APPLICATION OF COMPUTER SIMULATIONS IN MODERN PHYSICS EDUCATION

István Basa
Apáczai Csere János High School, Budapest, Hungary, sixfreed@gmail.com
Physics Education PhD Program, Eötvös University, Budapest

ABSTRACT

Teaching modern physics is an essential, yet challenging part of our curriculum. When introducing the main scientific theories and discoveries of the past century, we often find ourselves with a lack of experimental resources in it. My goal is to develop and test computer simulations which can be used in high school teaching as a virtual science lab, where students do not only passively observe, but also interactively perform measurements of modern physics phenomena. In most cases the technical conditions for real students' experiments are not given, or the observed phenomenon runs in an uncommon (ultra-fast or ultra-slow) time scale. Thus, a simulation is able to complete the students' experience already based on real observations.

INTRODUCTION

There are at least four essential questions that shall be answered according to modern physics education. "What shall we teach?" "Who shall we teach?" "When shall we teach it?" And finally, "how shall we teach it?" These questions are fundamental for all subdisciplines of course, but for teaching modern physics, they get a little more problematic.

In my paper, I aim to introduce the main challenges in teaching modern physics and give an idea on how to solve these problems. I will discuss the general role of computer simulations in teaching modern physics and present one of my simulations – the photoelectric effect – in detail.

TEACHING MODERN PHYSICS IN GENERAL

It is not in question that motivating our students to study or even love physics is one of the biggest challenges today. Surely there is a great amount of publications on developing teaching methods for enhanced motivation, but teaching physics – or science in general – shall always contain experiments for gathering knowledge. "Performing experiments is the basic and typical method of scientific research, learning and education. […] Experiments in teaching is typically the base in determining laws of physics and chemistry, and also the only (exclusive) tool of validating these deduced laws, hypotheses and theories, as well as the diagnostic tool for their validity limits" [1]. This excerpt is from the Encyclopaedia of Pedagogy published in 1997. It clearly shows how important scientific experiments are in our physics teaching but it's also a key method in keeping students motivated.

Also, the constructivist approach of teaching, particularly IBL – inquiry-based learning/teaching – moves several steps forward claiming that experiments shall always be executed by the students, letting them gather own experience, and allowing them to observe, measure, draw up a hypothesis and then validate it on their own. This is the ideal approach of motivating and teaching physics to our students. Chris Chiaverina and Michael Vollmer gives a statement based on results from a discussion workshop during the 2005 GIREP seminar in Ljubljana that experiments in future physics education will always play a central role, “however more will be computer based. Computer aided experiments will allow the inclusion of frictional and other effects in simple experiments” [2]. They also state that “Experiments will always be needed to motivate students.”

As for modern physics, I believe it is motivating itself, most of my student referrals in my classes state that modern physics was their favourite part of our physics curriculum and there are even ones admitting that learning about modern physics was the first time they ever wondered about studying science in the future. Therefore motivation is necessary, but manageable, though there is another challenge in teaching modern physics.

It is that it’s challenging itself, and – by a very thoughtful idea – it all comes down to the aspect of scales [3]. In classical mechanics we are working with relatively low speed and big sizes, which makes our student experiments easier to handle. The IBL approach of physics teaching works with a question-observation-hypothesis-experiment-answer system, where students are able to do their own experiments basically every lesson, not to mention the possibility of bringing these experiments home, as project works for example.

But topics in modern physics tend to happen at really high speed or/and in really small sizes. This itself makes experimenting difficult. Not to mention its theoretical challenges being far from our everyday-approach theories. (Wave-particle duality, theory of relativity, mass-energy equivalence, etc.) Students don’t observe electrons, only traces of electrons, or signs of traces of electrons, like a number on a counter. Time and number scales are also an issue, for the time of an event is often too long, too short, or it consists of too many participants.

These are the reasons why showing modern physics experiments is extremely difficult in a classroom. And even if there are really creative experimental tools, the cost of these makes it practically impossible to allow anything but a rare experimental presentation from the teacher.

Another key problem is the lack of time. Though it is part of the Hungarian physics curriculum, it is not uncommon that a student finishes high school without hearing anything about modern physics.

