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Flipped Learning and Interactive Methods with Smartphones in Modern Physics at Secondary Schools

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Abstract. We present an example of an active learning activity in modern physics at secondary school developed by us in the framework of flipped learning. The activity dealing with the black-body radiation was a part of our experimental course of modern physics at one of Slovak grammar schools. Using an inquiry-based form of the activity with an interactive demonstration as its introduction, students actively learned modern physics with a GeoGebra simulation as a fundamental tool of visualization, experimentation and measurement. Our results show that thanks to interactive simulations the interactive methods in the framework of flipped modern physics can be really viable, even in classical classrooms with currently widely available digital technologies – smartphones and a Wi-Fi connection.

INTRODUCTION

Teaching modern physics in secondary schools has a long tradition in countries such as the UK, Germany, Italy and the US, and in recent years it became also important in the Netherlands and France. In Argentina [1] and Norway (ReleQuant project [2]), we are witnessing expert discussions about modern physics as a part of secondary school curricula. Although students' conceptions and mental models from quantum mechanics introductory courses at the university level are well mapped, research at secondary school level appears still insufficient [3].

In Slovakia, on the contrary, in 1990s quantum mechanics ideas at secondary schools were removed from the curriculum. Despite the importance of modern physics, it did not gain more space and appropriate attention in the reformed educational program. In addition, according to the Slovak National Educational Programme for Secondary Grammar Schools, the physics instruction is presented in the form of 5 hours together per week for the entire period of four-year or five-year secondary schools. Each physics lesson is realized with the whole classroom and the so-called divided lessons, when a teacher can teach each half of students separately, are allowed only in one year of the study. Under such conditions, to carry out active learning as hands-on activities or projects, recommended by the methodological guidance in the framework curricula for grammar schools, seems no easy challenge for teachers.

During last thirty years, physics education research [4] has shown that interactive methods which were defined by Hake [5] as:

> *''Interactive Engagement'' (IE) methods are methods designed at least in part to promote conceptual understanding through the interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors,*

are much more effective than traditional methods. But on the other hand, IE methods require much more educational time compared with traditional teaching practiced in the classroom.

It is worth to mention that the time problem is being satisfactorily solved by the flipped learning model (or framework) which creates much more space and time for an application of interactive methods than traditional learning model. When we consider the current operational definition of flipped learning [6],

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"*Flipped learning is a pedagogical approach (framework) in which the first contact with new concepts moves from group learning space (classroom) to individual learning space (home) in the form of structured activity, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in subject matter*",

then the flipped learning is also in full accordance with interactive methods.

From the viewpoint of the cognitive theory of learning [6,7], flipped learning starts with activating links in the student's knowledge structure through his own lower-level cognitive activity during homework. Moving simpler link-activating tasks, in accordance with the learning objectives, from a classroom (group learning space) to home (individual learning space) (1) respects the well-known revised Bloom taxonomy classifying abstractness and difficulty of cognitive processes and (2) eliminates the cognitive overload of student's short-term memory typical during more complex tasks. As a result, flipped learning maximizes amount of classroom time for using interactive methods in small group learning modes such as Peer Instruction [8], Inquiry-based Education [9], Interactive Demonstrations [10] or Workshops [11] which allow the better mastering of cognitively and behaviorally more demanding physics concepts, ideas or skills.

Motivated by our experience with flipped learning [12–15], we have decided to explore interactive methods with the help of flipped learning in teaching modern physics. The aim of this paper is presenting a concrete example of an active learning activity dealing with the black-body radiation, one of themes of modern physics at Slovak secondary schools. The activity was a part of our experimental course of modern physics with more than 30 virtual simulations, 23 designed in GeoGebra for smartphones. Such type activity with prediction sheets was carried out in the class for the first time, therefore times for doing activities were estimated from our university's experience. The structure, ideas and research behind the course is described in our second paper in the proceedings entitled *Teaching Feynman's Quantum Physics at Secondary Schools Using Current Digital Technologies*.

