL.

The triumph of “hands-on” didactics changed the concept of learning and redefined the concept of teaching. But, today we are investigating a discerning didactics, which is like a subset of the previous one, called “hands-on, minds-on” didactics. Its speciality is that it focuses on the meta-cognitive and idea-building work. In this sense it is also an intersection with constructivist pedagogy. The 3 w-questions are crucial and point further than the key questions of “hands-on” didactics [R3.2.]. These are for the students:

- What are you doing?
- Why are you doing it?
- What does it help you do that is important?

In Hungary József Öveges (1895-1979) is a legendary representative of the history of physics teaching. He was a pious monk, a great teacher and physicist. His mission in his job was to make science enchanting for everybody, whilst he never let the scientific standard decrease. He made TV shows, wrote books, etc. One of his books is very special from our point of view; its title is “Let’s do experiments and Let’s think”. In this book he presents 323 experiments with tools that we can find at home, most of these experiments are with possible variations. In each case he gives the explanation, and turns our focus to everyday applications and observable phenomena. He is definitely a precursor of “hands-on, minds-on” didactics in Hungary.

„Hands-on, minds-on” didactics is surely considered as one of the best teaching practices. The University of Akron introduces the method with these words [R3.3.]:

„Many people might say, "Gee, those sound like buzzwords to me. Do they have any substance?" The answer is yes. If children are generating their own ideas in a student-

centered classroom, they need the freedom to be physically active in their search for scientific knowledge. How can children begin to understand the nature of the world in which they live if they experience it vicariously? For this reason, the majority of the activities that kids perform should be physical explorations. Physical explorations not only make the concepts more tangible but also appeal to children's diverse learning styles and take advantage of their multi-sensory strengths. If children are physically involved, they are more apt to be mentally engaged.”

Also, based on their practice and skills some of the teachers give it a try to widen their palette of methodological tools, and shares his –mostly- qualitative results. These provide a lot of material for the basic research of methodology, since most of them are of great use. Here is a list of some that are worth studying:

- <http://www.teachhub.com/actively-engage-students-using-hands-minds-instruction>
- <http://www.science.vt.edu/hands-on-minds-on.html>
- <https://www.teacherspayteachers.com/Store/Hands-On-Minds-On-Learning>
- <http://handsonmindson.org/>
- <http://sciencestandards.org/MSBOOK.htm>

We can find also “step-by-step”, cook-book-like manuals on how to implement in our methodology and teaching practice. Like this video:

- <https://www.youtube.com/watch?v=hpR0zmIkkU>

“Hands-on, minds-on” didactics is also a cutting edge of research. In 2007 Ünal and Ayas published their article titled “A hands-on activity to promote conceptual change about mixture and chemical compounds” [R3.4.]. In this article they are mapping preconceptions, prepare and carry out an intervention, and their result indicates positive effects both in qualitative and quantitative manner.

In 2011 Ates and Eryilmaz published their study on the “Effectiveness of hands-on and minds-on activities on students’ achievement and attitudes towards physics” [R3.5.]. Their conclusions are as follows.

- „However, the hands-on/minds-on activities did not increase the students' attitude towards simple electric circuits significantly more than the traditional method did.”
- „During observations, it has been noticed in this study that students were not used to perform hands-on/minds-on activities, so they had some difficulties following the manuals and doing the activities. The reason might be the fact that in their regular lessons, they were used to listening to their teachers and taking notes during lectures without performing experiments on their own.”
- „However, we may give some recommendations. For example, some courses including hands-on/minds-on activities might be developed in universities to familiarize prospective teachers with linking physics with daily life phenomena. Moreover, in-service trainings, workshops or projects may be organized for the teachers allowing them to gain practical experience and proficiency with hands-on/minds-on activities. Lastly, materials consisting simple set-ups or low-cost items that can be found and assembled very easily should be developed and provided to the schools in order to implement the curriculum efficiently and effectively.”

From this study a few points grabbed my attention. They proved that working with this method in some points of view is not significantly better than working with the traditional ones. But it is also a proof that it is not significantly worse. Therefore they can deservedly conclude that this method has the right to be listed among the offered types of teaching methods.

The other point is that they used these activities for a relatively short period of time. They mention in their article. Getting familiar with a method needs time. The new approach takes time to mature for students and teachers as well. In my research I tried to eliminate this problem: I kept in mind that getting familiar with new techniques in learning takes time and practice.

3.2. The Student's Measuring Project

The Student's Measuring Project (SMP) is a good example in methodology how "hands-on, minds-on" didactics can be implemented in our teaching practice. These are the main steps respectively.

- raising a problem
- understanding the problem
- preparing study with measurements included
- collecting the data
- analyzing the data
- derive a conclusion
- interpret our conclusion

For studying the effectiveness in all three aspects of competence in the practice of physics teaching I worked out a set of SMPs for my students.

Since currently physics is a 3-year course for secondary school students in public education I aimed to spread these evenly for the time period I can work with the groups. Also, these projects needed to fulfill a number of other requirements, since they are worked out to be offered to public education for anybody. Therefore the SMPs

- must relate to the current (national) syllabus
- must be of low cost
- must have everyday applications
- must contain measuring experiments (data collection) that can be done in a 45 minute lesson
- must be extra-safe for the students.

To follow the mentioned steps the students are to make a product to show what they have been doing. They are to sum up their work in a Record of Measurement (RoM).

The expounded type of the RoM seems to be the best to meet our goal in teaching. I also add some notes for the teachers. These are in Table 6.

RECORD OF MEASUREMENT	Notes for the teachers
<p>Name (+mates):</p> <p>Venue:</p> <p>Date:</p> <p>Investigation</p>	<p>We need to remember that our students are teenagers. The aim of our work is also to help them to give direction in their behaviour. This part underpins compliance in their personality. The pedagogical goal is in the focus.</p> <p>The students make the experiment with their mates. They show who they have the same readings with.</p> <p>The exact spot and date of the measuring experiments comes here.</p> <p>They name what the title of the project is, and so they specify the purpose of the work.</p>
<p>The scientific background of the project:</p>	<p>This part is to direct the student's attention to the notions, their interdependence, laws, etc. that are important elements of the theory they must be familiar with.</p> <p>I noticed that some students show special attention to the life of physicists and the historical background.</p> <p>In some cases I find not only possible applications, but also cross-curricular information of curiosity, put either in this part or in the "Notes" part of the RoM. These are more than welcome!</p>
<p>Steps:</p>	<p>In this part students have to think over clearly what they should do. They need to plan how they can collect data, how they will analyze these. They design a scientific investigation.</p>

Tools:	They need to name the tools they need for their measuring experiment.
Readings and analysis:	<p>The students have to find a way how they can write down their readings that they got in the measuring experiment in class.</p> <p>Then, they do the planned (in most cases mathematical) analysis with their data keeping in mind the goal of their study.</p>
Conclusion:	<p>An important step in active learning is evaluation. The students have to get to a conclusion in their work. They need to present in a simple way what their conviction is in the studied problem.</p> <p>If they can't verify a law, that is acceptable. But in my practice I worked out projects in which the possibility of this is close nil. These are "student-proof" projects.</p>
Notes:	<p>Notes on error, coincidences, any observations, or even questions are to be put here.</p> <p>If a student is eager to find any linkage to what is present in his life, he is asked to share.</p> <p>When working on this part of the project students also learn the need for reference and the way of citation.</p>

Table 6: The set-up of RoMs

3.3. Examples of SMPs for secondary education

I find it important to note that preparing our students for working with SMPs they need to get a short insight to measurement theory. As I had not known a course designed for 15-18 years old students of physics, studying the subject in public education, I worked out a

chapter, find it in chapter 2. In “The Wonderful World of Measurements” chapter I have already described two introductory projects, named “Measuring angles with SI base quantities” and the “Cinderella project”

In the following table (Table 7) I sum up the title of the investigation and the notions, laws and other specialties of these projects.

grade	title and specific task	notions, methods, interdependence	academic goal
10.	<u>Measuring angles project</u> Learn about how angles can be measured using length only	-length -radian and degree units	- understanding the difference between base and derived quantity in SI, and between a quantity and its units -preparing the concept of radian for math
	<u>Cinderella project</u> How many pepper grains are there in a 20 g package?	-amount -introduction to statistical analysis	-understanding that collecting the data from one target is not enough -getting started with basic statistics
	<u>Mikola tube project</u> Study how a bubble moves in a Mikola tube	-length -time -direct proportionality -(average) velocity	-investigating linear steady motion -understanding the difference between kinematic and dynamic study -understanding the difference between distance and dislocation -getting to know what direct

			proportionality means (graph method and ratio method)
	<p><u>Hook's law project</u></p> <p>Study how the length of a spring changes when se stretch it</p>	<ul style="list-style-type: none"> -length and elongation -force and weight -direct proportionality -spring constant, k(or D) 	<ul style="list-style-type: none"> -understanding the difference between length and elongation -understanding weight of a load -a great example how to make direct proportionality by defining a new notion from linear graphs -calculating the spring constant -application: measuring force - Hook' s life might be motivating for own study
	<p><u>Bouncer project</u></p> <p>Double-check the dynamic formula for the harmonic oscillation</p>	<ul style="list-style-type: none"> -time period -spring constant -mass 	<ul style="list-style-type: none"> - understanding time period - measuring mass, calculating weight and spring constant - giving credit to a formula -all-in-all demonstrating how theoretical results can be double-checked by experiments (reinforcing the Galilei turn)
	<p><u>Measuring gravity project</u></p> <p>Using a pendulum measure the value of</p>	<ul style="list-style-type: none"> -pendulum - length -time period 	<ul style="list-style-type: none"> -an experiment with very simple tools (a self-made pendulum) eliminating the fact that free fall is happening too

	gravitational constant, g		fast -measuring length and time -using a formula for calculations (-also introducing the Párkányi machine and the high-tech one with light gates and computer)
11.	<u>Thermal expansion project</u> Estimate the temperature of a metal rod by its thermal expansion	-temperature -length and elongation -linear graph -coefficient of thermal expansion	-the students can study how the length of a metal rod increases when it is heated -using literature they can give measurement based estimates to quantities (like temperature) in physics -suitable only for students who are disciplined, or in smaller groups, since it can be dangerous
	<u>The cool(ing) project</u> Characterize how a cup of hot water is cooling. Is the change linear?	-temperature -time -non-linear graph	-introducing a very simple phenomenon that is of exponential manner -measuring time and temperature -the graph is not a hyperbola, and our students might need help with getting this important idea (-read more in pages 51-55)

	<u>Boyle' law project</u> Study Boyle's law on ideal gases	-Boyle apparatus -volume -pressure -indirect proportionality, hyperbola	-by measuring volume and pressure the students can find indirectly proportional notions - a good example to study isothermal processes
	<u>Ohm's law project</u> Study Ohm's law	-voltage -electric current -direct proportionality -resistance (and maybe conductivity)	-the very famous law of electricity -measuring quantities we do not sense: current and voltage by meters -plotting a graph -calculating resistance
	<u>Discharging a capacitor project</u> Characterize how the voltage of a capacitor is changing during discharge	-voltage -time -non-linear graph	-measuring voltage and time -plotting a graph that is of exponential nexus
	<u>Snell's law project</u> Double-check Snell's law on refraction. Also, determine the relative index	-Hartl optical disk -angle -trigonometry in physics ($\sin\alpha$) -direct proportionality -the refractive index	-measuring angles by protractors -use of trigonometry - double checking Snell's law - calculating the refractive index
	<u>Measuring the speed of sound project</u>	-standing waves -fundamental mode and	-measuring length -the calculation is simple ($c=f\cdot\lambda$)

12.	Measure the speed of sound using a diapason	<p>higher harmonics</p> <ul style="list-style-type: none"> -length -wavelength -frequency -speed of a wave 	<p>where $\lambda=4 \cdot l$), but understanding the theoretical background of standing waves is not easy for our students</p> <ul style="list-style-type: none"> -when working on this project they are encouraged to think about reflection, interference, fundamental mode, higher harmonics, nodes and antinodes
	<p><u>Optician's project</u></p> <p>What is the optical power of the lenses?</p>	<ul style="list-style-type: none"> -object distance -image distance -focal length -optical power (and its unit: dioptré) 	<ul style="list-style-type: none"> -studying the idea of magnifying glass, glasses, etc. -strong link to everyday experience -meeting real image (on screen) -measuring length -calculation with reciprocals
	<p><u>Investigating half-life project</u></p>	<ul style="list-style-type: none"> -number of active nuclei -time -exponential curve 	<ul style="list-style-type: none"> - plotting a graph -getting started with modeling as a scientific method -understanding exponential nexus
	<p><u>The (radio)activity project</u></p>	<ul style="list-style-type: none"> -number of active (parent) nuclei -Geiger Muller tube -Am-241 sample 	<ul style="list-style-type: none"> -facing the statistical manner of some phenomena -“in-situ” measurement

Table 7: SMP for insertion in class

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4. Similarity theory and its feasibility in science methodology

4.1. Similarity theory in a nutshell

Similarity theory is not a well known discipline among teachers. Still, it is often used in many fields of science and engineering. It is a bridging between theoretical and practical engineering.

Its use can be exemplified in a number of research areas as well.

Research of car industry is a great way to demonstrate the use.

- Carrying out “direct” experiments with car-bodies is of high cost and time consuming in statics. If we find a law of modelling we can gain the learning in better conditions. Making the difference between essential and negligible conditions is not always easy. No doubt the working of the horn is unlikely to be an important factor in the study of a car-body freefalling from a height of 10 metres.
- Vaporization is an essential process in cars. It is characterised by a number of attributes: the geometry of the vaporizer, the quality of the material to be vaporised, the pressure, the angle of the realized beam-cone, the radius of the droplets, the effectiveness of the vaporiser, etc. Focusing on some variables can give us measurements that are more convenient for carrying out.

We can get examples from more disciplines as well, like: conduction of heat, diffusion, aerodynamics, turbulent flows, hydrodynamics, mass transport, thermo-diffusion, drying, oscillation of string or membrane, ventilation, etc..

First, we need to define what we mean by similar phenomena, and what the sufficient terms are. Secondly we can focus on the necessary terms.

The definition

We appoint a phenomenon. We need to find its state defining quantities:

$$x_1, x_2, \dots, x_n,$$

It is often called as state-vector (denoted by \underline{x}). These quantities suffices an “inner” function, we often call these laws, theorems or principles:

$$F(x_1, x_2, \dots, x_n)=0$$

In most cases it is a differential equation. We can call it a base-equation.

Two phenomena are homogeneous if the structure of their base-functions is identical. In this case

$$F(x_1, x_2, \dots, x_n) = 0$$

and

$$F(x'_1, x'_2, \dots, x'_n) = 0$$

simultaneously.

Let's consider the transformation C, where

$$\underline{x} = C\underline{x}'.$$

If $F(\underline{x}) = F(C\underline{x})$ is true, we say that the base equation is invariant for C transformation. If C transformation is a special homogeneous linear tensor of a diagonal pattern, we call C a similarity transformation. In this case the phenomena are similar.

In a pair of phenomena we call the phenomenon characterised by \underline{x} the model, and the one characterised by \underline{x}' the prototype.

In some cases the transformation of similarity is not easy to determine in a mathematical form. Dimensional analysis should be performed.

4.2. Similarity theory in physics methodology –is it possible?

“The book of nature is written in the language of mathematics.” The quote is from Galileo Galilei, who proposed in his era that God wrote two books: the Bible and the Book of Nature. He considers the Bible as the Word of God that should be interpreted by theologians, whereas the Book of Nature should be interpreted by mathematicians.

We can make a study of the natural laws in public education from a new perspective, namely from the aspect of similarity theory. A certain type of differential equation means a certain type of solution in its mathematical form.

In the public education of science we can distinguish these mathematical formulae:

- linear functions, this set includes direct (and in a way indirect) proportionality
- root (and power) functions, the square root is in the dominant role
- inverse square functions
- trigonometric functions that are found always in periodic phenomena
- exponential (and therefore logarithmic) functions.

Traditionally in physics the chapters are as follows:

- mechanics,
- thermodynamics,
- electro-magnetism,
- optics, and
- modern physics.

I will follow this subdivision as I introduce the idea in the example of linear functions, and when I negotiate the role of exponential functions.

4.2.1. Linear functions in physics chapters

Two quantities (like x and y) perform a linear function, if there are two parameters (like a and b) to fulfil the following equation:

$$y = a \cdot x + b$$

Plotting a graph we gain a line, this is the origin of the name: linear. (Fig. 12,[P4.1.]

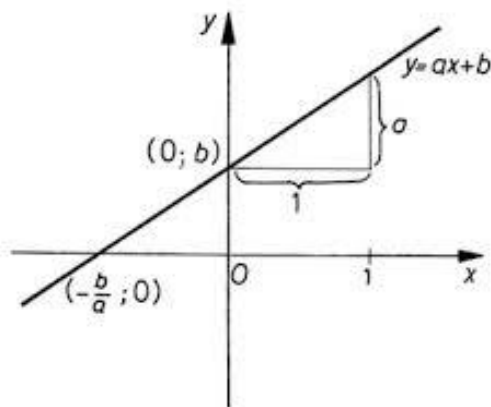


Figure 12 [P4.1.]: Linear nexus

If $b=0$ the graph crosses both axes in the origin. This case is called direct proportionality. This implies the possibility of defining a new quantity, as it means that the ratio of two quantities is constant. In this case

$$y = a \cdot x$$

or

$$y / x = a$$

, which is the definition of indirect proportionality.

We can easily find examples for linear nexus, since most of the laws we teach are examples of this interdependence.

In mechanics we can mention the distance travelled as the function of time in a Mikola tube by a bubble (of given tilt angle), or Hook's law for springs.

In thermodynamics when a given amount of gas is studied in either isobar or isochors conditions, in both cases the graphs will be linear: volume versus temperature, pressure versus temperature respectively.

In electro-magnetism Ohm's law is a great example: we take the electric current versus voltage graph.

In optics the first law of the opticians states direct proportionality between the size and the distance from the lens for image.

In modern physics we can mention the famous Einstein equation for the photo-electric effect, the kinetic energy of the emitted electron as the function of the incident radiation.

The following table (Table 8.) shows these. I highlight in blue the ones that are of direct proportionality. The quantities that can be defined are respectively: velocity (v); spring constant (D or k); --, --; resistance (R), or its inverse, called conductivity; enlargement; --.

the phenomenon	the quantity that is changing (y)	the quantity versus which one we study (x)
the Mikola tube experiment	the distance travelled by the bubble (l)	time elapsed (t)
Hook's law	the length of the spring (l) the elongation of the spring (Δl)	the weight of the load (F)
Gay Lussac's 1 st law	the volume of the gas (V)	the temperature of the gas (T in °C) the absolute temperature of the gas (T in K)
Gay Lussac's 2 nd law	the pressure of the gas (p)	the temperature of the gas (T in °C) the absolute temperature of the gas (T in K)

Ohm's law	electric current (I)	voltage (U)
description of the image	the size of the image (I)	the image distance (I)
Photo-electric effect	energy (or frequency) of the incident photon	kinetic energy of the emitted particle

Table 8: Linear nexuses in secondary physics

4.2.2. Exponential laws in the chapters of physics

If the nexus between y and x as variables is in the form of

$$y = y_0 \cdot a^{k \cdot x}$$

, we are facing an exponential nexus. Here a , y_0 , and k are constants. The graph is like in Figure 12 [P4.2.].