In the next section, I will give a brief overview on how computer simulations can help in solving the abovementioned problems.

INTRODUCING COMPUTER SIMULATIONS

For clarity we first make a clear distinction between simulations and animations. In our understanding animations can only be passively watched. In contrast, simulations are much more interactive: the students can set values of different parameters, sometimes even add new devices, or remove others, observe the results, perform measurements. They are much closer to the real world than simple animations. Whereas animations consist of a series of pre-recorded images playing in sequence, behind the simulations there is always a working mathematical model which constantly calculates the outcome.

As for the theoretical challenges, computer simulations always give us simplified images which could be visually helping in the understanding process. There are recent studies of how we can simplify even particle physics and make it understandable to even the youngest student groups [4]. It is vital to keep an eye on all these simplifications. The picture of a ball-shaped electron in a computer simulation can easily distract the students’ ideas from their wave function. But there is no doubt that the understanding process is enhanced when we see something leaving the cathode, not only a trace or a counter.

With the previously mentioned scales in time and numbers, we have a lot of freedom. One of the key possibilities of using a computer simulation is that we can set the time scale dynamically, allowing functions like switching between the time lapses (e.g. speed up or slow down a reaction), pause or even turn back the time. Also, we can work with a lot of particles simultaneously.

It is obvious how these simulations can make up for the lack of experimental tools in the physics departments. Surely, a simulation will never be able to fully replace the educational role of a real-life experiment. But seeing an electron beam's trace on a fluorescent plate is visually similar to see it on a computer screen, while in the latter case students can also investigate the base principles of the phenomenon and perform their own measurements. This final potential brings us to the possibility of expanding our classrooms' borders, creating virtual laboratories and helping students to do experiments at home, for a project work or further analysis of a problem. Through internet-assisted teaching they can help with the issue of the time frames, not only extending our teaching time, but adjusting it to the students' needs.

"What makes a good simulation?" If we strictly keep an eye on the goals to help out high school physics education, I would take the following attributes:

1) Accessibility. A simulation shall be available to run on all the student's current devices, including smartphones, tablets and notebooks, and on any operation systems without using separate applets. In 2015 the majority of the popular browsers dropped support for NPAPI, which impacted plugins for Java (only the applets) and Silverlight. This would require the majority of the currently available physics simulations to be rewritten to a more broad usage. With the quick spreading of smartphones and tablets, we introduce our students to teaching resources available on these platforms. Simulations written in HTML5 don't require applets, therefore they are considered safe.

2) Diversity. Simulations applied in high school education shall offer various possible activities for the students or the teacher. This makes them easier to implement in the lessons, personalize and also allows to differentiate and extend the time of student experimentation. A simulation which takes more time to prepare on a lesson than actually working with it, usually isn't worth the time, and it always takes a few minutes just to introduce how the controls work.

3) Simplicity and challenge. Students are different, therefore simulations shall have different layers of difficulties fitting the diverse abilities and motivation, in help of teachers to differentiate. Not all students will understand a method of a measurement, and not all of them will be satisfied with only a dynamic animation. The layers should be easily separated not to confuse students.

Not many of the currently available simulations fit these conditions. I looked up working simulations on a specific phenomenon – the photoelectric effect – and I found only one HTML–simulation out of five most popular ones [5]. The others required downloading an applet or adding the webpage to the browser's exceptions. This requires a careful preparation for the simulation-supported lesson, and means a lot of problems with the students' own devices.

The lack of diversity and possible student interaction was also a returning problem. It doesn't mean that the simulations are wrong, it just means sometimes the only possible way of using them is a brief show or tryout. Only one of them offered an idea on possible classroom differentiation, whilst the others were too simple or too difficult to understand for some students. A pleasant surprise was that three out of five offered the possibility of measurement. Trying out these in my classes I found that only one (the PhET simulation) can be used effectively, but it lacks a helping grid for recording the data, so needed real rulers for the students to make their calculations.

Out of the five, the PhET simulation was the most complex, which wasn't a surprise, knowing how much research and effort was implemented in their works, but there were some points missing, like accessibility and some extra possibilities in students' measuring exercises. My motivation in creating a new simulation of this phenomenon was to add these functions and to create a simulation that fulfills all requirements above that did not exist so far.