All our results from teaching modern physics in one of the Slovak grammar schools show that thanks to virtual simulations the interactive methods in the framework of flipped learning is really viable, even in classical classrooms with currently widely available digital technologies– smartphones and a Wi-Fi connection.

SELECTED ACTIVITY – THE PLANCK CURVE

Introduction

To illustrate our application of flipped learning together with interactive methods in modern physics at secondary schools, we present an activity example - The Planck Curve. As for physics content of the activity, we were inspired in this theme by two textbooks – Advancing Physics A2 textbook from the current UK secondary school A-level physics course [16] and textbook Unit T from Moore's innovative introductory physics course for colleges [17] which integrates modern and classical physics. Students' fundamental tool of visualization, experimentation and measurement is an interactive simulation also called *The Planck curve* (see fig.1, bit.ly/sim-Planck-curve) created in dynamic mathematical software called GeoGebra (www.geogebra.org) and designed for smartphones (it can also run in PC). The second digital tool for students is a Google sheet with the photon table called *Photons and their use* (bit.ly/tab-photons) which contains description of all types of photons. Each type of photons in the table contains basic photon characteristics: wavelength range, frequency range, energy range in Joules (J) and electron volts (eV) and practical application of photons in everyday life.

The group learning part of the activity has the form of an inquiry-based activity [9] with one interactive demonstration as its introduction [10]. The activity was designed for a 45-minute lesson. The lesson can take place

- in a divided class or the whole class; the divided class is more effective;
- in a computer room with a teacher computer and multimedia projector or
  in a classic classroom with a Wi-Fi internet connection, mobile devices for students (their smartphones or tablets) and a laptop with a multimedia projector for the teacher.

Students work in groups of up to four-five students. At least two mobile devices (or computers) are recommended for the group. Students have the activity worksheet/tutorial (see Appendix) printed or available online in the appropriate learning management system that the school uses to manage classes and teaching content. The activity can also be realized without a Wi-Fi internet connection if computers have locally installed GeoGebra software and all online materials are downloaded on them.

Home preparation

The fundamental part of flipped learning is students' work in their individual learning spaces, at home, before class group activities, which are strongly based on students' concepts obtained from the first pre-class contact with a study material. Regarding working time, on the basis of our experience, we require from students up-to 20 minutes of home preparation before any face-to-face lesson.

In our pre-class activity, students read the motivational text of one A4 page size and solve two simple problems based on the instructions in the text. The main physical idea of the first contact text is the fundamental knowledge of thermal and statistical physics: *The particles of all kinds of matter at temperature T (in Kelvin) have an average energy of the order of kT, where k is the Boltzmann constant.* The description of this simple general rule was taken from chapter 14 of Advancing Physics A2 textbook [16]. Our text is in the form of Google document (bit.ly/text-atoms) which also includes simple visualization tools - animated figures (gifs) giving better idea about the rule.

As we said, the students' preparation includes two warm-up problems - energy calculations for the Rigel star, the brightest star in the Orion constellation, and for proton beam collision temperature in Large Hadron Collider in Genève. The blue hot Rigel star, which is 10^5 times brighter and 50-120 times larger than Sun, has the surface temperature 11 000 K. Students try answer the questions: What is the average thermal energy per particle at the surface of the blue star? In what range of frequencies of photons does this star radiate? Find the value of the calculated energy in the photon table (Photons and their use) and write the corresponding frequencies to them.

The kinetic energy of each proton in a beam in the LHC accelerator has a value of 7 TeV. For comparison, the kinetic energy of a flying mosquito reaches approximately one TeV. Students answer the question: What temperature corresponds to the proton collision energy?