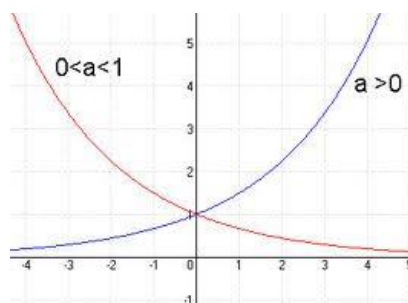


Figure 12 [P4.2.]: The exponential graph

In secondary courses of physics our studies are limited to the case $a < 1$. We call it the exponential falloff. We can castigate with a negative signal in the exponent if it is necessary. The base is often e , the Euler number. The fact, that e is not in the curriculum of mathematics makes it vital to study deeper what we can teach and how in this field in science.

In mechanics collisions that we can typify with the help of the collision constant, k ($0 < k < 1$) is a god example. Qualitative study is restricted to mentor classes, but with a ball we can easily exemplify the phenomenon: the maximum height of a bouncing ball on lever ground shows the exponential falloff (Fig.13, [P4.3.]).



Figure 13 [P4.3.]: Ball bouncing

But also damped oscillations can be shown for our students. The amplitude is following the exponential falloff (Fig. 14, [P4.4.]

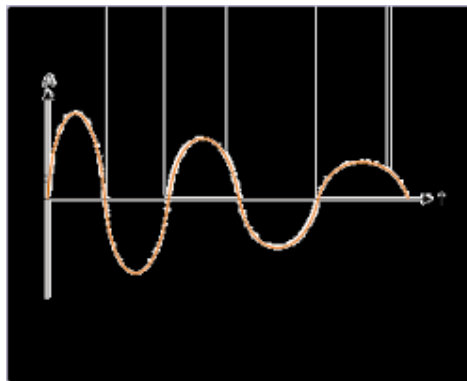


Figure 14 [P4.4.]: Damped collision

In thermodynamics the cooling law is an example we can turn to in our teaching practice. I dedicate a whole chapter to the methodology of this law (Fig. 15, [P4.5.]).



Figure 15 [P4.5.]: Cooling

In electro-magnetism discharging a capacitor is a great example. You can find more about it in the chapter “Peripatetic mentor classes”, in the sub-chapter “We can see voltage”.

In optics we can observe a series of images even on a plane mirror. The intensity of these can be described by an exponential falloff. What is behind it? A plane mirror is made using a thin plane glass, one surface of which is made reflective by silvering. This is covered by a thin layer of lead oxide thus forming the back of the mirror. We discuss the role of incident and reflected rays when discussing how the virtual image is created. But every surface reflects some of the incident light, so does the surface of glass of our real plane mirror. Only the refracted light can reach the reflecting surface at silvering. There it does reflect. And refracting to the air also, a usually negligible amount of light gets reflected back thus staying in the glass. The next figure shows how it goes (Figure 16)

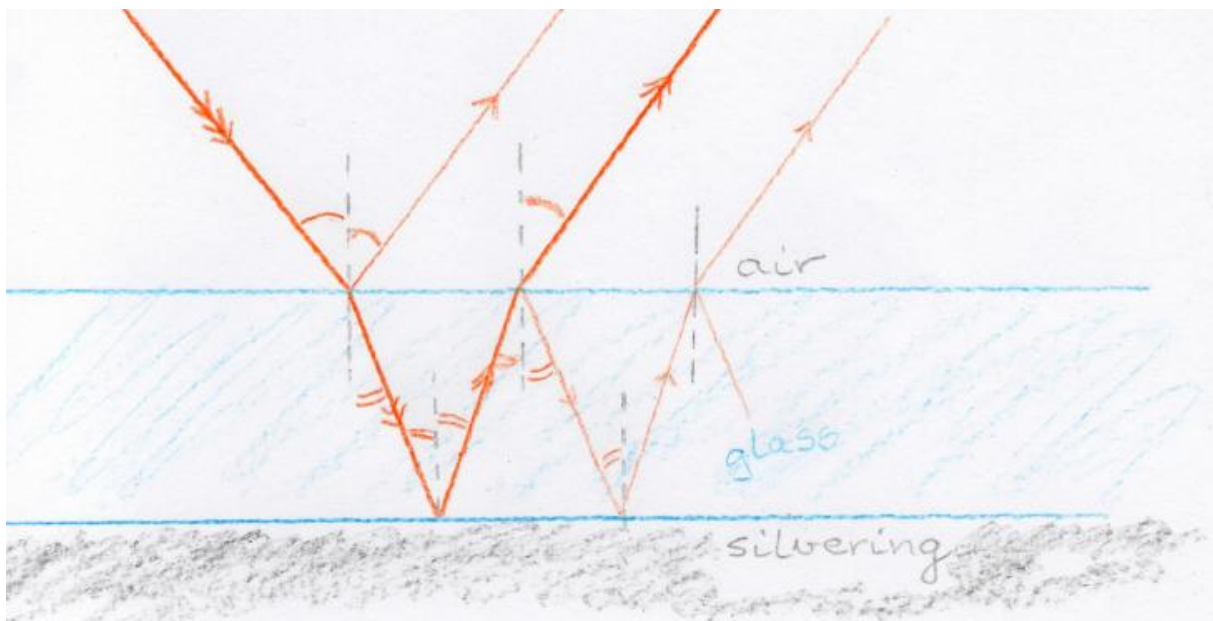


Figure 16: Real mirror giving a series of images

We can see how the image is getting fainter and fainter. Some of our student might show interest in the topic, but it is more for the teachers, since it is not in the syllabus.

In modern physics “the Christmas tree” of methodology is also an exponential law, the law of radioactive decay. I dedicate a grand chapter of my thesis showing a methodological solution based on “hands-on, minds-on” didactics that also meets the needs of the practicing colleagues.

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5. Investigating Newton's law of cooling in public education

5.1. Introducing the law to the teachers

Temperature is an intensive bulk property of a system. In thermal equilibrium the temperature of any part of the system is the same. So, letting a hotter object in a cooler environment we can study a phenomenon: cooling.

A well-known cooling law is also dedicated to one of the most famous physicists, Sir Isaac Newton. This law is known like this: "The rate of change in temperature of an object is directly proportional to the difference between its own and the ambient temperature. Ambient temperature simply means the temperature of the surroundings; in most measurements, it can be taken a constant value." [R5.1.]

We consider what this law really means, and find another mathematical form of the stated dependence.

We denote the temperature of the object by T , the temperature of the surroundings by T_{ambient} , time by t . The rate of change in temperature is $\frac{dT}{dt}$ and the difference is $T - T_{\text{ambient}}$. So the law can be expressed like this, where α is a coefficient of proportionality:

$$\frac{dT}{dt} = -\alpha \cdot [T - T_{\text{ambient}}]$$

Let's solve the differential equation by separating the variables method to prove that this experimental law can be written as an exponential formula.

$$\frac{dT}{[T - T_{\text{ambient}}]} = -\alpha \cdot dt$$

$$\int \frac{dT}{[T - T_{\text{ambient}}]} = \int -\alpha \cdot dt$$

$$\ln[T - T_{\text{ambient}}] = -\alpha \cdot t + c$$

$$[T - T_{\text{ambient}}] = e^{-\alpha t + c}$$

$$T = T_{ambient} + k \cdot e^{-\alpha t}$$

, where c (or $k=e^c$) is so called integration constant which can be determined from initial conditions. This gives the final expression

$$T = T_{ambient} + (T_o - T_{ambient}) \cdot e^{-\alpha t}$$

It is generally true that if a function is directly proportional to its derivative function then the function is exponential of the variable. Therefore the law of cooling states that the temperature of the object is an exponentially decreasing function of time, where the lower limit of the function is the ambient temperature.

5.2. Teaching the law in public education

We can learn also general lessons when we follow a series of hand-on measurements on a particular topic. I prepared a series of projects for our students of physics of different ages or of different background competences. I highlight my intention with the activities, and also make some remarks that I gained from working with my groups, as I use these projects in my everyday practice.

So, teaching the cooling law...

5.2.1. ...at primary school level (ages 10-14)

Motto: From perception to quantities & the concept of changing quantities

A measured quantity is the combination of two elements: a measured value (given to some significant figures) plus an agreed unit. We introduce the idea of measuring temperature and time. We introduce the use of thermometers and clocks. Everyday units of the two quantities are discussed and measured: temperature in °C, and time in seconds, minutes, and hours.

It is well known that if somebody enters into a room of 20°C, it feels warm in the winter when we come from a chilly environment whereas it is very refreshing cool in the summer when it is sweating hot outside. We can prepare three basins for our pupils: the first one has hot; the second one mild and last one has cold water in. The mild can feel hot if we

dive our hands into it after cold water. But it feels cold after the experience with hot water. The pupils can see that sense perception is not reliable, so they understand that we need to measure quantities (Figure 18).



Figure 18: Sense perception of temperature

From the practice we can find that pupils of this age are really fascinated to see materials (like we have mugs) that change their colour as their temperature changes. The name of the phenomenon is thermochromism, and the explanation of the colour-change is highly complex. But using a mug in class can enchant, hypnotize our pupils. It provides high motivation to help our work (Figure 19).



Figure 19: A boy aged 10 shows a gift mug at room temperature and the same one filled with cold water, thus demonstrating thermochromism

Also, we give a task to our students to do their own measurements with simple tools. We need a thermometer for each pair or small group, a watch, a cup, and some hot water. Their task is to jot down the results into a table and then show their results on a graph. Doing this task they can understand that as time passes by temperature is changing. Thus we demonstrate the dependence of two base SI quantities. It works well, if we pour about half a decilitre of 70 °C water into a measuring cylinder. We can ask them to read the data every minute, about 10-12 times, since this is how long their attention-span can last. During team-work they exchange ideas, experience the phenomenon, get involved in the measurement, analyse, sum up, practice, set questions, evaluate, etc., most of which are active ways of learning (Figure 20).

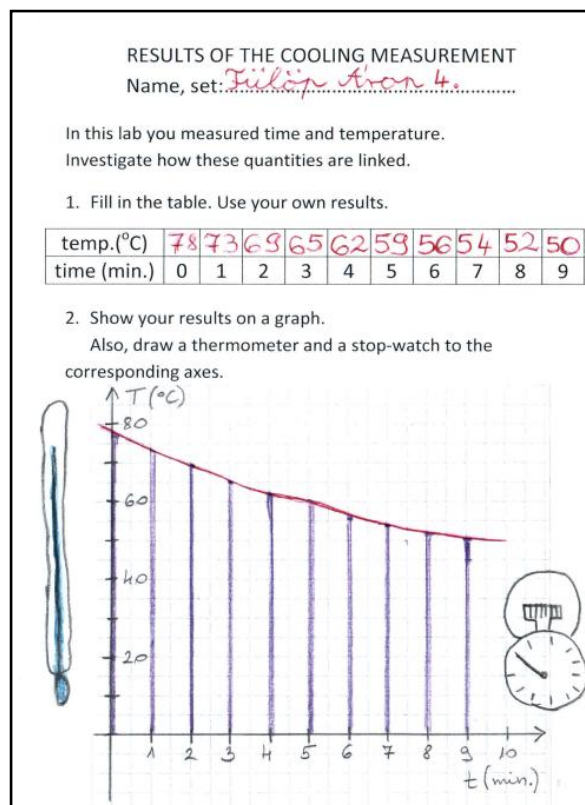


Figure 20: Boy aged 10 proudly presents his results

The time needed for demonstration and activities is one or two lessons only. We can give an insight of metrology, use of tables and diagrams. At conceptual level we did the very important first steps by introducing quantities and the objective description of changing.

5.2.2. ...at secondary school level (ages 14-19)

Motto: Disqualifying the concept of steady change in cooling

The way of change is not the same in natural phenomena. Steady (linear) changes are dominating in the experiments at lower level physics courses, because they are the easiest approximation.

Steady change can be checked easily in more ways. I mention three methods.

1. The first method is most often suggested by our students. It is as follows: steady change can be checked by constituting and comparing differences. If the change is linear, the differences calculated for equal time intervals are equal.
2. In the second method quotients are constituted and compared. If the change is linear, the quotients are equal.
3. The third method: a linear graph denotes linear dependence between two quantities. This method is popular among our students, because it is illustrative.

Students use the data measured in class. They can figure for themselves in more ways that the temperature change is not steady. They find that the temperature differences in equal time periods are not equal: in cooling these are decreasing respectively. The temperature versus time graph is not linear.

We use a liquid thermometer, a measuring cup, some hot water, a watch, some graph paper for each group. Our investigation is designed for two lessons. Students work in teams (Figure 21) benefitting all from the advantages of this setting.

I present the results of one of our groups and the steps of their work in “normal” classes.



Figure 21: Set in grade 11 investigating how water is cooling

There are the results the students got in Table 9.

T(°C)	75.0	66.0	59.0	53.0	48.0	44.0	41.0	38.5	36.5	34.5	33.0	32.0
t(min)	0	3	6	9	12	15	18	21	24	27	30	33

Table 9: Measured data: Water cooling at room temperature ($T_{\text{ambient}}=25^{\circ}\text{C}$)

In the task they had freedom to choose two methods to check if the dependence is linear. As usual, this team began checking the dependence with the first method. Their results are in Table 10.

number	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
ΔT (°C)	9.0	7.0	6.0	5.0	4.0	3.0	2.5	2.0	1.5	1.0

Table 10: Calculated differences in every consecutive 3-minute time periods

We can notice that a decrease can be observed in ΔT respectively. Therefore we can derive that the rate of change is proved not to show the linear nexus.

For a second study they chose to plot a graph. They showed the temperature of the water versus time. (Fig. 22)

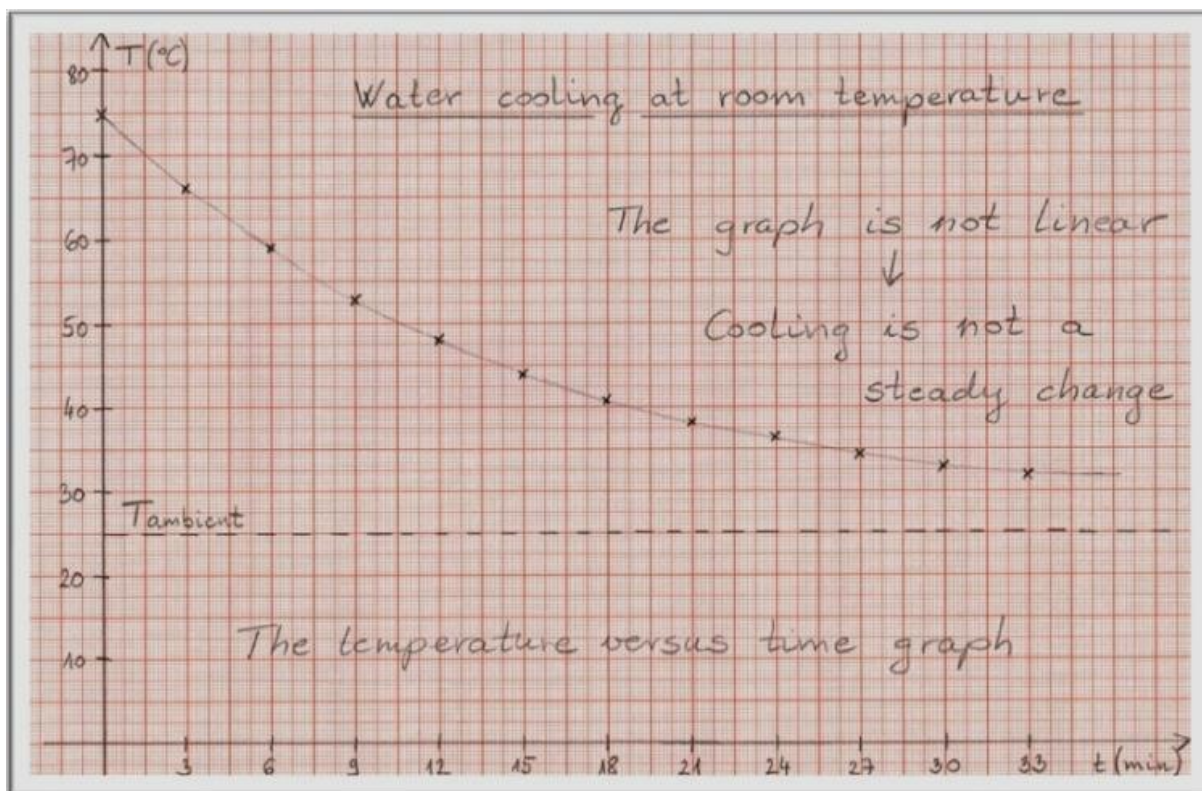


Figure 22: Water cooling at room temperature: temperature versus time graph

They also put as their conclusion what they figured out from the study onto the graph paper: "Cooling is not a steady change."

5.2.3. ...at mentor level (ages 15-19)

Mentor classes are a special course for gifted students at secondary schools.

I present two options for a deeper study of the law in secondary education. One is dedicated more to show the theoretical, mathematical deeper issues of the exponential laws and another more prepared for introducing the use of applied apparatus and pointing towards advanced technology as well as the use of computer aided measurements. For both projects I advise to plan three or four lessons to accomplish.

Motto: Numerical differentiation to verify exponential nexus.

The idea is based on the original wording of the law. We can verify with numerical method. The “access temperature” is defined, meaning the difference between the ambient temperature and the actual temperature. From (either the measured or the access) temperature versus time graph we constitute a few (4 or more) differential quotients. It is called the rate of change in temperature. These are the values of steepness of the tangents or of the chords: $\Delta T/\Delta t$. We can write these values into a table in pairs with the mean access temperatures. Now we plot a graph: the rate of change values versus the mean access temperature values of the studied intervals. This graph according to Newton’s law is linear; furthermore it is a graph of direct proportionality (a line through the zero intercept). Thus verifying the exponential nexus is done through checking a linear nexus of two newly defined quantities.

We will show the steps of this work using the data presented in the previous chapter. These students analysed on their own data in their additional mentor course. We present in Figure 23 the team of some gifted and diligent students working in the physics lab.