APPLICATION OF A SIMULATION ON PHOTOELECTRIC EFFECT [6]

I used the JetBrains WebStorm [7] program to develop the simulation. It works with HTML5, which means you can run this on any device including smartphones. The simulation adapts for the device we are running on, rearranging the simulation plane and the icons.

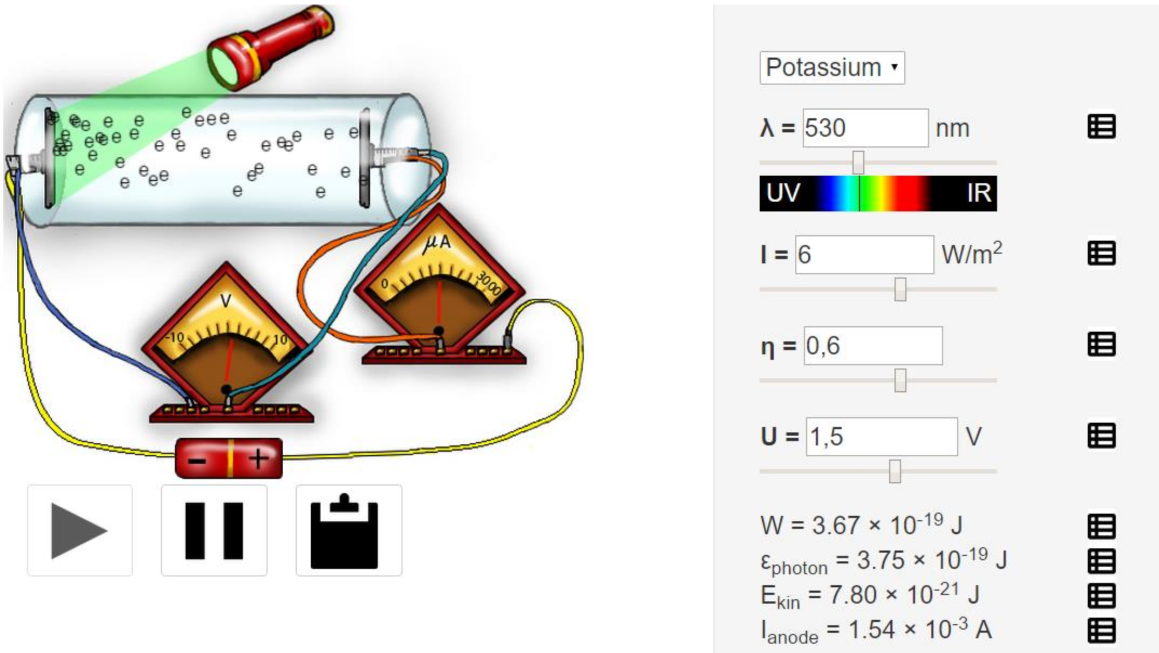

Fig.1. My simulation on the photoelectric effect

The main interactions of the simulation are the following. Students can set (see Fig.1.) the desired cathode material they are experimenting with, also the wavelength of the light, the intensity, and the percentage of the photons producing an actual photoelectric effect (as the efficiency). They can also give an accelerating or decelerating voltage on the photocells, thus making the electrons stop and turn back. The simulation solves the mathematical model of the photoelectric effect on the one hand, and the motion of charged particles (electrons) in electric field on the other. The result is visualized as (non-ball-shaped) electrons moving toward the anode, and the following output parameters are calculated: the photon energy of the selected light, the kinetic energy of the electrons when they leave the cathode, and the anode current.

The strength of the simulation is the possibility to make simulated measurements with the side icons. Students can save any or every data to a chart. Every time they change any of the settings, the data will be created in a new column. After the end of the measurement, they can export it to an Excel file, and they can freely work with it. There are many possible measuring tasks. For instance, wavelength versus kinetic energy, or wavelength versus stopping voltage which we can use for measuring Planck's constant.

As mentioned, we need to keep an eye on this simulation's simplifications. The simulation relies on fundamental physical laws (such as Coulomb's law and the photoelectric effect itself) but it does not include either the electron-electron interactions, for example, or the small fluctuations in the energy of the electrons. In my experience the simulation in its current form can be a helpful tool in classroom education, as mentioned below, although future improvements might be added for increasing the number of observable phenomena.