In class activity

The face-to-face lesson starts with a short mini-lecture aimed at responding students' ambiguities in the text, highlighting its main ideas, commenting on homework solutions, setting goals for the lesson and preparing students for a group activity. Finally, a teacher describes the simulation, *The Planck curve*, in the physical context connecting to the homework: any object with nonzero absolute temperature T radiates photons which spread over a range of frequencies. Similarly, as we model real gases by ideal gases, the photons from the object can be approximately described by the so-called black-body radiation or in other words ideal photon gas described by the Planck curve.

Each student gets a prediction worksheet/tutorial (see the appendix of the paper). In all problems, the student's individual and group task are always predicting what type of photons is radiated from a given object. There are three considered objects - the Sun, the candle flame, and the human skin. Each group also has the online or printed *photon table* for a quick connection between the calculated photon energy and type of photons.

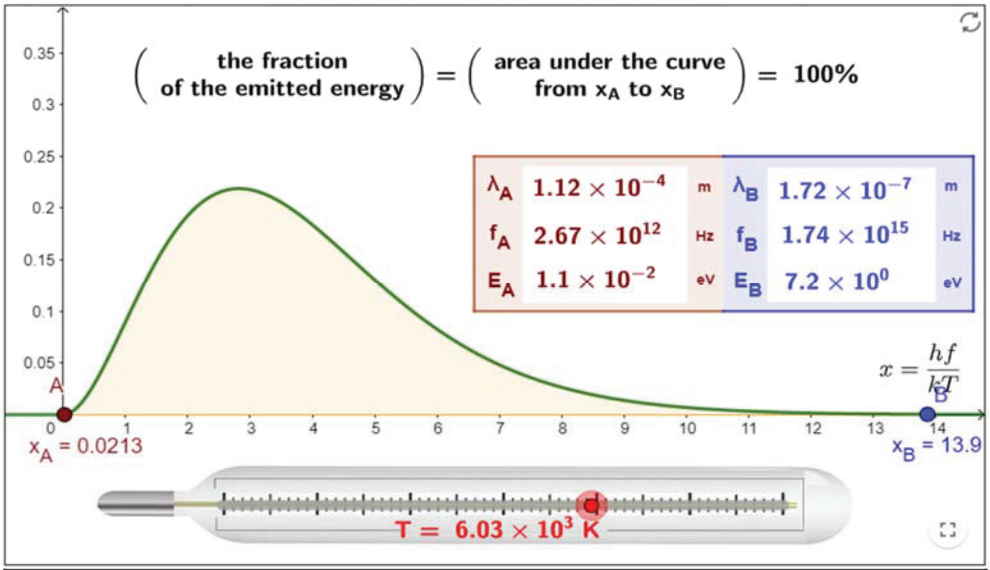
The first subactivity with the Sun is an interactive demonstration managed by the teacher. Students are asked to write their predictions on the following questions before the experiment: The temperature of the Sun on its surface is approximately 6 000 K. What type of photons (from the photon spectrum in the photon table) is emitted from the surface of the Sun? What percentage does a particular type of total energy distribution account for?

The teacher performs the subactivity in the simulation in the following suggested steps:

- he sets the temperature of the Sun on the thermometer to 6 000 K. He informs the students that the temperature does not need to be adjusted exactly because the curve itself is idealization which approximates radiation from a real object;
- he sets the endpoint x_A (as close as to zero) and then endpoint x_B on the curve so that the area under the curve includes approximately 100% of total energy;
- under his guidance
    - students read corresponding extreme energy values E_A, E_B from the simulation
    - students find the corresponding types of photons in the photon table.
    - students write in the worksheet answer on the first question: What type of photons (from the spectrum of electromagnetic radiation) is emitted from the Sun's surface?
- he moves endpoints x_A and x_B to the positions corresponding to the energy thresholds of the identified photon types from the previous question;

- under his guidance
  - students read the answer to the second question: What percentage does a particular type of total energy distribution account for?
  - students write the answer to the worksheet.