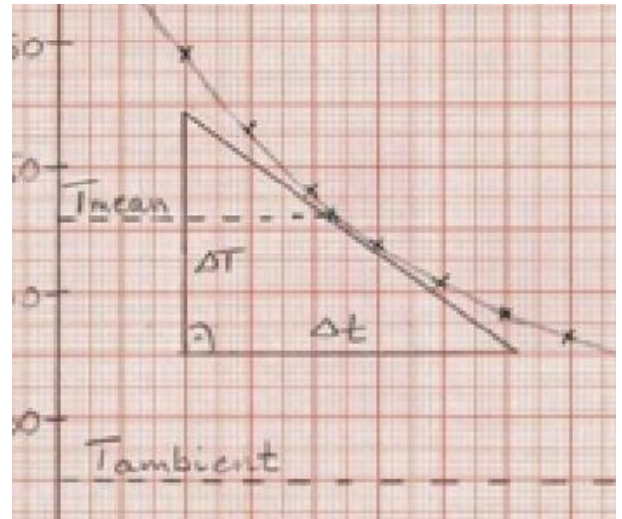
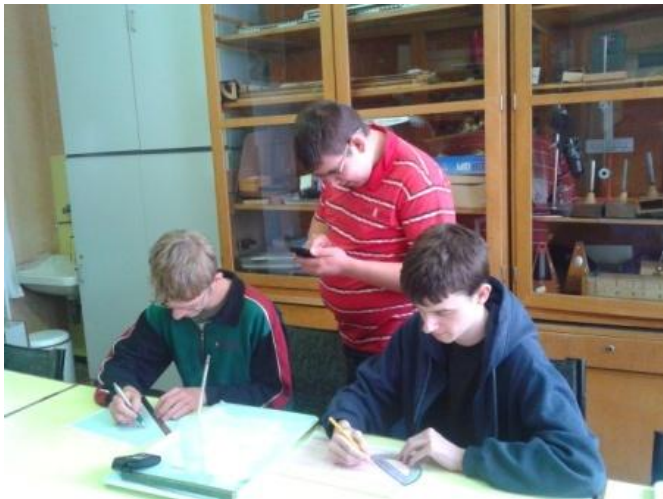


Figure 23: Tamás, Balázs and Dávid in “mentor” class in 2013
getting started with numerical methods

From the graph they calculated the values of steepness for more points, and showed their results in a table, see Table 11.

$\Delta T/\Delta t$ ($^{\circ}\text{C}/\text{min}$)	3.00	2.33	2.00	1.67	1.33	1.00	0.80	0.67	0.67	0.50	0.33
mean access T ($^{\circ}\text{C}$)	46	37	31	25	21	17	14	12.5	11.0	8.5	7.5

Table 11: Rate of change and mean access temperature

The results from the table above are used to plot a graph, as Figure 24 shows it.

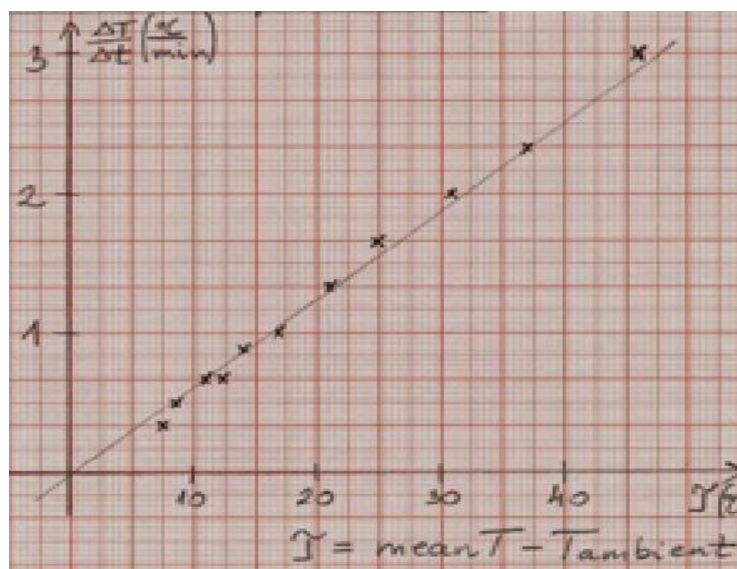


Figure 24: The rate of change versus mean access temperature graph

The direct proportional nexus seen in the graph verifies the law. The students may find it hard to understand how exponential and linear functions can be derived from each other, but can follow the steps of this guided task easily. They can get familiar with the new definitions.

Motto: Use of measuring equipment, evaluation with computer.

Introducing the use of apparatus is also intent in teaching science. We could teach how to evaluate the results gained from a Metex M-3660D meter with the help of a computer.

The Metex M-3660D meter has got a thermal sensor in the original set. This sensor can be easily attached to the meter. The meter can be connected to computers or laptops, but a serial adaptor to the USB port is needed. The program is on a 3,5" floppy disc. A DOS

based programme helps to set up the device. The data are logged in a *.txt file, then they can be analysed in Microsoft Excel. An exponential curve can be easily adjusted.

The law can be verified with computer supported evaluation (Fig. 25).



Figure 25: Our measurement setup

The use of technical devices can make a problem in the preparation of our teaching practice. Students and teacher, going through a number of technical difficulties, relying on one-another can make a group of curious scientists. They learn together in a team, where problems need to be solved also with brainstorming or other techniques, search for help, looking for tools that are essential to accomplish the purpose of the project: to create a system of instruments that are able to check the cooling law.

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6. Active classes on radioactivity

6.1. *The law of radioactive decay*

The law of radioactive decay [R6.1.] is a part of the syllabus of modern physics. It is well known in two ways. The law can be put like this using the number of radioactive nuclei, denoted by N:

$$N(t) = N(0) \cdot 2^{-t/T}$$

And also like this using the concept of activity, A:

$$A(t) = A(0) \cdot 2^{-t/T}$$

In both formulae the concept of half life, T is essential. As we can see from the formulae above this law is a representative of the exponential laws in science.

Teaching the law of radioactive decay is one of the most problematic issues in physics didactics, the infamous “Christmas tree” of physics methodology.

6.2. *Teaching radioactivity in the Hungarian classrooms in the very beginning of the 21st century*

In Hungary the radioactive decay law is in the syllabus of the compulsory physics course for all high school students. According to the national syllabus, the law is to be studied in grade 11, at the age of 17-18.

In a survey a number of active high school physics teachers were asked to report on how they can cope with the task in their everyday practice.

6.2.1. **Collecting the data**

In Hungary there is an annual meeting for physics teachers organized by the Roland Eötvös Physical Society. The one organized in 2015 was held in Hévíz, a spa in western Hungary from 27th to 30th of March. We estimate the number of practicing high school physics teachers at 2500+ in Hungary. The attendance of the event was about 160, from which the estimated number of high school teachers present were 65-70, as the organizers

reported. Others in the conference were lecturers, experts from companies or universities, colleagues, who work in primary schools or others, who are interested in physics teaching.

I left the survey sheets at the registration desk, but only five colleagues took one. As personal contact is very important, so based upon this, 47 attendants accepted the sheet, and 35 of them returned it fulfilled.

The sample of the colleagues I could work with

First, we need to see who are represented in the survey. The first task was to circle the type of high school the respondent has practice in. Some of the colleagues have practice in more types of schools. We counted each answer as a separate one. So we had 39 checkmarks. Table 12 shows what background of experience we can get information from.

type of high school	top third	medium third	bottom third	number of checkmarks
secondary grammar	7	10	4	21
secondary technical	5	7	3	15
vocational	3			3

Table 12: Number of teachers who gained experience in the given type of school

6.2.2. An overview

The survey was anonymous, because in our country following the syllabus is a compulsory task for the teacher. I chose this form because I wanted to find out as reliably as possible how (or if) teaching this law really happens in the Hungarian classrooms.

The second task in the survey was to provide information to what extent teaching the law happens in the practice. Many of our colleagues made a note saying “depending on the class”, so we considered each mark as separate answers. We gained 46 answers this way. The results the respondents gave are represented in Fig. 25. In Fig.25 a) we can see the full scale, whereas in Fig. 25 b) we specify the answers of those who reported that they face problems in their everyday practice.

We can conclude that a third of our colleagues are not satisfied with the work they can perform. It definitely is an issue we need to pay attention to.

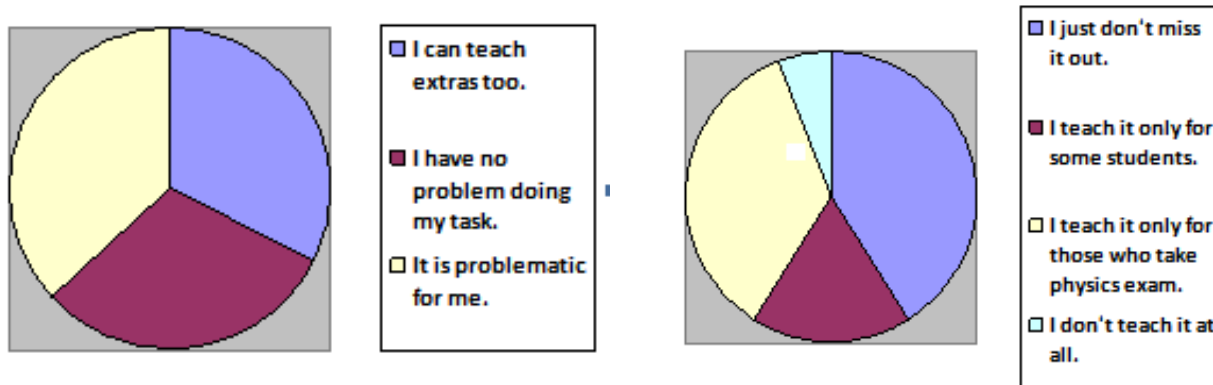


Figure 25: a) Can you teach it? b) Do you mention it at all?

6.2.3. A survey of the most outstanding problems when teaching the law

We asked the teachers to grade 10 statements. To best match the Hungarian evaluation system the grades were 1-5. (1 showing that the statement does not name a great influence on the problems, 5 meaning it is a very important factor.) The statements were put into 3 sets according the potential causes. Table 13 shows the sets of statements.

questions	sets of influences
A1, A2, A3, A4	the students' attitude as a factor of the problems
M1, M2, M3	mathematical skills as causes of the problems
S1, S2, S3	monitoring some scientific issues

Table 13: Types of statements

➤ Monitoring the students' attitude

We mentioned four aspects in this set:

- A1 Physics among our students is not popular: they don't like, understand or study this subject.

- A2 The attitude of our students is negative to atomic physics.
- A3 They already have fact-fragments in this topic from the media.
- A4 This topic is in the last year of the secondary physics course, and is not a compulsory subject to the High School Leaving Exam (érettségi).

Figure 26 shows the grades for the “A” statements.

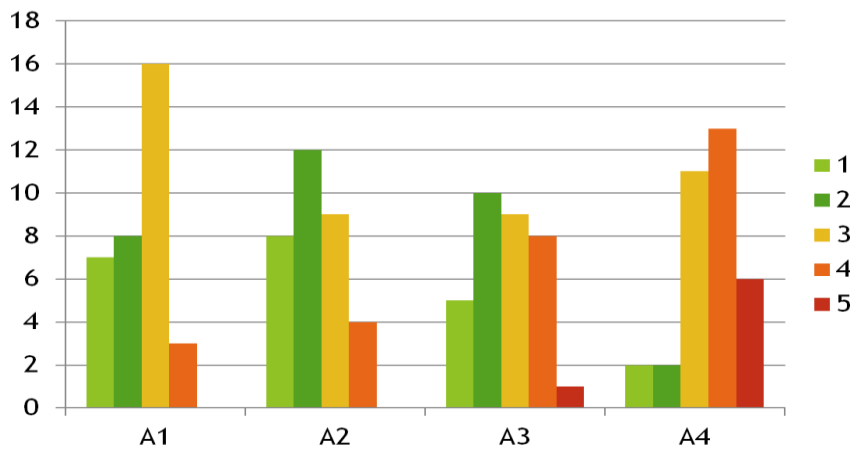


Figure 26: “A” statements graded

➤ Monitoring the students’ poor mathematical skills

We mentioned 3 aspects of mathematical skills.

- M1 The law is one of the exponential formulae. The students don’t know the exponential functions properly.
- M2 The low mathematical competence of the students effect that they are not able to apply their knowledge.
- M3 In mathematics classes there are not enough exercises for using mathematics in real problems and applications.

Figure 27 shows the grades for the “M” statements.

Homo Metiens

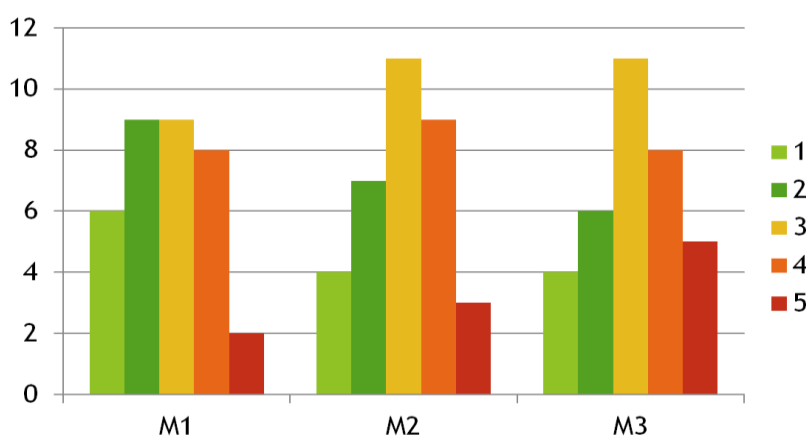


Figure 27: "M" statements graded

➤ Monitoring scientific issues

On the sheet the respondents found 3 statements. They had to grade them just as the previous ones.

S1 There is no possibility to carry out experiments.

S2 The scientific model students should use is too abstract for them.

S3 There is a lack of knowledge in the model they should also study in chemistry.

Figure 28 shows the grades for the "S" statements.

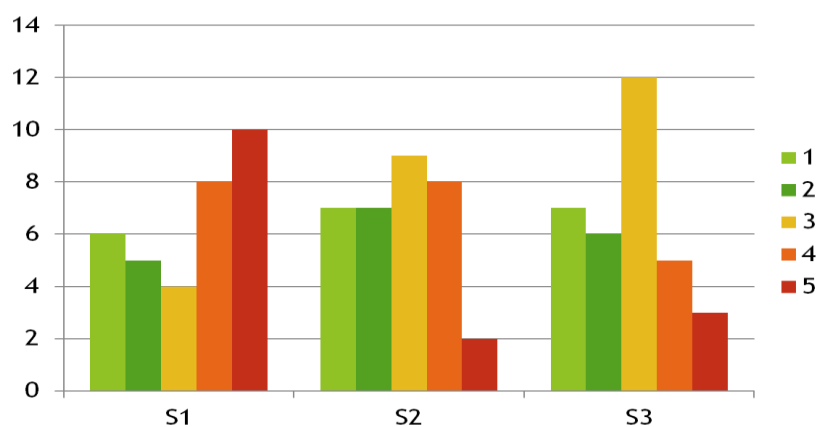


Figure 28: "S" statements graded

➤ Analysing the data

The mean values of the grades for the statements are in Table 14.

	Attitude				Mathematics			Scientific issues		
means (statement)	2.44	2.27	2.70	3.56	2.74	3.00	3.12	3.33	2.73	2.73
means (set)	2.75				2.95			2.93		

Table 14: The mean values of the grades

So the main problems that were highlighted by the teachers are as follows attentively.

- 1.) 3.56 (A4) This topic is in the last year of the secondary physics course, and is not a compulsory subject to the High School Leaving Exam (érettségi).
- 2.) 3.33 (S1) There is no possibility to carry out experiments.
- 3.) 3.12 (M3) In mathematics classes there are not enough exercises for using mathematics in real problems and applications.

Studying the answers, two remarks arose. These are really worth mentioning.

- We can envy some colleagues: they graded each but one (2 for S1) problems to 1. It might mean that they don't find teaching this law a problematic task at all.
- International surveys show bad attitude. Hungarian colleagues don't experience it, they think about it as a result rather than as a cause, or just don't rate it high as a problem.

➤ Further causes

In the survey we gave opportunity to share further causes and remarks to the mentioned topic for those who provide their opinion. It was an open ended question.

The *remarks (in italic)* we got are all listed with my remarks.

- *„Many have misconceptions; they can't differ from the distorted esoteric knowledge.”*

Definitely a very important point, we work also to illuminate this.

- *„Hungarian physicists' activity in the last century.”*

We are proud of our scientists. We can make good use of them for motivation. Sorry, I can't see clearly what to mean by this remark. I do not have a chance to figure out....

- *„They study no other exponential laws they have nothing to bind this law to.”*

A very important point was highlighted, my solution meets this requirement.

- *“In mathematics the statistical nature of the phenomenon, the incidental events are difficult to comprehend. But some students can get fired up just because of this.”*

I find it a very important comment from the colleague; my solution focuses on this issue.

- *„I didn't rate anything to 5, because my highest mark goes to Severe Literacy Problems.”* (The enhancement was strong in the original remark.)

It is a real problem in Hungarian education, but it is appointing far beyond physics methodology.

6.2.4. Interpretation of didactical solutions

➤ Our evaluation system

We studied also what methodological or didactical solutions are liked, known and in use in the teaching practice among our colleagues. We provided a list of didactical solutions they had to grade in two perspectives:

in column 1

in column 2

A – “I know and like the mentioned solution.”

 α – “Mostly this is used in my classes.”

B – “I am familiar with the method.”

 β – “I have experience with the method.”

C – “I don’t know that method.”

 γ – “I have no experience with it.”

➤ **Evaluating the didactical solutions**

Table 15 shows the listed didactical solutions, and the results of the evaluation.

didactical solution	Known?			Used?		
	A(+)	B(0)	C(-)	α	β	γ
Presentation & interpretation by the teacher.	22	9	0	30	3	0
Presenting on an educational film.	11	18	3	8	16	7
Processing literature (alone or in a group).	5	20	7	2	9	23
Project or drama pedagogy.	1	13	19	0	3	31
Home essay or student’s presentation.	13	16	1	8	16	8
Computer simulation.	18	9	4	13	15	6
Simulation game.	7	9	15	2	7	20
Data-processing, simulation game, in-situ measurement project, the “hands-on, minds-on” way.	4	10	17	0	10	23

Table 15: Teachers’ evaluation of the didactical solutions

We can find that our teachers present and interpret the law for their students. About a third of them spice this with computer simulation or inserting an educational film. A number of methods are known, referring to the fact that our colleagues are open to widen their palette of methodological proposals.

➤ Notes, remarks

In an open ended question we asked to share their further comments in this topic with us.

We can gain ideas from the *comments* and my notes:

- *„I am not familiar with the hands-on, minds-on method, though I expect I'd like it.”*

A remark could not be more encouraging!

- *„ I organize a presentation of measurement for the entire school every year. I warmly recommend it to others!”*

Great idea, really!

- *„Keep in contact with companies, and visit a factory.”*

Great, not exceptional.

- *„Measuring activity with Geiger-Muller tube, the sample is prepared with vacuum-cleaner and gauze.”*

It is a great idea from the HTPs (Hungarian teachers' Program) in CERN.

- *„Modelling the decay with beer-foam.”*

This process isn't an exponential nexus, but there was an attempt years ago for teaching the law like this.

There are some great ideas that are present in our colleagues' practice. I consider these as activities highly worthy of support, more as auxiliary tools in methodology. In my project I am planning a methodological solution that can be carried out in our 45-minutes lessons setting.

6.2.5. Conclusions of the survey

- The respondents are not a representative group of active physics teachers in Hungary. On one hand they may represent the most dedicated set of the colleagues; on the other hand they do not represent pro rata the colleagues working in different types of high schools.
- A third of the respondents have problems with teaching the law of radioactive decay.
- Most teachers alter the methods they use to best suit the classes.
- In the opinion of my colleagues mathematical and scientific issues are more defining problems than the students' attitude.
- In the respondents' opinion the most outstanding problems are respectively: no compulsory testing in physics, no possibility for experiments, and not enough applications in math classes.
- Teachers' presentation and interpretation spiced with computer simulation or educational film are the methods most in use in the Hungarian classrooms. A great proportion uses home essay or the students' presentation for his teaching.
- These colleagues know other methods as well and might be persuaded to try them.

