Introduction

> ... and there are many who recognise the need for science education in principle, but would rather reduce the time that young people devote to it. They argue that life in the 19th century is pulsating at a faster rate than in the Middle Ages, and that like our body, our mind also travels more swiftly in any direction now. They preach that our modern life, which presents challenges so rapidly and vigorously, also compels a faster preparation for it.
>
> (*Loránd Eötvös*)

The above quote is from the inaugural address [A] by Eötvös as rector of the university that now bears his name. I find it revealing because it sheds a different light on the ongoing effort to adapt to the challenges of an accelerated world never experienced before. In my own high-school years, we kept hearing "these kids are different, they need videos", and it was considered ultimate educational progress if every classroom gets equipped with a VCR. As the words of Eötvös sound amusing after a century elapsed, it will be equally amusing in another hundred years to look back upon the early 21st century and read how we lamented over the challenges of an accelerated age, and struggled to keep up with the facebook generation.

The lack of motivation is generally identified as a sign of the times, too. In my experience, young people are no less receptive than they used to be. The problem is that information is poured on them in such quantities that they cannot process it, and this is not caused by our accelerated age, but the severe reduction of the time allotted for the teaching of an increased amount of material. At the beginning of secondary education, students find physics interesting and appealing. In my school, for example, students in the zero-year (preparing for dual language instruction) nurture positive expectations regarding the new subject to be started the following year. By the end of year nine, however, enthusiasm will inevitably subside, as information is piling up.

When asked, students may answer that the problem lies with physics being "too theoretical". However, this may not reflect their own judgment but the trendy and deceitful opinion of the public that blames the subject and subject education should it not succumb to shallowness presented as an obligation of modernity.

Effectiveness, however, requires depth. The attention of students may be raised with anything that is allowed the time it takes, be that an experimental demonstration, a hands-on lab activity, a detailed explanation or even the lengthy process of developing a formula.

Goals and objectives

During my career as a physics teacher, I have always made a lot of effort to raise and maintain in my students an inclination to seek an understanding in depth. This kind of thoroughness also involves the consideration of content covered by other subjects, identifying the links to the subject of physics.

In the current curriculum of secondary education, the mechanical and thermal phenomena of the atmosphere and the seas largely belong to the subject of geography. In the practice of geography teaching, however, the physical background of these phenomena does not receive enough emphasis, or may not even be clearly identified. If asked in the physics lesson, students will reliably recount what they have learnt in geography. They may even remember the explanation, but a few questions will quickly reveal that they do not understand what they are talking about. It would be beneficial to both subjects to establish a treatment that fits contents together.

In my research work, I focussed on the physical implications of a selection of phenomena taught in geography, and the possible ways physics education may help provide a deeper understanding of these phenomena. As a teacher of Karinthy Frigyes Gimnázium, Budapest, my students have good abilities, they wish to learn and are not scared by mathematics either. In my work, therefore, I have always borne the education of this kind of student in mind.

Since, owing to the introduction of daily PE lessons, classes generally extend from early morning well into the afternoon, very few students volunteer to attend extra classes or clubs in the afternoon. This is why I avoided suggesting the treatment of any content as an extra, and tested everything in the classroom (regular or advanced).

Links and connections

The geography-related physical phenomena treated in my work belong to what is called environmental physics, in modern terms. The physical processes of the atmosphere and of the oceans are subjects of current scientific research. Since the issues of sustainable development, the depletion of energy sources, and climate change receive a lot of public attention, it is imperative that secondary education also take action. While the investigation and theoretical description of environmental systems normally lead to areas under current research (climate change, hurricanes, tsunamis, northern lights, etc.), secondary-school treatment sometimes involves finding an appropriate simplified interpretation of complex and abstract theories (such as accelerated reference frames or the laws of radiation) by adjusting the level of mathematics to the students.

Several of those receiving a degree so far in the ELTE physics education doctoral programme have touched on this subject of topical interest (as will probably many others to come). K. Baranyai constructed an experimental model for a classroom demonstration of heat transfer processes in the seas [B]. In addition to treating phenomena of atmospheric optics, I. Döményné Ságodi used radar images to make a simple weather forecast with her students [C]. M. Hömöstrei showed a sequence of climate models of the Earth that gradually have more and more complex features.

The Coriolis force is indispensable in explaining the physics behind geography. Because of the high degree of abstraction and the mathematics applied, the well established and clear description of accelerated frames in theoretical physics cannot be presented in secondary education. While [E] and [F] contain the most complete secondary-school treatments familiar to me, numerous simplified versions have been (and presumably will be) proposed for students of diverse ages, mathematical backgrounds and number of physics lessons per week.