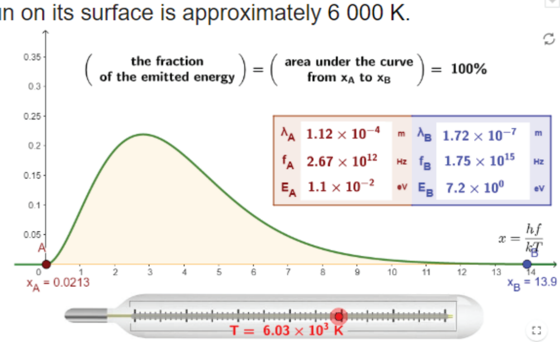
The results of this interactive demonstration are summarized by fig.1. Then students in groups alone repeat, with the help of the teacher as a facilitator and advisor, the procedure with the candle flame and the human skin.



Experiment 1:The temperature of the Sun on its surface is approximately 6 000 K.

In which interval (in eV) do energies of typical photons emitted from the Sun lie?

(1.1 x 10^{-2} ; 7.2) eV



What types of photons (from the photon spectrum) fall within this energy interval? What is the range of energies for each particular type of photons?

type of photon	*infrared*	*visible light*	*ultraviolet*
range of energies	*1.2 meV - 1.6 eV*	*1.6 eV - 3.3 eV*	*3.3 eV - 1.2 keV*

What fractions of the total energy emitted by the Sun correspond to given types of photons?

type of photon	*infrared*	*visible light*	*ultraviolet*
fraction of the total energy	*41 %*	*47 %*	*12 %*

FIGURE 1. The results of the experiment 1 in the tutorial.

In the last task, students measure with a real infrared thermometer based on the heat radiation to find the hottest and coldest object in the room. The goal of this subactivity is to connect the virtual experiment in GeoGebra with the real temperature measurement. Students records measured temperatures.

RESULTS AND CONCLUSIONS

We experimentally realized the activity with the standard third-grade class at one of Slovak grammar schools (N = 29 students) during the divided physics lesson when the class was split alphabetically into two big study groups according to the last name. Teacher was one of the authors (EP). Students worked in small groups (with up to four students per group) formed by students themselves at the beginning of the school year.

The first study group (N_1 = 14) carried out activities in the classical classroom where students had own mobile devices (1 tablet, 7 smartphones). In three subgroups, they had at least two own mobile devices to check the results within the group. In one subgroup there was only one smartphone with a small display. The second study group (N_2 = 15) conducted the same activities in a computer room where every student worked with the simulation on computer. Both individual and group prediction sheets were also available in the printed form.

Before the face-to-face lesson students completed their homework (see sec. Home preparation), which was checked during the first 15 minutes of the lesson where we also focused on the aims of the lesson, the organization of the lesson and very short minilecture about the Planck curve in the context of our simulation. After that first experiment and the predictions realized as an interactive demonstration, students had 25 minutes for group work containing last three activities when the teacher was an advisor and facilitator.

The following Table 2 shows the number of student predictions of the expected photon type for the Sun, candle flame and human skin. Seven individual predictions sheets from 29 were excluded from the table because students did not write their predictions, only experimental results. As for number of finished subactivities, the forth subactivity, a real experiment with a thermometer, was missed by half of groups (four). We explain these fails by the fact that this type of activity was carried out in the class for the first time. However, according to our several years long experience at university level, such fails should disappear with growing students' practice.

TABLE 1. Students' predictions during activities

	Sun				**Candle Flame**			**Human Skin**	
	Expected type of photons			**Other**	**Expected**		**Other**	**Expected**	**Other**
	infrared	visible	ultraviolet		infrared	visible		infrared	
Prediction (22 individuals)	19	18	21	gamma, micro-wave	16	22	UV, micro-wave	19	visible, micro-wave
Experiment (total 8 groups)	8	8	8	0	8	8	UV micro-wave	7	micro-wave

As for students' misconceptions, students were very surprised when they expected a much higher percentage of visible light photons (30% -50%) from the candle flame (1500 K) compared to the real measured percentage (0.2%). Surprising for students was also measured human skin temperature (32-34°C) by thermometer compared to expected 36.5° C. As for us, we did not expect such high correct percentage in individual predictions which we attribute to the home preparation as the benefit of flipped learning. We also did not expect some students (approx. 10%) to predict a non-negligible amount of gamma photons from the Sun or UV photons from the candle flame.