"PROBLEMS CAN NOT BE SOLVED BY THE SAME MIND SET
THAT CREATED THEM"

The quote mentioned above is attributed to Albert Einstein [R6.2.]. The fact, that there are more wording in the original English suggest that it is a paraphrase of what we can read by him published in the New York Times in 25th of May 1946 or 23rd of June 1946.

In the following I introduce a method that seems to be appropriate for teaching and also meets the needs and suggestions of experienced colleagues.

6.3. “Hands-on, minds-on” classes on radioactivity

6.3.1. Preparation

As the quote from Confucius says:

*“Success depends upon previous preparation and
without such preparation there is sure to be failure.”*

My goal was to plan, implement and evaluate to see if or how insertion of SMPs into the teaching practice changes the scientific competence of our secondary school students.

If we want to use SMPs, we need to introduce step-by step the elements of measurement theory. For this purpose I start the 3-year-long course with the unit specially worked out for secondary students, titled “The Wonderful World of Measurements”. It is planned for 7 lessons, and the last lessons are dedicated to working together on the students’ introductory SMPs. (Further details are in chapter 2.)

Learning from the study of Ates and Eryilmaz, the students should get many possibilities to really understand the methodology of SMPs. These are interpolated to the corresponding parts of the syllabus. I offer 2+13 SMPs to my colleagues all worked out for the different fields of classical physics. Surely the students get used to the “hands-on, minds-on” activities that are imbedded in the projects by gaining practice.

If we study the basic laws of physics that are in the syllabus of public education we can notice that linear nexuses (especially direct proportionalities) are giving the majority. From the study with our colleagues (detailed in chapter 6.1.) we can conclude that there is a need to introduce phenomena that are of exponential manner before teaching the law of radioactive decay. I have studied these phenomena and appointed two of them that are close to the syllabus, and are suitable in all means to have worked on within an SMP. These are “The cool(ing) law”, which is based on Newton’s law of cooling, and “Discharging a capacitor”.

In my plans they are built on one another, forming a tendentious block:

I will focus on how the students are dealing with the physical quantities.

Step 1.

First, we take “The cool(ing) project, that is Newton’s law of cooling. The active acts are in the project are:

sensing — collecting data — data processing

They do touch and sense hot water in the glass throughout the process. They use a thermometer to make the objective step of data collection, the reading. They do it about 10 times. Finally, they need to analyze the data (preferably in more ways, like using a graph, comparing the differences, to get to the conclusion. In room temperature 0.5 dl of water at initial temperature of 80°C in half an hour cools to 40°C, not in a linear manner. A RoM prepared for students who need much help with the SMP is available in the Appendix. The tools are like the ones on Figure 29.



Figure 29: Tools to study cooling

Step 2.

Secondly, the students build an electric circuit, in which a capacitor is charged up. They insert a voltmeter. Making a shortstop with a switch discharging happens. The students cannot see, feel or touch how voltage changes, but they can rely on the voltmeter: they can measure the actual values. The active acts related to voltage are:

.....-collecting data- data processing

A hand-out for students who are seeking much guidance for their work in the SMP is in the Appendix. Also the equipment needed for data collection is shown in Figure 30.



Figure 30: Equipment to study how voltage changes when we discharge a capacitor

Step 3.

Finally, we can get to the SMPs of modern physics, that are like Siamese twins: “Investigating half-life” and “The (radio)active project”.

Step 3.a)

When considering “in-situ” measurements, we are facing a problem. If the half-life of a sample is short enough (let say minutes) to demonstrate that the number of active nuclei is getting to the fraction of the initial value, a very active sample should be initially available in our laboratory. This opportunity is restricted, obviously. If the half –life of our sample is big enough to provide low activity for long, our students cannot see the “drop-off” in the activity in one 45-minute lesson. It means that we can consider the change of the readings as measurement error or even as statistical fluctuation.

A solution is that the students get a Record of Measurement that is partly filled in. It is available in the Appendix.

They have data in a table: the number of radioactive nuclei versus time. Their task is to do the step of data processing only:

..... --..... -- *data processing*

The task is not easy, though it seems to be. Plotting a graph from the data provided is an easy task. But studying the special characteristics of the graph can challenge our students. Their task is as follows:

- Appoint a reading for the number of active nuclei.
- Find the corresponding time (from your graph).
- Take the half of the appointed number of active nuclei.

- Find the corresponding time.
- Calculate the time-span.

Do the steps above with any initial number you like, do it at least five times.

Figure 31 shows how it goes.

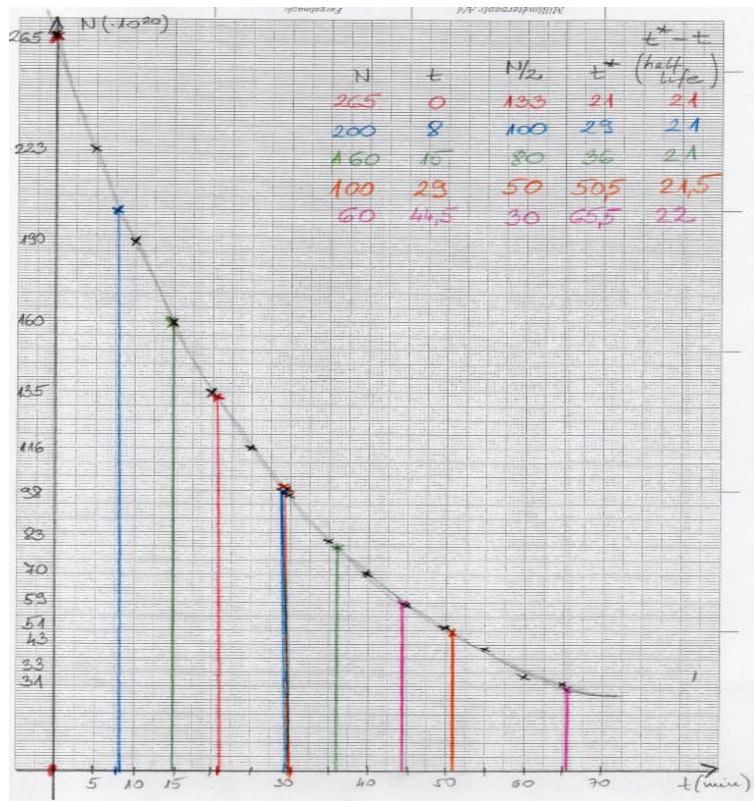


Figure 31: A study of the exponential “fall-off”

No question, our students calculated half-life of a sample from a graph. But at the same time, they learned about exponential curves.

As both the hyperbola and the curve of exponential decay is a demonstrative of a “fall-off”, our students need help to distinguish these.

- The first clue to spot the difference is that the hyperbola does not have an intersection with the vertical axis, while the exponential one does.
- The second clue is that simply multiplying the factors of a corresponding data-pair, we get a constant in the case of hyperbola, whereas it is not so for exponential curves.
- The third clue is a great help to introduce half-life. Each exponential curve has a span on the horizontal axis in which the corresponding readings double or as in our case get half. It is not true for hyperbolas.

These points can encourage or even enchant the talented students, as I have experienced: they are fascinated to see the differences in the characteristics.

Step 3.b)

The task of teaching the law of radioactive decay is a project in which our students might need extra help from their teachers. The structure of the project is this:

*model experiment- collecting data- data processing-
"in situ" measurement- data collection- data processing*

The study is of two parts.

The first part is a model experiment. We can model the radioactive nuclei by two-sided coins: one side is red; showing that it has a lot of energy in, the other is yellow. Representing the elapse of a half-life is modeled by a toss. If the coin lands on the tray yellow-side-up, this "parent" nucleus have decayed during the previous half-life; therefore it turned to a nucleus of the daughter element. We take out these coins from the set. From my practice I noticed that I need to change my original idea slightly. My students, particularly those who had difficulties with science, found it a support not only to take out the nuclei that are not radioactive anymore, but putting in one colored coins to bear in mind that the number of nuclei does not change during the process, only some type of nucleus turn to another type of nucleus. The task is to begin with a given number of nuclei; in my case we had 60/group. The students play the game till they have even one radioactive nucleus (=a coin of double color), and collect the data, and show them on a bar graph. They are likely to get a result like the one shown in Figure 32.

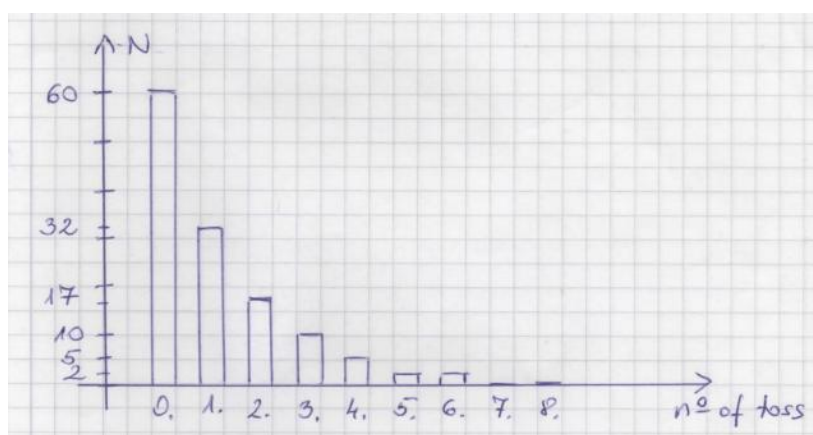


Figure 32: A bar graph of the "active" 60 coins

Soon, the students notice that the results of the groups are similar, but also differ. We can easily understand that beginning the game with 60 coins ends after about 7 rounds. Some finish after 5, some after 10. Now, we can collect the data from each of the groups. They can see the tendency, but also face the statistical nature of the phenomenon. Again, we can analyze the data of a significantly bigger sample with a bar graph. Now, the students get closer to the exponential nexus.

A detailed RoM set for introducing the law of radioactive decay is in the Appendix.

In most of our schools we have got a radioactive sample and a Geiger Muller tube. In the previous step our students faced the problem that our phenomenon has a statistical nature. They noticed that the more the initial number of the active nuclei is, the more punctually the bar graph follows the exponential curve. This step is dedicated to study how many nuclei are present in a radioactive sample.

Before doing the experiment, we can discuss that there are strict regulations to prevent the health of our students in the school. There are great examples how we can exemplify this. Two that my students liked most are these simple ones:

1. The use of aluminum: now and then

A few decades ago nearly every household had dinner-pail and kettle made of aluminum (Figure 33, [P.6.1.]. (There was not a wide range available in the socialist regime of household products.) Now, probably my students' grandparents still have some of them. But, they are now banned. They can't be used in catering or can't be on sale anymore in my country. These items of kitchenware don't seem to be dangerous, but studies show that they are more hazardous for our health than the radioactive sample that is kept in the school.



Figure 33 [P6.1.]: Kettle and dinner-pail made of aluminum

2. The use of mercury

Also, we can demonstrate the idea above with the fact that the famous experiment made by Torricelli to prove the existence of atmospheric pressure, had been on the syllabus as an “in-situ” experiment until 2000, a few years ago. Today mercury cannot be kept in the physics labs in Hungary.

Also, it is still an everyday experience to meet amalgam filling in the teeth (Figure 34, [P.6.2.]). Amalgam is an alloy of mercury. It had been used for filling teeth since about 600 B.C. Now, studies had proved that mercury and copper release from the filling, and these elements (absorbed in the mucous membrane in the mouth) do cause poisonous symptoms. Today, this material is banned also.



Figure 34 [P6.2.]: Amalgam filling

Later in the studies, we can turn back to this question, when we talk about the biological effect of radioactivity, and its measures. But trying to ease the scare of our students is a crucial pedagogical task. For good reason, repetition is the mother of retention. I find that several of my students have found this topic very motivating, and did their own studies primarily on the internet to learn more about how the biological effect or hazard is defined. Some of them took the opportunity I offered to make a small presentation of what he learned, when we discussed the biological effect. Surely, the relationship with everyday experience and other subjects are also the advantage of these examples. We can also encourage the students to find reliable information on the internet on these, mentioned topics. This task would help them to find out how they can figure for themselves if the information is reliable or not.

So, we can use our sample and gauge. We measure the number of ticks in a minute a few times, so we get an average of our readings that is characterizing how active our sample is. We know what exact radioactive isotope we have got, therefore we can look up

its half-life in the literature. From this information we can estimate the magnitude of the number of radioactive nuclei. It is a very rough estimate, we can discuss, but it stands for the magnitude. Our result for an Am-241 sample is 10^{11} .

Now, we can compare it with the results of the first task: $N_1(0)=60$, the second task: $N_2(0)=600$, and a barely radioactive sample: $N_3(0)=10^{11}$. The fact that in radioactive samples the initial number of the active nuclei is so big (and still not even close to the Avogadro number of moles) shows our students that statistical deviation is not determining.

In some schools the tools I mentioned above are not available. For the colleagues that are in this situation there is another possibility. We can buy a program for a cell phone for a few dollars to turn it to an alpha-particle counter. The sample can be self made too; we need only about 10 layers of medical gauze, a vacuum cleaner, and put this into a polluted cellar. We leave the vacuum cleaner on for hours, and we will have enough radioactive radon present. There are problems that we need to face in this case:

- How can we prove to our students what active elements have we got?
- Although radon is an alpha particle emitter, in its decay chain it also has Po-218 and Pb-214. These are alpha-decaying. At this stage it is far too complex to understand decay chains also.

Although this experiment is familiar for the teachers, I don't find it a good idea to use it for more than demonstration. This simple demonstration to show the existence of background radiation is grabbing the students' attention. But a quantitative study can be very misleading.

6.3.2. The implementation

I planned a project to study how using "hands-on, minds-on" methodology influence the competence of our students. I had a chance to plan a three-year-long project in a bilingual technical secondary school in Budapest: the Trefort Ágoston Kéttannyelvű Műszaki Szakközépiskola (<http://www.trefortszki.hu/>). The specification of the school and its classes are in the Appendix.

Four parallel classes studied physics in their 10th, 11th, and 12th grade. This period is the following academic years: from September 2012. to April 2015.. They had 3 – 2 -- 2 lessons per week respectively in the grades. From each class we could form two sets for the

physics classes. In one of the classes (D) forming the groups was not in our authority: it was done for mathematics, and we had to take this setup. Otherwise we used a random method: those who were born on days of even or odd numbers.

I worked with my colleagues in this project. We followed the syllabus, the rules, and appointed methodological tools, that we worked out as a department. We also agreed on evaluation, testing, etc.

We paid attention to introduce the Wonderful World of Measurements and building on that to use as many the SMPs as possible with the experimental group, but strictly using the traditional way of teaching in the control groups.

We did with all of the experimental groups the following insertions (Table 16):

grade	SMPs used in all experimental sets
10	(0. the introductory unit: The Wonderful World of Measurements) 1. Measuring angles project 2. Cinderella project 3. Mikola tube project 4. Hook's law project 5. Measuring gravity project
11	6. The cool(ing) law project 7. Boyle's law project 8. Ohm's law project 9. Discharging a capacitor project
12	10. Snell's law project 11. Measuring the speed of sound project 12. Optician's project 13. Investigating half-life project 14. The (radio)activity project

Table 16: SMPs for the experimental groups

With these projects the timing followed this pattern:

- introducing the phenomenon or law as it is in the syllabus, in class
- prepare for the measuring experiment in groups as homework
- instead of deeper study and discussing related problems in class, do the measuring experiment in groups, in class
- prepare an individual RoM as homework (hand in about in one weeks time, the deadline was selected to have a weekend in, in case the students need it)

We agreed that we will only introduce the SMP method with SMP1 and SMP2. We followed the students' work attentively, helped their development with feedback between student and teacher. Apart from a few exceptions, they handed in RoMs that showed thoughtful and earnest work. From their remarks we learned that they declare SMPs a time consuming tasks, but worth working with, because they realize they can understand better what we are studying:

- they could use help(, which also decreased their stress),
- they could think into the details,
- perceive the gist of not only the law they study, but also the method how scientists can get to the conclusion and state the laws of nature.

6.3.3. The result of our methodological experiment

I evaluated only one element of our methodological experiment. I noticed that the students I teach with the insertion of "hands-on, minds-on" methodological solutions are happy to work in with the SMPs. I have found that it is a useful tool to make the students take part in studying in an active way. I have also noticed that these students are better motivated.

Two questions arose:

1. Can I underpin my observation with statistical data?
2. Can I recommend this method to my colleagues for teaching the law of radioactive decay instead of the traditional (presentation + interpretation spiced with an educational film or computer simulation) way?

Introducing half-life and the law of radioactive decay happened with hand-outs. You can find these in the Appendix. These hand-outs are a combination of worksheet and RoM

types of teaching aid. The form is one of the ROMs. It has got the to-does list on, and enough space to fill in as they follow the steps. However, filling in the gaps, like defining half-life and the law of radioactive decay is a constructive task for the students. Some students found the tasks very easy and entertaining, but some were wrestling with them. They could find their way to ask for the help of their group-mates, the use of the internet, or turned to the teacher for help.

Memorizing for the end-of-unit test is a skill which is richly rewarded in the Hungarian classrooms. But the well-approved goal of science education is developing scientific competence. We can also develop mathematical competence also with tasks or problems of physics that are adequately modified to this later mentioned purpose.

I wanted to see the effect of the SMP method on the longer term competence of the experimental groups. Still, I needed to consider the timing of the last academic year. I had to appoint a date when the follow-up survey can be handed out. Also, the students are all very busy with preparing for the school-leaving ceremony, the school-leaving exams, with the applications for their studying further or finding a job. All-in-all, I drew the limits of the follow-up measurements.

- I decided to collect the data in a written form, a questionnaire, on a hand-out. Firstly, because it is simple and often used way of gaining information from our students. Secondly I had all the tools needed for it.
- The hand-out was a mixture of a survey and a test. Here are the advantages of these types of questionnaires I relied on:
 - i. I wanted to use the following benefits of surveys:
 - it is often anonymous
 - it is evaluated on group level
 - there are correct and incorrect answers
 - ii. I wanted to make the best use of tests:
 - it can be clearly evaluated
 - it is used for measuring in a demarcated area
 - it can be easily quantified
 - the diagnostic type can be evaluated on item level
 - the summative type can be evaluated on subtest level

- My questionnaire couldn't be long, so that I can expect the senior students to pay their best attention to it. I limited the extent to 2 pages. It excluded the possibility of double-checking the validity of the items and so reduced the accuracy of the follow-up.
- I found it important to include questions for
 - recognition: a close type of question, often in the form of choice
 - coupling: an open type of question, often asking for (short, long or essay type) answers

I asked for the help 6 excellent experts to check the questionnaire to best meet the goal of the measurement. My aim was to raise the validity and objectivity to its possible maximum. The questionnaire is in the Appendix.

The competence is of 3 main areas:

- knowledge,
- ability, and
- attitude.

In the first part (I.) there were 5 questions: some measured the information the students can recall, others the information the students can recognize.

a) Questions to study the information students can recall:

Question I./1.

The students were asked to name radioactive elements. They mentioned 15 elements. They listed 0 to 6 correct answers. The elements most often (10 or more times) recalled are respectively:

- in the experimental group: Uranium, Plutonium, Polonium, Radium, and Americium
- in the control group: Uranium, Plutonium and Polonium

The experimental group used Americium for "in situ" measurement before, the control did not. This reason is very likely to explain this difference.