In my paper, I also expand on a possible approach of inertial forces (the basis of my second thesis) that I have applied in my class. Since the dissertation by Á. Szeidemann (2014) also includes experimental and numerical simulation techniques for teaching the Coriolis-effect [G], I find it essential to point out the new features that distinguish my own approach from preceding teaching practice. Szeidemann claimed that with the help of the lab activity he designed for measuring how deflection depends on distance and how it is related to speed and to the angular speed of rotation "the effect can be taught quantitatively without introducing the concept of the Coriolis force, and the knowledge [acquired in this way] is sufficient for the understanding of several geographical phenomena, such as cyclones, the trade winds or ocean currents." His very creative method explicitly avoiding the introduction of the Coriolis force, however, can be identified as the quantitative version of the explanation that geography texts also provide. My teaching experience and surveys carried out with students revealed that these simplified explanations of the deflection, all restricted to the special case of an object starting from the North Pole, create the impression that the Coriolis force only acts on bodies that are moving in the north-south direction. Therefore I sought a possible approach that introduces inertial forces quantitatively, only uses mathematics available at the end of the ninth year, and works in the general case, at any geographical location.

THESES

1. Detailed investigation into the factors that hamper the understanding of the physics behind geographical phenomena [1], [3], [4], [6], [7].

With the help of multiple choice surveys addressing the mechanics and thermal physics behind geography, I established that it is necessary to include quantitative explanations and problem solving in the teaching of some topics traditionally treated only qualitatively by geography texts, or even some physics texts.

The questions on the surveys were formulated based on the detailed study of the geography curriculum and of the geography text books by several publishers. The distractor answers offered along with the right ones were composed to reflect the misinterpretations allowed or even suggested by the texts.

Survey results revealed that the key factors to impede understanding geographic phenomena lie with the lack of clear concepts, and with the lack of a thorough knowledge of the underlying physical laws, and all this can often be traced back to an approach refraining from all quantitative considerations whatsoever. Without quantitative treatment, misconceptions remain undetected: students may be lead to think they understand the phenomenon since they have read and memorized the explanation formulated in scientific terms.

This conclusion set me out on the course of all my further research.

2. Supplementary material for the introduction of inertial forces and applications in geography-related problems. [6]

The teaching of geography and of physics handle the issue of reference frames and inertial forces differently, which results in several difficulties in understanding. Therefore I assembled a teaching supplement that introduces inertial forces quantitatively without resorting to any mathematics beyond what is available at the end of the ninth year. I have shown that the material including applications to the rotating Earth promotes the understanding and setting in context of what has been learnt in geography before.

In physics education, the description of motions lays great emphasis on the concept of reference frame, and on the idea of the inertial frame in particular. Counterexamples, however, are only mentioned but not discussed in detail. Geography texts describing the motions of the atmosphere and the seas, on the other hand, just use their “natural” frame attached to the rotating Earth without addressing the issue of reference frame at all. In their explanations, they refer to the centrifugal force and to the Coriolis force, while inertial forces do not even appear in physics curricula. If it is not made clear that the difference lies in the choice of the reference frame, students will have no chance to understand the phenomena covered in geography.

In addition to setting the geographical phenomena in context, the supplement relies on a broad range of content from dynamics, making it a possible means of providing students with something novel during the end-of-year revision.

3. Application of pressure charts to enhance the development of the field concepts, and to determine wind direction and wind speed with secondary-school methods. [3], [6], [7]

Phenomena related to the rotation of the Earth also include the large-scale motions of the atmosphere and the oceans. The explanations in geography texts, however are often based on the wrong interpretation of the underlying physical principles. I have shown that isobar maps (featuring in the geography syllabus) can serve as a basis of activities and problems to determine wind direction and wind speed, thereby helping a correct interpretation. Furthermore, the application of isobar and isohypse charts has also proved to provide an effective contribution to the development of the abstract field concept.

Students correctly remember from geography that the motions of the atmosphere are brought about by pressure differences, and air currents are determined by the distribution of pressure. Since the thermal characteristics of gases are only covered in tenth-year physics, following all physical geography education, the ideas acquired in geography exert a great influence on the concepts appearing the reasoning of students. Even the correct explanations of geography texts are too brief and hard to follow without sufficient physical background knowledge. Thus the treatment of winds also poses difficulties in understanding.

Students in my advanced physics group found it interesting to complete unusual tasks involving the interpretation of information supplied in the form of maps. Later on, during the discussion of the equipotential curves of the electric field, they recognized the analogy, and referred to what they had learnt about pressure maps.