IMPACT ON STUDENTS' PERFORMANCE

For observing the impact of the simulation impact on students' performance I also give them an exercise on the topic taken from the Hungarian physics graduation exams, where they have to find the wavelength limit, the speed of emitted electrons and the stopping voltage of a given photocell. Then, without any further discussion they are introduced to the simulation with a user's guide on its key functions. Then, after several minutes of independent work, they are asked to solve a similar exercise. The first results were recorded in two half-class sized groups with a total number of 27 students. I used the authorized correction key provided for the original graduation exam and split the total 12 points into 10 parts, as the correction key did the same. Then added up all the points of the students before and after working with the simulation. They used it for only 25 minutes though (with 10 minutes for each task). Use of a calculator and also a table containing the primal scientific functions and laws – as in the real exam – were allowed. The results can be seen in Fig.2. below:

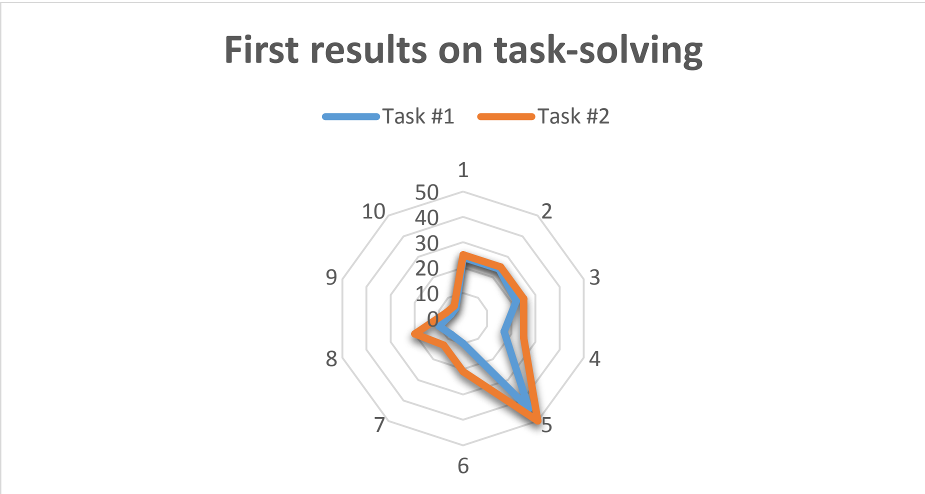

Fig.2. First results on solving a calculation task about the photoelectric effect

As one can see, all the parts showed slight or bigger improvement. The students didn't get any help on how to solve the problem between the two parts besides using the simulation. The three biggest differences were on the 4th, 6th and 8th parts of the task. The 4th one was the last part of the first question, about findig the wavelength limit. The 6th (and 7th) one was the last part of the second question, about finding the speed of the emitted electrons. There wasn't much difference on parts 1-3 and 5. These points were given for finding the correct physics laws and writing down the needed equations. Points 4 and 6-7 were given for using and transforming the equations to find the solution. As the equations were known (or could be looked up in the table of functions) this is hardly a surprise. It is comforting though that the simulation helps to make these equations be understood. The 8th part (containing two points) was understanding how the stopping voltage works and writing down the correct equation. This was the hardest one for the students, but many gave good explanations after using the simulation, for instance "the energy loss of the electron in the field of the stopping voltage equals its initial kinetic energy" – even though not being able to find the correct relation between the energy and the voltage (U·e).

There are examples on giving more detailed and more correct explanations on the calculated problem after using the simulation.

The research was done on a regular physics class without previous notification of the students. This means that a vast part of the students were naturally unprepared for it, though they were all introduced to the topic and calculation examples before in the previous classes.

CONCLUSIONS

Of course, further investigation is needed for a complex view on the efficiency of using these simulations, but my first feedbacks show that even if the performance on solving the concrete task doesn't change, the students' answers are more complex and precise, not only writing down equations but also trying to explain the phenomenon. I believe computer simulations are not the exclusive method, but a great source as teaching materials, helping in many of the challenges we face while teaching modern physics.

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