Question I./3a.

The student defined half-life. The number of correct answers is 17 (=35%) in the experimental, whilst 10 (=23%) in the control groups.

Question I./5.

The law of radioactive decay was presented correctly by 18 (=37%) versus 4 (0.9%) students.

b) Questions to study the information students can recognize:

Question I./2.

Our students underlined the names of scientists who became famous for their discoveries in radioactivity.

In the experimental group Geiger 31 (63%), Becquerel 24 (49%), and Curie 23 (47%), whilst in the control groups Becquerel 34 (79%) and Geiger 22 (51%) were the top correct answers. The experimental groups used the GM tube for “in-situ” measurements, the control group only saw and the equipment.

Question I./3b.

The magnitude of half-life is on a wide time-scale. The students were asked to circle the possible values.

Each value is the half-life of an element. See the matches in Table 17.

half-life	$1.4 \cdot 10^{10}$ years	53 months	3.8 days	19.7 minutes	0.16 seconds	$3 \cdot 10^{-7}$ seconds
isotope	thorium- 232	radium- 226	radon- 222	bismuth- 214	polonium- 219	polonium- 212

Table 17: Half-life values on a wide time scale

From the experimental groups only 8 (=16%) scored total, while from the control groups only 4 (=0,9%).

I asked the same question from my colleagues also, in different forums. I faced that it can be a problematic question for science teachers, too. One possible answer is that in the calculations we often meet data of a narrow range for half-life, and it can be misleading.

Question I./4.

I offered graphs; the students were to circle the graph of the radioactive decay.

From the graphs 45 (=92%) students chose the correct one in the experimental groups, and 36 (=84%) in the control groups.

Table 18 shows the arithmetic means for each question in part 1 of the groups.

INFORMATION										
	EXPERIMENTAL GROUPS					CONTROL GROUPS				
	D	A	B	F	total	D	A	B	F	total
RECALLING INFORMATION										
1.	2.69	2.00	1.00	2.25	1.96	2.38	1.67	1.70	1.64	1.88
3.a)	1.46	1.00	0.43	1.00	0.96	0.77	0.67	0.40	0.82	0.67
5.	0.54	0.30	0.36	0.42	0.51	0.15	0.22	0.10	0.55	0.26
RECOGNIZING CORRECT INFORMATION										
2.	3.61	2.10	1.86	2.42	2.51	2.08	0.67	2.80	2.50	2.26
3.b)	4.38	2.00	2.14	2.08	2.69	2.38	2.22	3.40	2.45	2.60
4.	2.00	2.00	1.71	1.50	1.80	1.85	2.00	1.60	1.27	1.77

Table 19: Average of the groups for the questions in part 1

In the 2nd part of the questionnaire the students faced problems they had not met before (we, teachers agreed to avoid these questions in class).

Question 1 was a multiple choice type of question about half-life checking if they really understand the meaning.

In question 2 the half-life of two polonium isotopes were given, and the students had to compare the activity of the samples. Nobody got the correct answer, but they could word true statements, thus getting points for those.

In question 3 the task was a calculation of two steps: first calculating the number of half-lives (with direct proportionality), then substituting it into the well-known formula (or calculating the 2^{-6} times of the given initial value). We can conclude that our students are not skilled to cope with this task.

Finally the students had a list of 9 phenomena, all of which was a decrease (in question 4.). There was also an exponential graph. The students needed to decide if the

phenomenon from the given point of view fits the exponential nexus or not. They were also given the possibility to sign “not sure”.

The exponential decrease phenomena were: 2., 4., 5., 6. and 7..

We had some space for the students, who could write any other phenomenon they can think of as a representative of the curve. 20 (41%) had a try from the exponential group, and 10 (23%) from the control groups. Most of the answers made us remember that we are dealing with teenagers, demonstrating their humor: “the level of TV broadcast in time”, “my mood as weekdays pass by” and similar ones. There were tries that are of other nexuses, like: magnetic induction versus the radius, the efficiency of motors (but versus what quantity?), distance against time in deceleration. Three students just reinforced radioactivity by mentioning.

The following table (Table 20.) shows the average points each group scored.

ABILITY										
group	experimental					control				
	D	A	B	F	total	D	A	B	F	total
1.	3.00	2.70	2.36	2.50	2.63	2.93	2.67	1.90	2.36	2.49
2.	1.92	0.30	0.29	0.75	0.84	1.50	0.67	0.20	0.55	0.67
3.	2.23	1.90	0.64	0.25	1.22	0.00	0.78	0.00	0.27	0.23
4.a)	3.02	2.87	2.59	2.69	2.80	2.03	1.95	1.80	1.91	1.93

Table 20: Average scores for part 2

In the 3rd part of the questionnaire I wanted to study attitude. The students used a Likert-type scale of 4 ordered response levels: 1 meaning strong disagreement and 4 meaning strong agreement. I chose this solution, because when using the odd number level scales the neutral option is an easy one to take.

The students rated 7 statements.

Considering the scores in Table 21 we can say that the members of the experimental groups find this topic

- 1.) more important,
- 2.) more interesting,

- 3.) more understandable,
- 4.) easier to follow,
- 5.) more natural,
- 6.) less discouraging, and
- 7.) more preconditioning the participation in informative programs or films in the topic.

Also, from the answers for the open ended questions we can learn about the level of the students' motivation and attitude. 13 (27%) students did extra personal study for own interest in the topic from the experimental groups. This value is 10 (23%) in the control groups. From the experimental groups 25 (51%) mentioned his favorite episode, and 16 of these (64%) named the "coin-game" or the "RoM" as they called it. From the control groups 15 (35%) students specified their favorite episode: the historical background (5) and watching the educational film (5) were in the leading role.

ATTITUDE										
groups	experimental					control				
	D	A	B	F	total	D	A	B	F	total
1.	2.77	2.70	2.08	2.73	2.46	2.23	2.44	2.00	1.90	2.15
2.	3.38	3.20	3.00	3.09	3.04	2.15	3.00	2.44	2.50	2.49
3.	2.84	3.00	2.17	2.36	2.53	2.15	2.11	2.11	2.50	2.22
4.	3.23	3.00	3.08	3.00	3.02	2.62	2.56	2.11	2.40	2.44
5.	3.00	3.10	2.92	2.55	2.83	2.08	2.67	2.11	2.20	2.24
6.	2.92	2.60	2.58	2.82	2.68	1.92	2.89	2.11	2.80	2.33
7.	3.00	2.50	2.33	2.27	2.49	1.92	2.33	0.44	2.00	1.88
*	*	*	*	*	*	*	*	*	*	*
„look-ups“	3	4	1	5	13/49	2	5	1	1	10/43
favourite/activity	10/9	4/1	4/3	7/3	25/16	5	5	3	2	15

Table 21: The averages for part 3 questions

Incorporating the results

I used color-code in the previous tables. The average score for the experimental group is colored green, if the result is at least 10% bigger than that of the matching control group. It is colored red if it is at least 10% less. Otherwise it is not colored, representing that the results are similar. Table 22 shows how many cases I could rank the result as better, similar or worse.

average	better	similar	worse
information	13	6	5
ability	12	3	1
attitude	23	4	1

Table 22: How experimental sets performed due to the questionnaire

The result of my measurement shows that using insertions of SMPs to teach the laws of nature were

- maintaining motivation for the students,
- surely enhanced the attitude of the students,
- equipped them with better skills,
- helped them remember the information better.

We need to bear in mind that the students were technical students of secondary education, therefore practical tasks and activities in the field of technical studies are not peculiar for them. A question arise: Would it be a similar result with students in secondary grammar or art schools? I hope I will have a chance to work on this topic.

References

- [R6.1.] J. Breithaupt: "Understanding physics for advanced level", ed.: C. Hutchinson, Stanley Thornes Ltd, Leckhampton, England, 1991, pp 446-450, ISBN: 0-7487-0510-4
- [R6.2.] <http://icarus-falling.blogspot.hu/2009/06/einstein-enigma.html>
- Pictures
- [P6.1.] https://www.google.hu/search?biw=1920&bih=964&tbm=isch&sa=1&q=%C3%A9thord%C3%B3+alum%C3%ADm%C3%ADm&og=%C3%A9thord%C3%B3+alum%C3%ADm&gs_l=psy-ab.3...49176.53427.0.57013.14.11.0.0.0.0.131.868.10j1.11.0...0...1.1.64.psy-ab..5.1.130...0i13k1.h0GWFcvXs-E#imgsrc=OSK-ggBGAOxuCM:
http://versmindenekinek.network.hu/kepek/emlekszel_meg/aluminium_teafozo
- [P6.2.] <http://www.szajsebeszet.wlap.hu/hu/szajsebeszet/fogaszat/>

7. The Sledge Project

Sitting on a train travelling home from a physics competition with eager students, we discussed some issues that arose due to the questions in the competition. A well-known question came into our focus: “Why is it easier to pull a sledge horizontally than to pull it on a slope upwards?” Some of the students (Roland Szabó, Tamás Berényi and Balázs Simó) paid outstanding attention to the problem and showed motivation to participate in a deeper study.

7.1. *A study of the typical qualitative answers*

We met answers in the Hungarian literature of physics competitions and methodology that are similar to this reasoning: “In both cases we need to exert a force against friction, plus on the slope we must exert force against a component of gravity as well.” There is a problem, as follows: We agree that the force against gravity is an increasing value as the tilt angle of the slope is increasing, but the force against friction is a decreasing one. When we add up these two functions, their sum is not necessarily an increasing function.

Some of the answers we met are similar to this: “Besides energy dissipated in friction, extra mechanical work must be done to give „height”/ „positional”/ „potential”/ „gravitational” energy.” But when talking about an “easier pull” we associate it with forces rather than with energy. Work, energy and force are different notions. If we want to make a connection, we need to study distance as well, which complicates the situation.

7.2. *The Newtonian analysis*

We used Newton’s laws, which are also well known as basics of classical dynamics for the theoretical analysis of the case. Our solution is often studied also in upper secondary physics courses in Hungary.

We apply the standard notation of dynamics and use the symbols F , m , a , μ , α , etc.. Quantities characterizing pull on a horizontal surface are marked by *. Vectors are set in bold.

Based on Newton's 2nd law the force needed for a uniform motion...

✓ ... in case of horizontal pull is as follows:

$$*F_{\text{pull}} = -*F_{\text{friction}}$$

, since

$$\sum *F = 0 ,$$

so

$$*F_{\text{pull}} = \mu \cdot m \cdot g$$

✓ ... in case of pulling up on a slope (Fig. 34) is as discussed below:

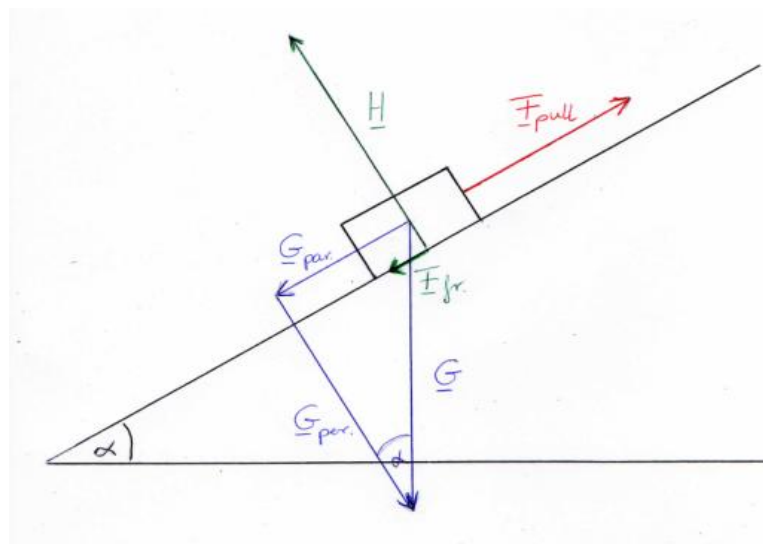


Figure 34: Study of forces on a slope

Newton's 2nd law is a law of vectors. We often need to use two simultaneous equations for the components. It is so in this case. These are for the components parallel and perpendicular to the surface of the slope. The + directions are perpendicularly away from the surface of the slope, and crosswise up.

- Studying the components perpendicular to the surface provides H , the force that is exerted by the slope

$$H = -G_{\text{perpendicular}}$$

, therefore

$$H = m \cdot g \cdot \cos\alpha$$

- So we can calculate friction

$$F_{\text{friction}} = \mu \cdot H$$

, so

$$F_{\text{friction}} = \mu \cdot m \cdot g \cdot \cos\alpha$$

- The parallel component of gravity can be given as

$$L = -G_{\text{parallel}}$$

, that means

$$L = m \cdot g \cdot \sin\alpha$$

Based on Newton's 2nd law the force of pull is

$$F_{\text{pull}} - F_{\text{friction}} - L = 0$$

, which gives us that

$$F_{\text{pull}} = \mu \cdot m \cdot g \cdot \cos\alpha + m \cdot g \cdot \sin\alpha$$

$$F_{\text{pull}} = m \cdot g \cdot (\mu \cdot \cos\alpha + \sin\alpha)$$

Our original goal was to compare the forces of pull in two situations. To compare these in the mentioned cases we formed a function

$$\psi = F_{\text{pull}} - * F_{\text{pull}}$$

We received that

$$\psi = m \cdot g \cdot (\mu \cdot \cos\alpha + \sin\alpha - \mu) .$$

If we study the $\text{sgn } \psi$ function, we can figure out if our original statement is true or false. We need to face a problem: analysing a function like $\text{sgn } \psi$ is not in the secondary school curriculum. A few decades ago we could not have coped with this analytical task.

7.3. Numerical analysis, a study of the $\text{sgn } \psi$ function

Two of the students (Balázs Simó and Roland Szabó) were senior students of a secondary IT software course at the time. Relying on their choice and supervision we wrote a programme in C++ using SDL, which works in 1000x180 pixels.

Since $0^\circ \leq \alpha \leq 90^\circ$ on the vertical axis we can easily represent the tilt angle, α if $1^\circ=2$ pixels. So, on the horizontal axis we can represent μ . With a multiplier we can adjust the maximum value to what we want to study.

Our programme works in two cycles. This means 90,000 data-pairs to calculate with. We presented the results according to our purpose in a colour code (Table 22).

Pull on slope	Pull on level ground (*)	$\text{sgn}\psi$	Colour code
bigger	smaller	+	red
smaller	bigger	-	blue

Table 22: Our colour code to study $\text{sgn}\psi$

We were very excited to see the results: if a blue area appears, it means that the original statement is not necessarily true in all circumstances.

Our results in the numerical analysis:

1.) For all possible angles, if $0 \leq \mu \leq 0.25$ see Figure 35.

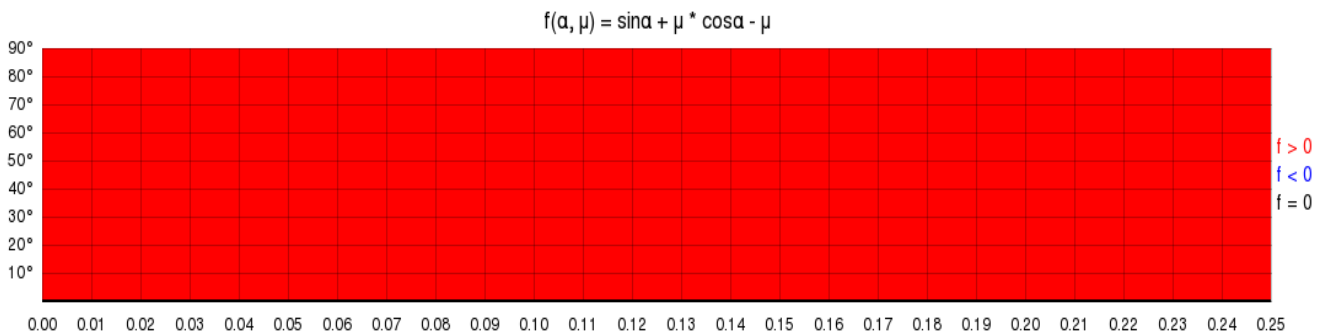


Figure 35: Phase for small μ values

2.) For all possible angles, if $0 \leq \mu \leq 2.5$ we present Figure 36.

Homo Metiens

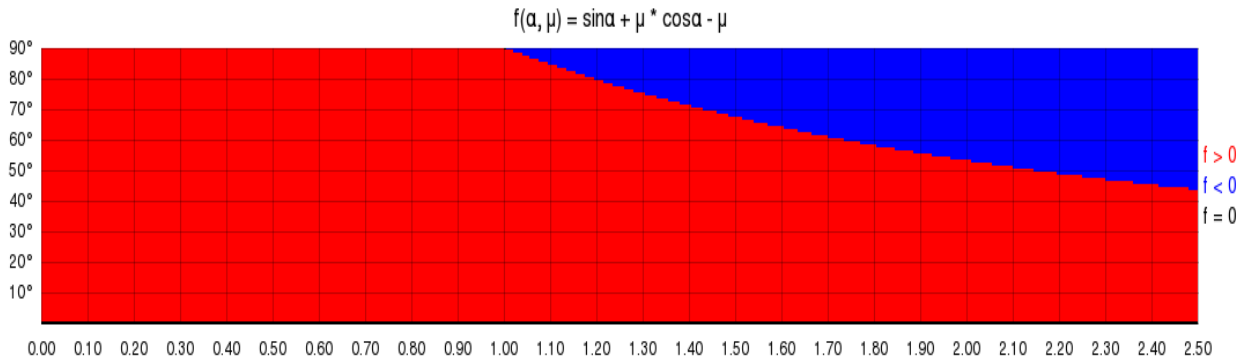


Figure 36: Phase for bigger μ values

3.) For all possible angles, we allowed μ up to 50, you can check Figure 37.

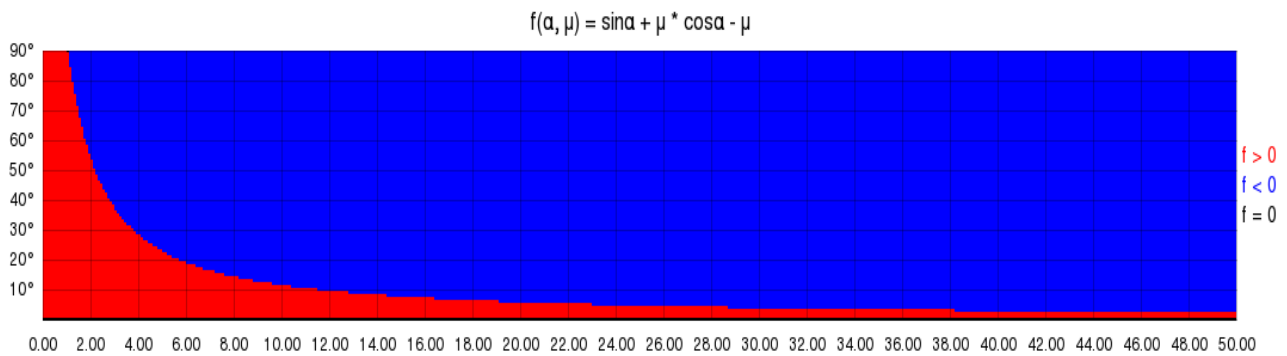


Figure 38: Phase up to extreme μ values

Needless to say we were more than excited when we saw the blue area in the graph. I refer to one of Aristotle's quotes:

"Educating the mind without educating the heart is no education at all."