4. Order-of-magnitude estimations for the size of the tidal bulges and for the flattening of the Earth. [2], [3], [5].

For an advanced group of students with solid mathematical background, I developed a quantitative estimation that illustrates how the decrease of the Moon's attraction with distance leads to the formation of tidal bulges. The estimation is based on calculating the slope of the ocean surface on a hypothetical planet completely covered by an ocean. With an analogous technique applied to the sloping of the surface on a rotating Earth, I also developed an estimate for the flattening of the Earth. I have shown that quantitative treatment helps eliminate the misconception resulting from an erroneous explanation.

The treatment of tides in geography texts is a striking example for the limited understanding of the underlying physical principles. In all the geography texts, the Moon's attraction is responsible for the tidal bulge facing the Moon, while the bulge on the opposite side is caused by the centrifugal force resulting from the orbiting about the centre of mass of the Earth−Moon system.

This explanation is not only mistaken because it refers to the attraction per se rather than the decrease of attraction with distance, but also because it overlooks the fundamental laws of dynamics: The behaviour of a system is not determined by one force or another in itself but by the resultant of all the forces. Furthermore, the centrifugal force in itself cannot be responsible for a tidal bulge, since it is only present if a rotating reference frame is used, while the experience that there are two bulges should appear in an inertial reference frame, too.

The first explanation one hears, however erroneous, is so deeply imprinted that it is very hard to correct later on. I explained the phenomenon of tides qualitatively at the end of the treatment of gravitation to no avail: when I asked my students during revision for the final exams, they repeated the words of the geography book again. No one in my advanced group referred to the decrease of gravity with distance. Although in Hungary the quantitative treatment of tides is only taught at university level (e.g. [H]), this failure prompted me to experiment with a quantitative treatment that is accessible for mathematically able high-school students, too.

If there is not enough time to work through the calculations, the same reasoning may be presented in a semi-quantitative way, too, with the help of vector diagrams representing the so-called tide-generating force.

5. Estimation for the sloping of the ocean surface across the Gulf stream. [2], [3], [7]

Although it is not mentioned in geography texts, students find it interesting that ocean currents also involve a sloping of the water surface. By two different estimations for the slope of the surface, I showed that same result is obtained in the inertial reference frame as in the frame attached to the rotating Earth, thereby demonstrating the importance of the choice of a suitable reference frame.

As also mentioned in geography texts (without a detailed explanation), the Coriolis force plays a role in the formation of the ocean currents, too. Although the sloping of the surface across the currents is university material (e.g. [I]), it can also be explained at secondary-school level.

The explanation for the sloping of the surface owing to tidal phenomena requires basically the same mathematics, whether investigated in an inertial reference frame or in a rotating one. Since the description of the sloping across an ocean current involves the Coriolis force in the rotating frame, it is not so easily translated to an inertial frame. Complicated as it may appear, it is worth making this transition since it is instructive for students to observe how the choice of a suitable reference frame may simplify description.

In the inertial frame, the sloping of the surface across the ocean current can be determined by calculating the acceleration of a point on the surface, just like in the standard example of a tub of water accelerating on a tabletop.

6. A practical application of the cyclic processes in heat engines: measurements investigating the efficiency of the "drinking bird" toy. [4]

By applying the drinking bird toy as a heat engine, I constructed a set of measurement activities for students. The experiments provide quantitative verification for the increase of efficiency with temperature difference. I have also shown that the measurements synthesizing knowledge across many areas of the mechanics and thermal physics syllabus also enhance the understanding of the concepts of saturation vapour pressure, relative humidity and dew point, all familiar from the geography classes.

The physics curriculum requires that students be familiar with the concept of engine efficiency and its limitations. As opposed to a wide range of experiments demonstrating the fact that heat transfer between bodies of different temperatures may deliver mechanical work, the issue of efficiency is only treated theoretically in physics texts and classrooms alike.

Air humidity appears in both physics and geography curricula. The physics curriculum only requires qualitative ideas about factors influencing relative humidity and causing the formation of precipitation, while geography also requires calculations related to air humidity.

The drinking bird toy is driven by the temperature difference between the body of the bird and its head evaporating water. Since the temperature difference depends on the ambient temperature and on air humidity, the measurement of efficiency allows for quantitative conclusions.

As a closure to the thermal physics chapter, the measurements and the explanation of the results can also serve to induce students to synthesize knowledge by connecting the concepts of thermal physics to concepts (such as work, energy, power, or even communicating vessels or pendulum motion) learnt previously in mechanics.