Regarding work in groups, groups with at least one student of leadership type and groups of students interested in physics or work with simulations had no problem in completing all tasks. The main feature of groups which failed in completing all tasks was that they contained almost all students with insufficient internal motivation and lack of willingness to initiate communication with the teacher as an advisor. In this case we suggest increased teacher attention and assistance in organizing their work.

Concerning used digital technologies, there were no observable difference in completing tasks between study groups in the computer room and the classical room. Only the group with one small smartphone had problems with using the simulation. Therefore, our suggestion is the use of smartphones with the screen bigger than 5 inches. It seems that such smartphones, called phablets in IT terminology, are really suitable for our GeoGebra simulations as it was also demonstrated in other learning activities.

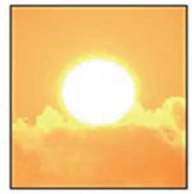
As for discussion and conclusions, we report them in the frame of our mentioned paper in this proceedings, presenting a detailed description of our theoretical background, general goals, research design, methods, tools and possible generalizations of obtained empirical results together with future research directions.

APPENDIX

Name:________________________________

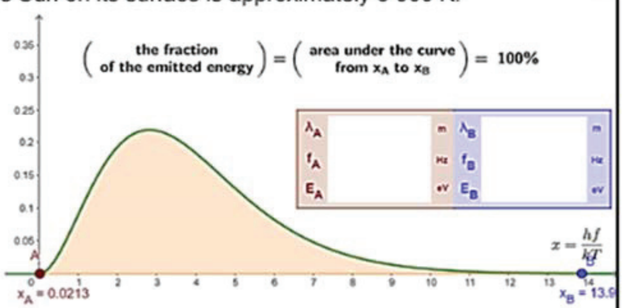
TUTORIAL / Prediction sheet
THE PLANCK CURVE
Directions: This sheet will be collected. Write your name at the top and follow instructor´s directions.
Geogebra simulation: bit.ly/sim-Planck-curve

Prediction 1:The temperature of the Sun on its surface is approximately 6 000 K.
What types of photons (from the photon spectrum) are emitted from the surface of the Sun?



What fractions of the total energy emitted by the Sun correspond to given types of photons?

Experiment 1:The temperature of the Sun on its surface is approximately 6 000 K.
In which interval (in eV) do energies of photons emitted from the Sun lie?



What types of photons (from the photon spectrum) fall within this energy interval? What is the range of energies for each particular type of photons?

What fractions of the total energy emitted by the Sun correspond to given types of photons?

Prediction 2:The temperature of the candle flame is approximately 1 500 K.
What types of photons (from the photon spectrum) are emitted from the candle flame?

What fractions of the total energy emitted by the flame correspond to given types of photons?

Experiment 2: The temperature of the candle flame is approximately 1 500 K. In which interval (in eV) do energies of photons emitted from the flame lie?

What types of photons (from the photon spectrum) fall within this energy interval? What is the range of energies for each particular type photons?

What fractions of the total energy emitted by the flame correspond to given types of photons?

Prediction 3: The temperature of human skin is approximately 300 K. What types of photons (from the photon spectrum) are emitted from the human skin?

What fractions of the energy emitted by the skin correspond to given types of photons?

Experiment 3: The temperature of human skin is approximately 300 K. In which interval (in eV) do energies of photons emitted from human skin lie?

What types of photons (from the photon spectrum) fall within this energy interval? What is the range of energies for each particular type photons?

What fractions of the energy emitted by the skin correspond to given types of photons?

Experiment 4: What is the temperature of the coldest and hottest objects in the classroom? (Use an infrared thermometer.)

object	estimated temperature [°C]	measured temperature [°C]

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