At this point we made a small celebration: we went for an ice-cream to a mall near our school. My intention was to put emphasis on the fact that we achieved surprising results in our study. This was the turning point when the work in our mentor group changed direction. We realized and discussed that our results are worth publishing, and pointed out the direction on and methods of our further work.

We can conclude that α and μ are the main quantities that define motion on a slope. The blue area appears only if $\mu > 1$. We left the question open if there is a significance in physics of $\mu = 1$.

7.4. “Hands-on” measurements

We wanted to see what the typical values (for μ and α) are, when playing the sledge.

7.4.1. Measuring the friction constant

We pulled a sledge on level ground at constant speed. We used an 80213-141 Kamasaki digital scale (dynamometer) that we bought cheap in a fishing shop. We also needed a bathroom scale and a sledge. We made measurements on 3 different occasions, which means 3 different circumstances. We decided to note 3 readings each time. We formed the mean value by calculating the arithmetic mean. Our results are in Table 23.

measurement (Budapest XXI. ÁMK)	$F_{\text{gravity}} \text{ (N)}$	$F_{\text{pull}} \text{ (N)}$	$F = \frac{F_{\text{pull}}}{F_{\text{gravity}}}$	μ_{mean}
9 th Feb. 2015. late evening with a young girl on	351+51.7= 403	45.15	0.112	0.118
		49.46	0.123	
		47.88	0.119	
10 th Feb. 2015. afternoon	51.7	9.88	0.191	0.178
		9.20	0.178	
		9.45	0.166	
16 th Feb. 2015. early morning	51.7	4.90	0.095	0.092
		5.10	0.098	
		4.35	0.084	

Table 23: Our results for the friction constant

In the 1985/5 issue of the Hungarian journal “KÖMAL” (<http://db.komal.hu/KomalHU/felhivatkoz.phtml?id=35450>) we found that the friction

constant measured (with a different method) is $0.02 \leq \mu \leq 0.3$. We were happy to see that our results match those we found in the literature. Measuring tilt angles 2 ways

7.4.2. Measuring tilt angles

Our first problem was that we could not get an inclinometer and did not know anybody we could borrow from. Since this instrument is not cheap, we had to work out a conventional method for measuring tilt angles, “ α ”-s. We needed a bubble level (0.8m), a 1-meter rod, and a pendulum (string & load). Figure 39 and 40 demonstrates how we used our tools.

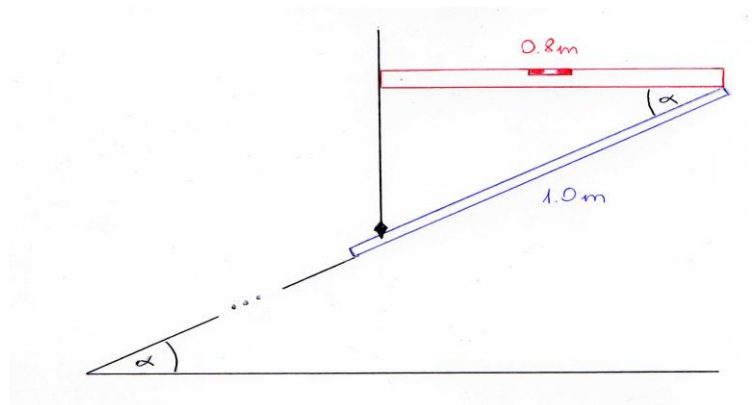


Figure 39: Our “inclinometer”

We also used applied apparatus to measure tilt angles, the GPS system. The students were very eager to use two types and showed interest to compare their results. We worked with the two versions that were available free.

We made our measurements in different playgrounds in Budapest on 23rd June 2015.



Figure 40: “In-situ” measurements using GPS

Table 24 includes our results. We denote by * our results with the GPS system.

	spot	$l_{\text{projection}}$ (cm)	$\cos\alpha$	α_{actual}	α_{mean}	* α_{actual1}	* α_{actual2}	* α_{mean}
Slope 1 Bp., 1095 Petőfi u. 2.	1/1	84.0	0.9524	18°	15°	16°	13°	15°
	1/2	85.0	0.9512	20°				
	1/3	80.5	0.9938	6°				
Slope 2 Bp., 1091 Kékvirág u. 2.	2/1	80.5	0.9938	6°	11°	11°	14°	12°
	2/2	81.5	0.9816	11°				
	2/3	83.3	0.9639	15°				
Slope 3 Bp., 1107 Bihari u. 3-5.	3/1	83.5	0.9581	17°	17°	15°	14°	15°
	3/2	85.0	0.9412	20°				
	3/3	82.5	0.9697	14°				

Table 24: Our results for α

Our results range from 6° to 20° and a characteristic (mean) value is 14°.

I find it very important to remark that secondary school students in Hungary do not study measurement theory. I offered my students to go deeper into error calculation, but none of them showed willingness for a deeper study. We discussed some basic problems that arose and decided to consider our results to be “measurement-based” estimates rather than going into deeper error calculations. This turning point underlined the heuristic (and therefore peripatetic) quality of our mentor class.

7.5. *Incorporating the results of our theoretical and practical studies*

„Why is it easier to pull a sledge on level ground than to pull it up a slope?”

We provided two answers:

- 1.) Since $\mu < 1$, from the theoretical study we learned that there is no need to give a typical value to α (Figure 41). A correct answer is: As the typical $\mu < 1$, it is easier to pull a sledge on level ground than to pull it up a slope.

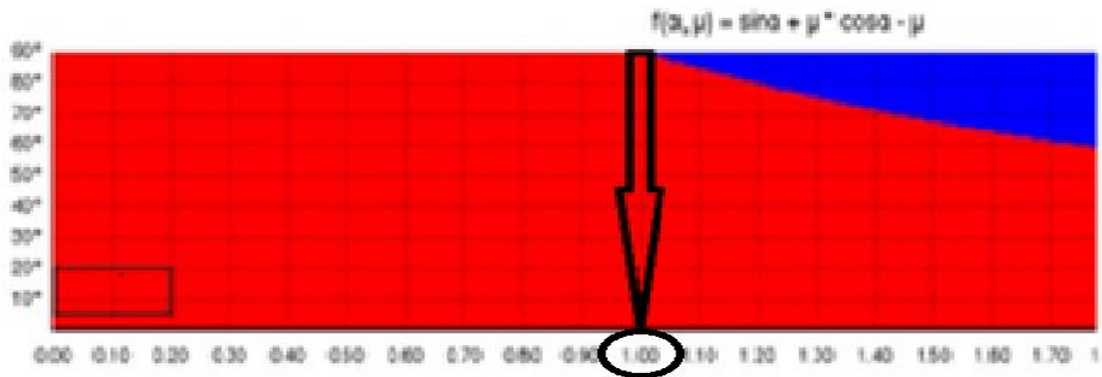


Figure 41: The case when $\mu < 1$

- 2.) We studied the area denoted by the typical values based on our measurement (Figure 42). Another correct answer is: It is easier to pull a sledge on level ground than to pull it up a slope, because of the real values of α and μ .

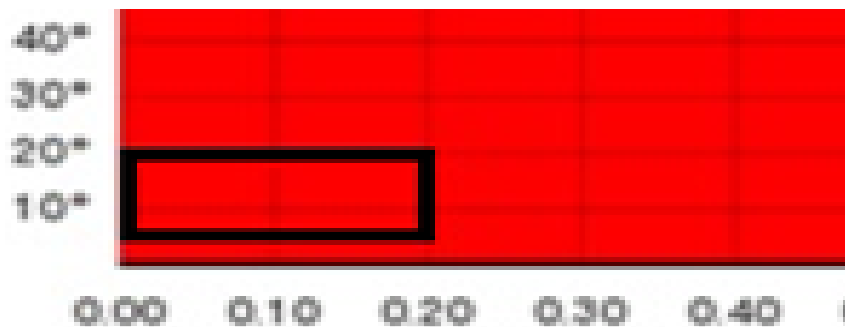


Figure 42: Real sledging values

7.6. *An interdisciplinary forum of science*

In this mentor class teacher and students studied a question that had been studied before only in a qualitative way in public education. First, we have found that the typical answers in this case are not correct. Then we turned a “why?” question to a “yes-or- no”

type of question. Easily we got to a function of two variables. From this point on computing skills were needed to carry on with our project. We planned and carried out measurements to get reasonable estimates for quantities in real events. After a quest we compared our results to those in the scientific literature. Finally we prepared a presentation, a ppt and an article for a conference and participated in it as a research group.

In two months a surprising request found us: based on our article in TPI 2015 we were invited to an AIS Conference. The four of us revisited our presentation, ppt and article and adjusted it to the theme of another conference. We highlighted the possible applications of Information Technology, since it was the topic of this later conference. The title of our presentation and article this time was: "IT promoting physics projects".

Our mentor class turned into an interdisciplinary forum of science.

8. Excerpts from mentor projects

8.1. *One-to-one mentor projects*

Mentor classes are optional for students in Hungary; very often a one-to-one or one-to-few class is formed. We can say these students (and very often teachers, too) sacrifice from their free time to participate in these classes. This voluntary participation provides that students are highly motivated; however they still need positive reinforcement. There are no strict academic goals that need to be fulfilled. In most of our cases our goal was to prepare a project for a science competition, but we considered this goal mostly as a help to plan and organize our work around. The teacher is becoming more like a guide in mentor classes, whose main task is to cooperate with the student(s) as the most experienced, most skilled person in the team of eager scientists.

Due to my experience secondary school students are interested and motivated to work in peripatetic (read more in the Appendix) mentor classes. I found that setting a goal often helps to maintain hard work, therefore to train perseverance.

Each year I had some students who showed interest, and nearly every one of them finished his project. I had these projects in the last 5 years that ended up with a booklet or a report of the work and results: The Faraday Gun (Gábor Pető), Sparks and Flashes (Tamás Molnár), Another Tesla Coil! (Benjamin Bödecs), Control Technology and Ohm (Ádám Bujtás), The Colour Changing Light Sensor (Balázs Kertes), and 3 more that I will promote as great examples. When I decided which three projects to choose for a more thorough presentation, I was facing a hard task. The ones I decided for are very special in many ways.

8.2. *The Tesla Project with Dénes Paál*

Building a Tesla Coil

The Tesla coil is an electrical transformer circuit of high frequency resonance and a high voltage generator. Basically we can mention two factors that make it different from the transformer. Firstly, both the primary and the secondary circuits are in resonance with the operating frequency, which means that it changes the frequency of the power supply. Secondly, it is an air-core design.

The classic system consists of a high voltage transformer, a capacitor connected to it in parallel, a spark-gap connected in series, primary and secondary coils, and a top-capacitance.

The first resonant circuit is the primary circuit and the capacitor, which is switched on and off by the spark-gap. When the transformer is under voltage the charging of the capacitor is started. When the voltage on the capacitor reaches the voltage that is needed for forming sparks, the electric field between the electrodes of the spark-gap ionizes the molecules of air, which drastically decreases the resistance. The circuit has been considered as a closed one so far, but a spark closes it allowing the current to flow in the primary circuit. As the effect of the current starting to flow, a magnetic field is induced. It is transmitted to the secondary coil, and it means that to the secondary circuit and at the same time the top capacitance also. In these an Eddy current is formed due to the voltage induced by the change in the magnetic flux. As the ionization stops, the closed circuit opens, which means that charging up the capacitor can begin again. The self-induction, the capacitance of the used capacitor determines a time constant. Resonance occurs, which insures that the frequency does not depend on the frequency of the power supply.

We used the diagram in Figure 43 to build our Tesla coil.

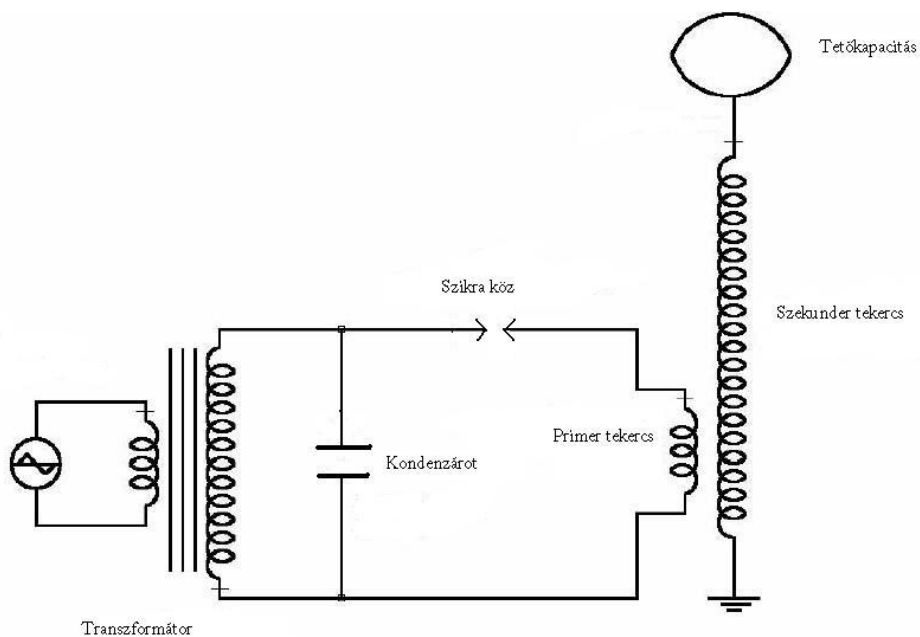


Figure 43: The Tesla coil

The parameters of our coil are as follows:

- two transformers in series, both taken out from microwave ovens, with 5kV output
- a self made capacitor of 65 μ F (we used kitchen and polyurethane foils to make it)
- a spark-gap, we used a rotational spark gap, that we made from a grinder by winding 8 pieces of 8mm screws into a disk, which was attached to the machine, thus we made an asynchronous spark-gap
- primary coil: a brass band spirally wound in 13 loops
- secondary coil: 0.4 mm copper wire hand-wound in 2000 loops onto a PVC pipe of 15 cm in diameter
- roof capacitance: a toroid made from aluminium tube

Figure 44 shows our fixtures. From the spark in the figure we can estimate the voltage. Since the breakdown field strength of air is 30 000 V/cm, the output of our coil is about 600 000 V.



Figure 44: Making our spark-gap, capacitor, 13 loops of brass band, toroid, roof capacitance

We collected some experiments to demonstrate:

1. Low-current and high-voltage sparks can be touched. 60-80kV means 3-4cm sparks in air (Figure 45). Still, they are not hazardous. We had a small coil for this purpose.
2. The Glimm lamp flashes up. It also works in a chain of more students.
3. The gas discharging tubes light up in high voltage. We can also study the spectra of these using a prism or a spectrometer (Figure 45).
4. A light bulb, even if it is bad, turns to be a plasma bulb.
5. We can demonstrate the lightning rod principle: a very pointed metal rod has a large concentration of charge at its point, therefore a large electric field.
6. We can show the enchanting electrical Segner wheel.
7. The light sword experiment (referring to Star Wars): without contact any (even normally useless) fluorescent lamp can be luminous in high voltage



Figure 45: We can touch high voltage (, if low current),
and study discharging tubes

Further elements of the project

In our peripatetic project it became a goal to widen the perspective and do steps for making not only our apparatus, but other related areas more popular beginning from of the original project. We set up a presentation based on the Tesla coil, but the main points were these:

- An introduction of Senta, the capital of Serbia. (Since the student was born there, this point was appealing to him.)

- Serbs and Croats both claim Nicola Tesla as a scientist of their nationality. The next of our points was introducing Tesla and so some morsels from the History of Science. We highlighted Tesla as a scientist, but also went into funny details of his personality. We paid special attention to the “War of Currents”, or “Battle of Currents” that was between him and Thomas Edison in the late 1880s. We gained information from the internet [R7.1.]
- And finally we turned to our scientific and engineering project, and enchanted the students who decided to pay attention to our presentation.
- We also invited those who brave enough to participate in the experiments.

We can note that peripatetic methodology is open between doctrines: we built up our presentation starting from a phenomenon in physics, and looked out not only into experimental physics and engineering problems, but also to geography, social studies, history of science and related areas. It became a great example of experience aided learning. Figure 46 shows Dénes in a presentation.



Figure 45: Dénes in a Tesla presentation

Our attempts to make physics popular through our presentation were:

- We advertised an open show on “Trefort day” (in our secondary school).
- Two presentations were needed because of the great interest on the “Science at Night” program (also in our secondary school).
- We offered (via a poster and the school’s newsletter) our presentation to classes for physics, science or technical classes. Many classes and teachers were interested.

- We did a presentation at ELTE, at the “Természettudomány Tanítása Korszerűen és Vonzóan” Conference in 2010. Based on this we have a publication in the Conference Proceedings, 2011. <http://csodafizika.hu/fiztan/letolt/konfkotet2011.pdf>
- We made a short video of our Tesla coil working, and uploaded it onto youtube [R7.2.] <https://www.youtube.com/watch?v=mh74cWmJgXg>
- Our presentation was invited to the popular “Scientists’ Night” programme by Mr. Károly Härtlein as a part of the official programme of the Technical University of Budapest (BME) in 2011.

These events cover a wide palette from the possibilities of informal settings in science education. The direction of this part of our work is popularization and management, which is another important doctrine that we came familiar with.

All the way long in the project in smaller or bigger parts of the project some other students helped out in our work and enriched the project with either their knowledge, with their great ideas or just with their helping hand. We also relied on the help of technical teachers (, who in Hungary must be engineers) and our relatives.

8.3. We can see voltage with Tamás Berényi

Teaching voltage and potential

Presenting voltage as a quantity at secondary level is not an easy task. We can meet this concept very often in everyday life, so it is very important to help our students to best understand the concept.

Usually we give the definition based on the electric bell experiment. In the experiment we have two parallel metal plates on an isolated stand. We charge up one of them. We hang in between a small metal object attached to a thread. In this setting electric division is formed in the neutral object in the middle. It moves towards one of the plates. Hitting it, the small object gets charged up, which means it moves towards the other plate due to attractive and repulsive forces. It hits the “vis-a-vis” plate, where the majority of its charge is passed. This process is easy to demonstrate for the teacher, and to understand for the pupils. Figure 46 shows how it happens in class.



Figure 46: The perspective forming experiment

It is important to note that (mechanical) work was done in the experiment. On one hand it proves the existence of electric energy. On the other hand we can define voltage as work done on one unit of charge whilst transferred from place A to B. We get the idea of voltage between two points that is U_{AB} . We know that $U_{AB} = -U_{BA}$. Our students can fathom it easily. We can discuss that in SI the unit is 1V (volt), meaning that between A and B 1 joule is needed for the transfer for 1 coulomb charge.

Electric potential is also on the syllabus. Still, the scientific definition is very abstract for most of the teenagers: the electric potential is the amount of work needed to move a unit of charge from infinity to a point in the electric field. Using the formalism above it is as follows: $U_{\infty A}$. In technical physics (, viz., in electric engineering) the specific point instead of infinity in the definition is Earth. Thus “earthing” or “grounding” has an obvious meaning. I often introduce the concept for my students the “technical” way, and indisputably mention the scientific definition when they have got the notion meaningfully. Furthermore, I can build on their analytical thinking when drawing parallel between altitude (a notion they know from geography) and electric potential. They have no problem to understand

- that potential can be negative or positive,
- that an appointed spot is needed for the definition,
- that voltage can be read as potential difference,
- that sign is a part of the value.