7. Applying calculation problems in the teaching of thermal radiation. [1], [3], [5].

I have shown that a quantitative treatment involving Wien's displacement law and the Stefan–Boltzmann law is effective in reducing the inconsistency and uncertainty surrounding the concepts of energy, power and intensity.

The concepts of energy, power and intensity are frequently heard and misused concepts in everyday speech and in the mass media. (Sometimes even scientific texts use them interchangeably.)

Thermal radiation comes up twice in physics education: In thermal physics when it is mentioned qualitatively as one of the means of heat transfer, and later on, in the introduction to modern physics when we point out in relation to Planck's hypothesis that difficulties were raised by quantitative description. It may not even be clear to students that these are the same phenomenon. It is also a common misconception that "thermal" radiation may only be infrared. The concepts of incoming and outgoing radiation also appear in geography, without explanation. The energy production in stars features in the curricula of both subjects, and in geography (just like in version "A" of the physics curriculum) it precedes all atomic and nuclear physics.

In addition to students taught the national curriculum, my school also has a class of students each year who participate in the International Baccalaureate (IB) Programme. The IB physics syllabus traditionally contains the laws of blackbody radiation: the Stefan−Boltzmann law, Wien's displacement law, and the inverse square law for intensity. The application of these laws in astrophysics problems and other energy-related problems requires an accurate knowledge of the concepts. Our students regularly perform well in the examination questions on this topic, and my experience as an examiner for the IB programme supports the same conclusion worldwide.
Such problems are easy to incorporate in the teaching of the national curriculum, too, since students are generally interested in astronomy, and the syllabus already contains all but the statement of the two laws.

8. Promoting knowledge transfer with the help of physics problems that can be addressed in the mathematics class. [1].

I showed that the solution of problems involving the apparent and absolute magnitudes of stars, as well as the decibel scale of sound intensity level in the mathematics class successfully enhances the conscious use of the concepts of power and intensity.

Logarithmic scales are widely used in sciences, including geography. This provides an opportunity to extend the collaboration of subjects beyond the connections of physics and geography: mathematics also requires practical applications. With the use of logarithmic scales, I assembled exercise sets to support the teaching of the concept of logarithm. Since the problems on magnitudes do not rely on nuclear fusion processes or the physics of wave propagation, no preliminary knowledge is required but the concepts of energy, power and intensity. Students in my advanced mathematics classes found these problems interesting, and performed well, demonstrating a solid understanding of the concepts.

The utilisation of the findings

Having focussed my entire research activity on the teaching of environmental physics, I am hoping to join with the preceding accomplishments by others and with the work of those yet to follow, and contribute to achieving the goal of incorporating environmental physics in secondary physics education.

The quantitative considerations presented in this paper may also serve to widen the horizons of future geography teachers. It would help provide solid theoretical foundations, and support the professional use of clear concepts. Without that, I can but applaud the faultless logic of the colleague in the geography department who formulated a question based on what he had read in the text books: why does he not experience tidal effects in his soup bowl? With an appropriate knowledge of the physical background and the underlying concepts, he could have answered that question for himself.

The theses are based on the following publications:

1. Gróf A.: Asztrofizika feladatok a Nemzetközi Érettségin, in: *Természettudomány tanítása korszerűen és vonzóan*, Conference Proceedings, Ed.: Tasnádi, Péter, ELTE Természettudományi Oktatásmódszertani Centrum, Budapest, pp348–353, 2011.
2. A. Gróf: Integrating Aspects of Geography in Physics Teaching, Physics Competitions Vol. 15, No 2, pp49–58, 2012.
3. Gróf A.: Földrajz a fizikaórán, in: *A fizika, matematika és művészet találkozása az oktatásban, kutatásban*, Conference Proceedings, Ed.: Juhász, András and Tél, Tamás, ELTE , pp247–252, 2013.
4. A. Gróf: The Drinking Bird Engine, in: *Active learning – in a changing world of new technologies* ICPE-EPEC Conference Proceedings, Eds.: Leoš Dvořák and Věra Koudelková, Prague, pp702–710, 2013.
5. Gróf A.: Gyakorlatias fizika, avagy: „A nagy teljesítmény titka: gyorsan és sokat.", Fizikai Szemle 2014/4, pp131–135, 2014.
6. A. Gróf: Carousels to Coriolis, or how physics supports understanding geography, in: *TPI-15* Conference Proceedings, Eds.: Király, Andrea and Tél, Tamás, Budapest, pp119−124, 2016.
7. Gróf A.: Honnan fúj a szél, avagy okosabb-e egy ötödikes, mint Sylvester Stallone?, Fizikai Szemle 2017/3, pp. 89-93, 2017.

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