On the following picture (Figure 47) you can see how the presentation is happening in the classroom.

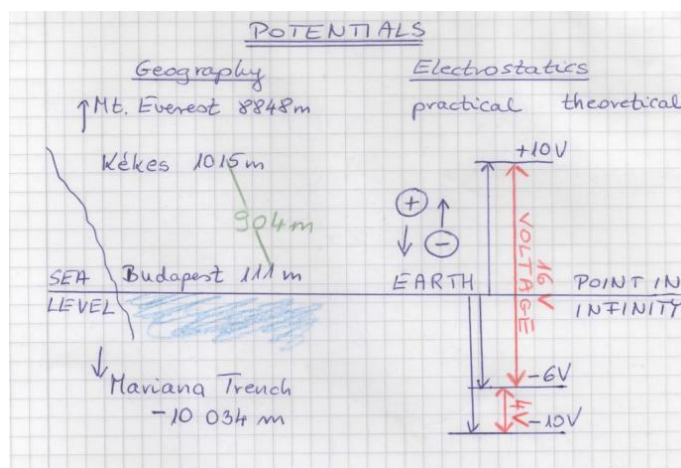


Figure 47: Altitude and electric potential

Tamás can make voltage visible

One of the school students, Tamás(, who was a freshman) paid special attention to these concepts, and showed interest for a project. He wanted to show voltage visibly to his mates. I will show the details based upon the booklet we made.

Tamás and his friends at work are in Figure 48.



Figure 48: Tamás and his friends at work

We made a booklet from our work in the mentor project. He learned how to present his work:

- we wrote an abstract (in English and in Hungarian also)
- we worked on the table of content, (which helped him to see the structure of the work,) acknowledgements, references
- we made extra-curricular studies on capacitance, types of capacitors, history, production and application of capacitors, the theory of charging and discharging a capacitor

We, with his friends did the “Discharging a capacitor” project together. We used

- a capacitor, of 2000 μ F
- a load of 68k Ω
- a power supply of 12V
- a digital multi-meter
- wires
- a stopwatch

We read the current values of voltage in every 10 seconds. The readings are presented in their work as it is in this figure (Figure 49):

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
10,46	9,62	8,91	8,33	7,80	7,30	6,86	6,42	6,02	5,68
11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
5,32	5,00	4,71	4,40	4,16	3,92	3,69	3,49	3,28	3,11

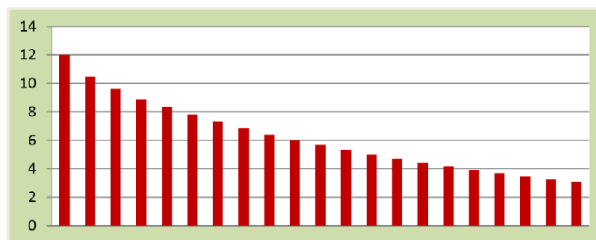


Figure 49: Voltage of a capacitor during discharge

There was much left to learn for Tamás, we can conclude from the figure above, but my focus was to support him in a peripatetic way. At the time he was a junior in the school, had not even getting started with secondary physics (surely not with SMPs) at the time, but a junior student of IT and electrical studies.

The main point of the project was to present voltage in a visible way. He combined the decrease of voltage in the previous experiment and his idea. So, we made a circuit in which we could see (not measure) how voltage is decreasing. We needed the following:

- an IC, LM3914
- a capacitor, 2200 μ F
- a resistance, 1k Ω
- a resistance, 33k Ω
- switch
- 10 (green) led lights

- printed circuit board
- a power supply
- wires

On the pictures we can see that as the voltage drops, less led lights are lighting. See Figure 50.

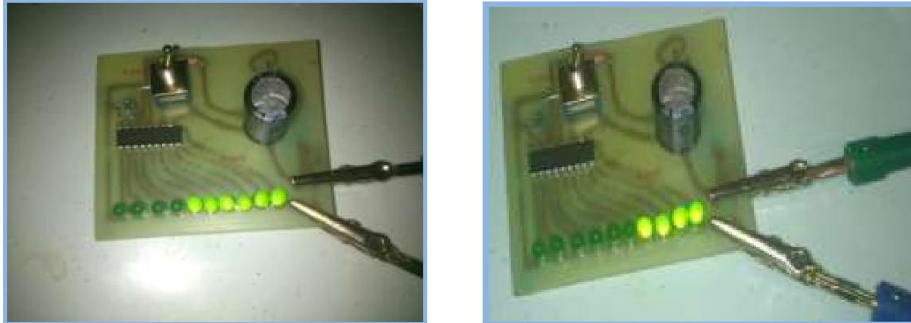


Figure 50: Led lights showing the lower integer of the current voltage

For possible further development he mentioned that a matrix could be build out of led lights of different colours, and each column would be activated with a time delay.

As this circuit can show the lower integer of the current voltage, to characterize the discharge we can read the exact second of the going out of the consecutive led light. With these data we can easily plot a graph like the one in Figure 51 to show the exponential nexus.

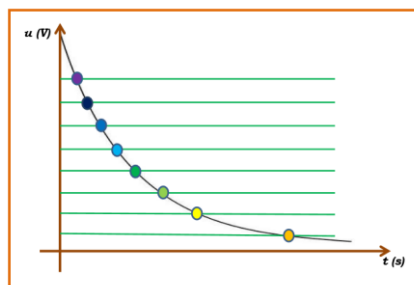


Figure 51: The idea of a matrix

Tamás applied with his work for two completions:

- the Lánzos competition (<http://web.t-nline.hu/theiszgy/lanczos/index.html>), and
- a competition for experimental physics at Szeged (<http://exp.physx.u-szeged.hu/kispaly.htm>).

He was invited to the national finals in both competitions and was very eager to have physics classes in his secondary school studies.

8.4. *Fire and Water!* ***We light a match with H₂O, if Dénes Vincze is around***

Our students in secondary schools are teenagers. We all know that this period of life is not easy at all. Extremes are very engaging at this age. The following project targeted this truth.

A project with Dénes Vincze

We use matches (or lighters) every day to set fire, still don't know much about them. Dénes Vincze asked for my help to tutor him to make the best from his interest in the topic. When we list the main uses of water we can mention that we can extinguish fire. But lighting a match with water seems like an odd idea. In our project we studied the history of fire and matches, created a clever gadget that makes this odd idea reality.

We studied and analyzed literature on matches and fire. I dedicate a few paragraphs to the information that are special from interdisciplinary point of view, and may grab our students' attention. We used the internet to get information from [R7.3.].

We have proof that the passive use of fire was a routine even for the Homo Erectus, about 680 thousand years ago. Prevailing over fire opened the possibility to new form of civilization, since it inferred sociological changes. Cultivation and the change of human nutrition have changed the lifestyle. Even today, most of energy is gained by fire.

Before inventing matches fire was lit in numerous ways, like using flint. The history of matches can be put to China, to 600 A.D. These were sulphur saturated sticks. In the end of the 18th century there were wooden sticks with white phosphor, but these were still not Turkish (rubbing) matches. In 1827 John Walker, an English chemist invented matches; his work based on the results in 1680-ies of Robert Boyle (, a name well known from physics). This was a mixture of antimony-sulphide, potassium-chlorate, rubber crop and starch. Samuel Jones bought the rights of production, and put "Lucifers" (Figure 52,[P8.1.]) on the market.

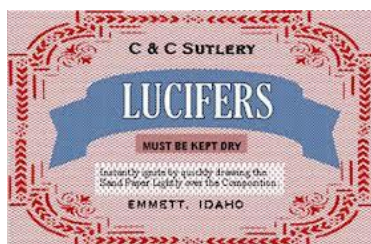


Figure 52 [P8.1.]: Lucifers, the first matches on sale

“Lucifers” was very bed smelling, proved to be hard to inflame, and the size of the flame was unpredictable. In 1831, the French Charles Sauria added white phosphor to the mixture. But this material is to be kept hermetically and is poisonous.

Safety matches that are available today are also called Swedish matches. There are different standards for the stick and the mixture.

Surely, in our work building a tool is a “hands-on”, active part of the project. To astonish the listeners we built our simple tool, a handy gadget to light a match. We figured out what theory we can rely on, thus we confirmed the utter need of theory, that refers to “minds-on” line of didactics.

The criteria for lighting fire are:

- flammable material, that is in our case a match,
- agent of combustion, that is oxygen from air for us,
- ignition (or higher) temperature. Seemingly, this is the only criterion water can be used for.

This is how we made our “handy gadget”:

We need a copper tube, about 5mm in diameter and 1 m long. We form a spiral of 6-7 loops on one end, leaving a 5 cm beak. We asked a plumber to help out with this dangerous task. The end of the beak was flattened by pliers.

We also need a Bruckner flask, and rubber tube to connect the copper tube to the flask. While doing the experiment we close the top of the flask with a cork. Figure 53 shows this.

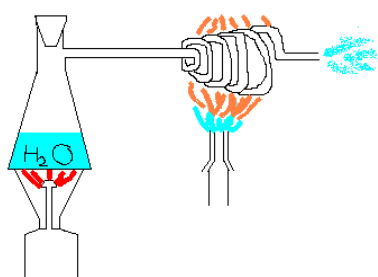


Figure 52: The plan and the tool, when ready

In the experiment we put some water in the flask, we close it. We heat up with a gas cooker to boiling point. Steam flows into the tube, and it leaves it.

We can show it with putting a mirror in the way of the steam (Figure 53).

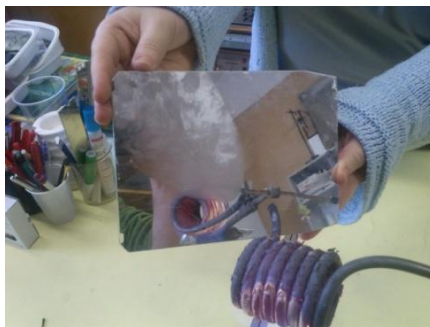


Figure 53: Demonstrating how steam flows out

We learned that the flask is sensitive to heat bridges, so we need to prevent it from direct flames. For this purpose we used an iron plate on the stand.

With another gas cooker or Bunsen burner we heat up the spiral loops of the tube. Its incandescence (Figure 54) refers to the fact that we have at least 600°C . In room temperature cooling is very rapid, since the ambient temperature is big, the steam flowing through and later out from the tube still provides the ignition temperature of red phosphor (300°C). A longer beak would allow the steam to overcool.



Figure 54: The spiral made from the copper tube at red glow

We have to place the match to about 1.5 cm from the end of the beak (Figure 55). The flow of steam can blow away our flame, so we need to dislocate the match soon.



Figure 55: The match lit up

The teacher's notes

We also made a course booklet about our work. He took all the advantages of this task, also.

We used our studies and experiment to provoke thoughts for his fellow students, and also teachers. We made presentations

- in our school's project week
- in the "Science at Night" program
- in the Lánzos Kornél competition
- in the physics teachers' annual meeting in Hévíz.

But based on this work, there are "after-life" projects as well.

"Afterlife" projects

Physics for everybody

The Roland Eötvös Physical Society (ELFT) has announced the "Physics for Everybody" programme three times, since 2015. In 2016 I announced a programme in my secondary school (MIG, Madách Imre Gimnázium, <http://mig.hu/>) linked to this event. Its title was: "Physics (and chemistry) for everybody 2.0". With my colleagues we presented experiments in which water and fire are both present. We also made a tableau as a reminder that there were 167 participants in the project (Figure 56).

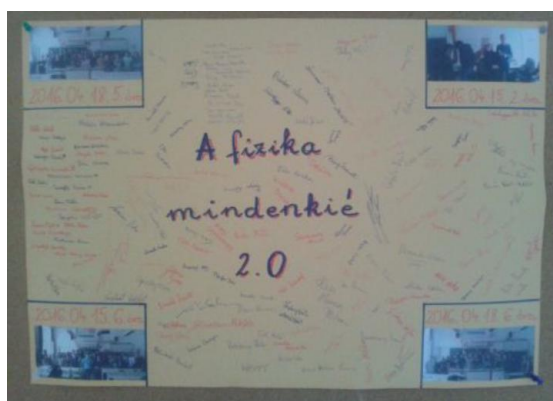


Figure 56: Advertising the event, and the tableau

Our project was awarded with "The most creative programme-2016" prize [R7.4.]. An almanac was published for the 135th anniversary of the foundation of MIG. In the issue our project was presented.

Researchers' night

Another great annual programme is the "Researchers' Night" (<http://www.kutatokejszakaja.hu/2017/>). The Ericsson Institute is also a great promoter of science education. In 2017 I had a chance to make a presentation of my favourite experiments. I decided to excogitate a new project based on the "Fire and Water!" project (http://www.kutatokejszakaja.hu/2017/esemenynaptar/index.php?menu_id=4&hely=141).

The motto is a citation from Alban Stolz (1808-1883), the popular writer of his age and professor of pedagogy and theology:

*"When water and fire get together, there will be hissing and steam;
fire protects itself, and then gets extinguished;
water evaporates leaving smutty moisture behind."*

The experiments I made are these:

- We lit a match with H₂O, in two ways. Surely the one we made with Dénes, and the other was by letting a water-drop on sodium.
- Our hanky was in flames, but didn't burn, since the liquid (we soaked our hanky in) is half water, half alcohol.
- We crushed a can, which is a well-known demonstration for the pressure difference between hot and mild air.
- The foam in our palms turned to flames, as in the bubbles we put gas in.
- We boiled water in a balloon.
- The surface of water caught fire.

The program was a gorgeous out-reach program. Some photos (Figure 57) demonstrate that science is enchanting, even not long before midnight.






Figure 57: The Researchers' Night at Ericsson

We discussed what the role of water and fire are in each of these experiments, breaking the boundary between physics and chemistry. Figure 58 shows one of the slides and also how the corresponding experiment goes.

Fire and water! / Fülöp Csilla

A cracking good experiment

<p>Fire: heats water to its boiling heats the air inside the can</p>	<p>Water: boils, thus shows us that the temperature is high</p>
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KUTATÓK ÉJSZAKÁJA 2017
Az Ericsson K+F Központjában

Öveges Tanár Úr Utódai
Fizikai kísérletek nem csak tudósoknak



Figure 58: The role of fire and water in an experiment

References

- [R.7.1.] https://en.wikipedia.org/wiki/War_of_Currents
- [R7.2.] <https://www.youtube.com/watch?v=mh74cWmJgXg>
- [R7.3] <https://en.wikipedia.org/wiki/Match>
<https://en.wikipedia.org/wiki/Fire>
- [R7.4.] B. Jarosievitz, Cs. Sükösd: "Fizikai kísérletek – nem csak tudósoknak"
ed.: J. Lendvai, Fizikai Szemle, Eötvös Loránd Fizikai Társulat, Budapest,
October 2017, p 329, Hu ISSN: 0015-3257 [http://fizikaiszemle.
hu/http://afizikamindenkie.kfki.hu/?g=arch-vum-2016](http://fizikaiszemle.hu/http://afizikamindenkie.kfki.hu/?g=arch-vum-2016)

Pictures

- [P8.1.] <http://www.ccsutlery.com/store/lucifermatches.html>

Summary

The crisis of STEM worldwide is urging the scientists to find a way out. Research of science pedagogy is needed. Finding ways of teaching new content and new, motivating solutions for classroom use pry open the palette of methodology research.

In my work I made a study on the possible solutions “hands-on, minds-on” didactics can offer, focusing on measurement projects in physics.

I worked out an optional chapter on measurement theory for use public education. Building on that, I introduced a method, called the Student’s Measuring Project. I offered a list of natural laws that can be taught this way in a classroom setting.

I grouped the basic laws in the syllabus from a new perspective: their mathematical formulae. I deeper studied the linear and the exponential ones. A fine representative of the later ones is Newton’s law of cooling. This law is fundamental in our everyday experience. I studied its possibilities in teaching at different levels of public education.

Teaching the law of radioactive decay is a problematic task. A set of my colleagues affirmed it in a survey. A tendentious block of teaching exponential laws in “hands-on” approach can ease the peril according to my experience.

Helping the talented and motivated students (mentoring) is the icing on the cake in a teachers work. I presented how I formed an interdisciplinary forum of science in the Sledge Project. Our forum found real answers for a well known question that had skin-deep answer. I also highlighted a few of the one-to one projects from the previous years: the Tesla Project, the “We can see voltage” Project, and the “Fire and Water” Project.

I hope that more and more students can apprehend, see clearly, understand and grasp the laws of nature if they can get familiar with the idea of how science and research works.

The work I divulged has opened topics for further study. For me, it has surely been only “that first mile” of a long marvellous run.

Összegezés

A STEM világméretű krízise a tudósokat arra ösztönzi, hogy keressenek kiutat ebből. A természettudományok pedagógiájának kutatása egyértelműen szükségessé vált. A szakmódszertani kutatások palettáját két véglet feszíti ki: az új tartalmak tanításának módszereitől a motiváló jellegű tantermi megoldásokig.

Munkámban a “hands-on, minds-on” didaktika által javasolt lehetséges megoldásokat tanulmányoztam, különös figyelmet szenteltem a fizika területén belül a mérőprojekteknek. .

Kidolgoztam egy, a közoktatásban használatra ajánlott témakört a méréselmélet tárgykörében. Erre építkezve bemutattam egy módszert, melyet „Tanulói Mérő Projekt”-nek hívtam. Egy listán ismertettem a természetnek azon törvényeit, melyek e módszerrel taníthatóak osztálytermi keretek között.

A tantervekben szereplő alapvető törvényeket új nézőpontból csoportosítottam: a matematikai formájuk alapján. Alaposabban megvizsgáltam a lineáris, és az exponenciális típusokat. Newton hűlési törvénye nagyon szép példája az utóbbi típusnak, és napjaink tapasztalataiban alapvető. Megvizsgáltam hogyan tanítható a közoktatás különböző szinterein.

A radioaktív bomlástörvény tanítása különösen problémás kérdés. Kollégáim egy csoportja megerősítette ezt egy felmérés keretében. Egy szisztematikusan, az exponenciális törvényszerűségek tanítására felépített egység, melyet “hands-on” megközelítésben dolgoztam ki, tapasztalataim szerint megoldást nyújt, így enyhíti a problémát.

Különösen motivált és tehetséges diákokkal való munka a tanári feladatkörben hab a tortán. Bemutattam, hogy a Szánkó Projekt hogyan alakult egy interdiszciplináris kutatói fórummá diákjaimmal. Egy közismert kérdésre adott felszínes válaszok helyett valódi indoklást adtunk. Ismertettem még néhány olyan szakköri munkát, melyek az elmúlt években teremtettek értéket: a “Tesla Projekt”-et, a “Látjuk a feszültséget” projektet és a “Tűz és Víz” projektet.

Remélem, hogy egyre több diák látja át tisztán, érti meg, ismeri fel a természeti törvényeket, ha megismeri, ahogyan a természettudomány és annak kutatása működik.

Az ismertetett munkám sok további ajtót is megnyitott a kutatás számára. Számomra, bizonyos, hogy csak az első lépései voltak egy hosszú, csodás útnak.

Appendix

The Wonderful World of Measurements
a topic on metrology for secondary school students,
planned for 7 lessons, each lasting 45 minutes

- 1st lesson: Introduction, welcome
The definition and a simple model of measurements
- 2nd lesson: The 3 elements of a result: magnitude, unit, uncertainty
Errors and their propagation, significant figures
- 3rd lesson: The history of SI
Base and derived quantities, standards
Length and Time
- 4th lesson: Mass, electric current, temperature, luminous intensity, amount of
substance
Prefixes
- 5th lesson: The Record of Measurement
“Specifying angular measure” project
- 6th lesson: The Cinderella project
- 7th lesson: An overview of the unit focusing on the particular claims of the specific
group

***Some additional information for the implementation
of the insertion of SMPs into the teaching practice***

Trefort Ágoston Bilingual Secondary Technical School, Budapest

The school is for students aged 15-20. In the first 4 years the students have the compulsory subjects of the common knowledge, and basic training for technical professions. Having finished this course they can either finish their education, or stay for further technical training (a further training for 1 or 2 years, depending on the choice) in this very school, or any similar ones, or also can go to universities. I had a chance to work with all four parallel classes, who studied physics in a three-year-course framework.

The following list shows what specialization each of the classes had:

- class D (1+4 years) a bilingual class, they studied also physics in English, IT hardware specialization
- class A (1+4 years) a class with advanced training in English, mechanical studies and IT specialization
- class B (1+4 years) a class with advanced training in English, electrical studies and IT specialization
- class F a class for IT specialization

The number of participating students

The number of students who participated in the whole secondary course on physics, and also on their decision felt competent to fill in the questionnaire is shown in the following table.

class	A	B	D	F	total
experimental group	10	14	13	12	49
control group	9	10	13	11	43

My fellow colleagues

I worked with Ms. Otilia Bartha and Mr. László Fülöp, the other members of the Physics Department at Trefort. I show who took the sets throughout the course.

My colleagues are Ms. Otilia Bartha (later MSOB), and Mr. Laszlo Fülöp (MRLF). I refer to myself as MSCF.

This is who the teacher of the group was during the course:

class	set	grade 10	grade 11	grade 12
D	experimental	MSCF	MSCF	MSCF
	control	MRLF	MRLF	MRLF
A	experimental	MSOB	MSCF	MSCF
	control	MSOB	MSOB	MSOB
B	experimental	MSCF	MSCF	MSCF
	control	MSCF	MSOB	MSOB
F	experimental	MSCF	MSCF	MSCF
	control	MSCF	MSCF	MSOB

End of semester and questionnaire

Presenting the notion and law in question happened in classes in 2015. from 27th February to 25th March, but varied from set to set. The prolonged data collection with the questionnaire was 5 weeks after the insertion. The academic year for seniors finishes in the end of April each year, in 2015. it was the 30th April. This timing limited the time-span we could work with.

***RoMs in hand-out forms
to introduce phenomena of exponential nexuses
for students in secondary public education***

RECORD OF MEASUREMENT

Is cooling a steady (linear) change?

Name:
 Class/set:
 Date:
 Site:



In this research you need to investigate if cooling is a steady (linear) temperature loss in time, or not.

You will need the following equipment:
a measuring cup, some hot water, a thermometer, a watch (you can use a cell phone set in 3 minutes alarm)

This is how you can **set your equipment ready** to measure, and prepare your mind for the study:
You will get hot water close to its boiling point into your cup.

Note how much you got:.....

Immerse a thermometer. Wait a few seconds so that the thermometer can show correct results.

Why do you have to wait?

How much time did you wait till your first result (0 minute) you consider in your measurement?

What quantity do you measure with a thermometer?

What do we mean by 1°C?

What quantity do we measure with a watch?

What do we mean by 1 minute?

Now, measure temperature and time, and fill in the chart with your results (work on evaluating your results while you are waiting for your next reading)

You may not have enough time to fill in the last few spaces in the chart in class. If so, do not worry. Work with at least 10 pairs of matching results.

time (min)	0	3	6	9	12	15	18	15
temp. (°C)								

time(min)	18	21	24	27	30	33	36	39
temp. (°C)								

Two quantities may show a linear function. How can we check if change is linear? We pick two ways of doing this. **Show these methods here.** How do the results turn out if the function is linear?

1. (forming differences and comparing)

2. (plotting and analysing a graph)

Now, analyse your results.

1. Check the differences in temperature between the consecutive results.

3-minute time-span change in temperature (°C)	0-3	3-6	6-9	9-12	12-15		
15-18	18-21	21-24	24-27	27-30	30-33	33-36	36-39

What can we say from this analysis?

In equal time spans the differences in temperature are

It means that the function of these two quantities in this phenomenon is

2. Plot a graph (temperature versus time). Use graph paper and give the graph here.



What can we derive from this analysis?

The graph is

It means that the function of these two quantities in this phenomenon is

Now, we evaluate this analysis.

From both methods to check if the function between temperature and time is a linear one in cooling, we conclude that:

Surely, the temperature of the environment makes an effect on how something cools.

What was that temperature during your measurements?

We also know the statement of a famous physicist on cooling. It is known as Newton's law of cooling. It states that „the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature (i.e. the temperature of its surroundings).“

Compare your results with the law mentioned just above.

Notes you made during your research:

RECORD OF MEASUREMENT

Is discharging a capacitor a linear phenomenon?

Name:

Class/set:

Date:

Site:



In this research we can examine whether the voltage of a capacitor during discharge changes evenly in time.

You will need the following tools:

a 2000 μ F capacitor, a 68k Ω resistor, a 12V DC power supply, a voltmeter, 7 wires, 4 alligator clips, a watch (you can a cell phone set to 10 seconds reminder), graph paper, 1 switch

This is how you can prepare for collecting data and for the study of the phenomenon:

- Set up the following electric circuit!

The capacitor is charged from the power supply.

Disconnect the resistor while charging to help the progress to be done faster.

- If the capacitor is fully charged, connect the resistor into the circle. When the power supply is disconnected, start the watch to study the progress of discharge.

Measure voltage and discharging time, and fill in the table with the measurement results. Reading of the actual value of the voltage should be in 10 second intervals. Share the tasks in your group: time-trustee, reading-trustee and note-down-trustee. Since the phenomenon is strict in time, it requires teamwork.

time (s)	0	10	20	30	40	50	60	70	80
voltage (V)									

time (s)	90	100	110	120	130	140	150	160	170
voltage (V)									

Two quantities may show a linear function. How can we check if change is linear? We pick two ways of doing this. **Show these methods here.** How do the results turn out if the function is linear?

1. (forming differences and comparing)

2. (plotting and analysing a graph)

Now, analyse your results.

1. Check the differences in voltage between the consecutive results.

10s timespan	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
voltage drop (V)								

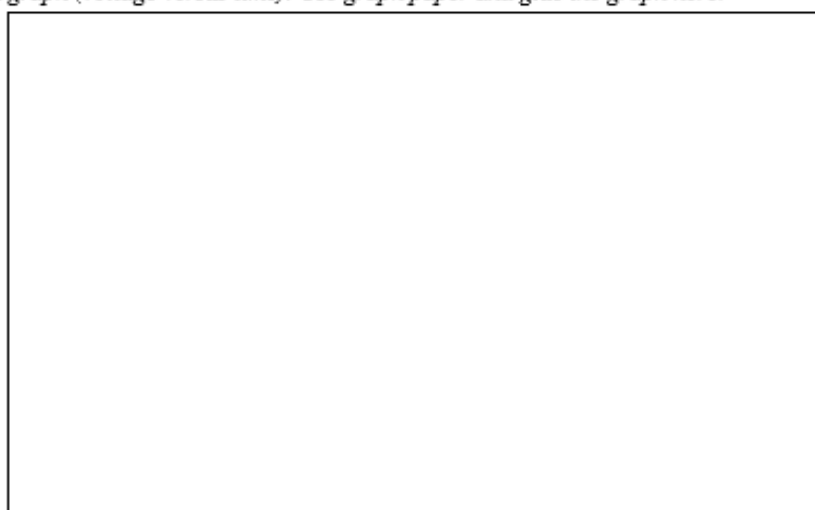
80-90	90-100	100-110	110-120	120-130	130-140	140-150	150-160	160-170

What can we say from this analysis?

In equal time spans the differences in voltage are

It means that the function of these two quantities in this phenomenon is

1. Plot a graph (voltage versus time). Use graph paper and glue the graph here.



What can we derive from this analysis?

The graph is

It means that the function of these two quantities in this phenomenon is

Now, we evaluate this analysis.

From both methods to check if the function between voltage and time is a linear one in discharging, we conclude that:

Notes you made during your research:

Investigating the radioactive decay

Name, set:

On this worksheet you can investigate what is meant by half-life.

A radioactive material sample was examined in a laboratory. The primary analyzes were carried out, so the following partial results were reached. Complete the evaluation of the measurement.



Particles of a radioactive sample are transformed through radioactive decay. The number of the nuclei of the isotope that is able to decay is shown in the table below:

time elapsed (minutes)	0	5	10	15	20	25	30
number of nuclei (10^{20})	265	223	190	160	135	116	98

time elapsed (minutes)	35	40	45	50	55	60	65
number of nuclei (10^{20})	83	70	59	51	43	33	31

Plot a graph. It should be showing the number of nuclei versus time.
Use an A4 sheet of graph paper that you attach to your worksheet.

What is the half-life of this sample?

Determine the half-life based on three initial points.
Use your graph to read the necessary information.

initial quantity (number of nuclei 10^{20})	corre- sponding time (at minutes)	half of the initial quantity (number of nuclei 10^{20})	corre- sponding time to „half“ (at minutes)	half-life (minutes)

Based on the three half-life results you got from your analysis you can get the half-life of the sample by calculating the arithmetic mean:

What radioactive material could have been used in the experiment?
Consult the data in your chart. Interpret and compare to other half-life data.

Notes you made during your work:

RECORD OF MEASUREMENT

Modelling the law of radioactive decay

Name, set:.....

In this worksheet you can understand how the decay of radioactive materials happens. We don't examine the phenomenon itself, but play a game which is modelling the process.

These tools are required to play: 60 pieces of two- different colour- sided, so called dual-sided coins (often used for counting in primary school), 60 pieces of one- colour coins, graph or grid paper.

This is how to play:

This team will work with a set of 60 from the particle multiplicity.

We take 60 of the dual-sided coins representing a set of 60 nuclei of the radioactive isotope. These are representing the particles of the so called „parent-element“.

Toss up the 60 dual-coloured coins. They should fall on a tray on the bench or to the floor. There are two options for each fallen coin: red or blue upwards.

Set aside those coins which were red upwards, these coins "decomposed." Replace them by one-colour coins that represent the nuclei of the „daughter-element“.

Count the dual-sided and one-colour coins. Show your results in the following table.

Repeat the process until the dual-sided coins (parent particles) run out (, so all of the radioactive nuclei are decomposed).

steps	start	after tossing 1st	after tossing 2nd	after tossing 3rd	after tossing 4th
number of „parent“ nuclei	60				
number of „daughter“ nuclei	0				

steps	after tossing 5th	after tossing 6th	after tossing 7th	after tossing 8th	after tossing 9th
number of „parent“ nuclei					
number of „daughter“ nuclei					

Plot a graph on a graph or grid paper to show your results. The graph should be the number of dual-sided coins (number of nuclei of the „parent-element“) versus steps. Attach your graph to your worksheet.

What is „half-life“ in our model?.....

Compare your results with those of other teams in your physics group or class. Now concentrate on the number of particles of the radioactive „parent-element“ (the number of dual-sided coins). Fill in the table with the results of the other teams.

team	start	1.	2.	3.	4.	5.	6.	7.	8.	9.
	60									
	60									
	60									
	60									
	60									
	60									
	60									
	60									
	60									
	60									
all in all	600									

Compare the graphs of the teams. What can you deduce? Is there any significant difference between the results of the teams?

Plot a graph of the decomposition based on the combined results representing a sample of 600 nuclei. Attach it to your worksheet.

What is the number of nuclei that are to decompose in a real radioactive isotope sample? Estimate the magnitude. Use the data from literature.

We could notice that we can't predict which nucleus will decompose in the following step. What is the role of this incidental decomposition of a given nucleus regarding a real radioactive sample? Consider the number of nuclei of an "in use" sample.

To what extent do the results of measurement diverge in real, "in use" samples? The degree of difference:

none - minimal - observable - small - medium- high - important - essential - determining

Notes you made during your work:

***The questionnaire the students filled in
to show their scientific competence
restricted to the studies of the radioactive decay law***

Questionnaire for students

Dear Student,

Methodological research is done at ELTE TTK Physics Education Doctoral School. Our goal is to find out how physics could be taught in a more effective and likable way. For my research I ask you to fill this questionnaire at your best knowledge, and most of all honestly. Your answers will provide data for a statistical study. If you are not 18+, please, consult the teacher, who gave you this sheet, because your parents' permission is needed to participate in the study.

I. In this part I am curious what information you remember about radioactive decay.

1. Name some radioactive materials.
2. Underline the physicists who became famous for their contribution in radioactivity.
Becquerel, Maxwell, Tesla, Einstein, Gray, Curie, Wilson, Geiger, Planck
3. What do we mean by half-life?
Which of the following can be the half-life of a radioactive element?

1.4·10¹⁰years 53months 3.8days 19.7minutes 0.16seconds 3·10⁻⁷seconds

4. Circle the graph that represents the number of active nuclei in a radioactive sample versus time.



5. What is the law of radioactive decay?

II. In this part you can show understanding and applications

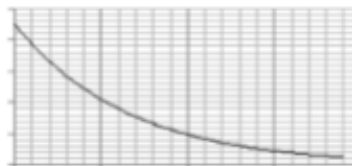
1. Consider this statement:
"Half of the active nuclei decay in the first half-life, the other half during the next."
Circle which of the following is the closest to your
A) True, because each nucleus decays.
B) True, because this is what half-life means.
C) False, because in the next half-life half of the remaining nuclei decay.
D) False, but I don't know why.
2. What do we know about the activity of the radioactive samples?

polonium isotope	half-life
Po-210	4.5 months
Po-218	3 minutes

3. Half-life of ^{210}Bi is 5 days. A sample contains 10^{18} nuclei of this isotope today. How many active nuclei will contain the sample in a month (30 days)?

4. You can see a graph on the right. What can be the phenomenon that it represents?

- ✓ – if it is the correct graph
- ? – if it is possible, but you are not sure
- X – if it is an incorrect graph



conductivity versus temperature for a metal wire	
temperature versus time in cooling	
magnetic field versus temperature in a ferromagnetic material	
number of radioactive nuclei versus time in a sample	
amplitude of a damped oscillation versus time	
voltage of a discharging capacitor versus time	
the size of the image versus the distance of the object in a flat mirror	
centripetal acceleration versus the radius of the circle	
gravitational field of a point mass versus the distance from it	

If you know a corresponding phenomenon to the graph, please, note.

III. In this part I am curious about your personal opinion about radioactivity and the classes you took part in. Circle the based on this:

1-not at all 2-rather not 3- rather yes 4- fully

It is important to learn about it. Everybody needs to know the bases.	1	2	3	4
It was interesting for me.	1	2	3	4
I feel I understand how it works.	1	2	3	4
I could follow attentively.	1	2	3	4
I understood better this phenomenon in the nature.	1	2	3	4
I find radioactivity less scary.	1	2	3	4
I can imagine participating in a program or watching a film in this topic.	1	2	3	4

Did you consult a book or the internet in topic just from your personal interest? What was it?

Budapest, 15th January 2015.

Thank you for your work and assistance.

Mrs. C. Fülöp, physics teacher

What is peripatetic pedagogy?

Aristotle and peripatetic pedagogy

Aristotle, the Greek philosopher had his education from his teenage years for nearly two decades at Plato's Academy. He was then appointed as the head of the Royal Academy in Macedon. He later established his own school in Athens: the Lyceum. His focus turned to physics, metaphysics, ethics politics and poetics. He put emphasis to art and science as different aspects of studying the same phenomenon.

His pedagogy differs from Plato's and other contemporaries' like Pericles's, Socrates' or the Hellenistic model. We often call Aristotle's model of pedagogy as peripatetic.

Peripatetic pedagogy is pertaining to Aristotle. The word peripatetic (= walking together) refers to the fact that he taught his philosophy while walking in the Lyceum of ancient Athens.

What are the main characteristics of peripatetic education?

- Students' skills are in the focus in two ways. Firstly, these are to be known beforehand, so that we can build on these (in this sense it is a precursor of constructivist pedagogy). Secondly, reinforcing these skills is an important task in the process.
- Surely, it is a highly motivating way of education.
- It is open between doctrines.
- It has no extreme requirements or outputs.
- It is a heuristic method, which means that the approach to solve a problem does not have to be optimal or perfect, but very importantly, sufficient for the actual goals. It is a great way of problem solving, learning or discovery; since it helps to ease the cognitive load of decision making. Heuristic methodology contains common sense, profiling, competent guessing, stereotyping, relying on intuition and the like.
- It is also an erotematic (often called as Socratic) method. Socratic means "named upon Socrates", since it is the method in Plato's dialogues. Teaching happens based on rhetorical questions rather than on lectures.

The peripatetic method of education is a great example of inductive teaching. For the learner it provides an active and constructivist approach of learning. Many teachers and students find it one of the most effective methods.

Ernő Fináczy analysed peripatetic didactics in terms of its contingency in a school setting [A1.] He highlights these positive aspects of the method:

- It is a method that suits best to pupils' willingness.
- Also, it has the best potential to encourage pupils to think.

He also confirms the fact that peripatetic didactics can be rarely used in schools. He is reasoning that it requires a lot of time, is not applicable to the entire curriculum, and does not help the students to see the goal clearly.

Reference

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Acknowledgments

“Standing upon the shoulders of giants”, as Newton would say.

I express my special gratitude to

- my parents and family:
 - my mum, who would let her only daughter do “strange practices” even at home; and my dad, who was always there to assist and help with whatever practical or other cajoling I needed.
 - my husband, and our son and daughter for showing interest in what I do, always lending me a hand when needed, and letting me take the time and financial support from the family.
- Mrs. Etelka Orbán, Mrs. Veronika Tóth and Mr. Miklós Nagy, who were my science teachers in primary and secondary school; they encouraged and mentored me.
- my teachers at ELTE, especially
 - Dr. Andrea Bartal, who set an example in methodology to me that I could follow,
 - Dr. Elemér Sas, who dignified me to accept being the supervisor for my MSc thesis,
 - Dr. Katalin Radnóti, who shared her dreams and work with me, and taught me to work as I had never done before.
- the headmasters of the secondary schools I worked and work in
 - Mr. Károly Varsóci (2009-2015, Trefort SzKI, Bp.) for giving me a chance to implement active pedagogy into my classes, supporting my course and research,
 - Mr. Csaba Mészáros (2015- , Madách Imre Gimnázium, Bp.) for setting me an example of a brilliant colleague, teacher and headmaster.
- all the scientists, who called the Physics Education Program Eötvös University to life, but especially Dr. Tamás Tél and Dr. András Juhász, who are establishers, operators and organizers of the program. Also great support for me, and so many.
- my supervisor, Dr. Judit Illy for her trust, encouragement and thorough remarks. She has become more like a friend in profession and role model to me in the past years.
- so many pupils, students, colleagues and friends I have no chance to list, but made their contribution to make a step further.

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