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SIMULATIONS AS A COMPLEMENT AND A MOTIVATION ELEMENT IN THE TEACHING OF PHYSICS

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Abstract

Science instruction, and in particular physics instruction, has to be taught in a way that explanations are complemented with demonstration experiments and calculation exercises, encouraging students to explore independently—this means that they themselves perform a few experiments and substantiate them with relevant calculations (they discover relations between quantities, variables, and constants).

In this article we give examples of cases where a simulation replaces an experiment that cannot be carried out i.e. it complements an experiment allowing observation at a different time and space scale. Experiments that cannot be performed in the classroom include the shape of the lunar trajectory, lunar phases, a demonstration of the difference between the solar and sidereal time, and the motion of objects that fly away from a space station. Experiments that cannot be followed in detail since they happen too quickly include the fall of a stick (for different coefficients of static friction between the stick and the supporting surface), and an interesting case of the dynamics of a system consisting of a circular tube with two balls sliding in it without friction. We also show the propagation of transversal and longitudinal waves and the formation of standing waves by the interference of incoming and reflected waves.

We also give an example from quantum physics: falling of a "quantum card", which in the beginning stands vertically on a horizontal surface. We show the time development of the wave function and illustrate the unusual behaviour and the non-classical description of the quantum-mechanical system. We compare it with the classical description as shown in the case of a falling stick.

Possible situations where students themselves create simulations and animations are also presented.

Key words: *instruction, simulations, animations, experimentation, mechanics, quantum physics*

Introduction

The approach to the instruction of science, and of physics in particular, both regarding the content of curricula and basic approach to teaching, has not changed much in recent decades. A noticeable progress can be seen in the use of learning tools—instruments and other materials used to prepare and perform experiments, in curricula topic emphases have changed somewhat to reach the required competences. The basic »body of knowledge«, acquired in physics in schools (in grade and high schools, and in college courses for non-physics majors), has remained the same. This is not surprising, since it has to include basic notions and laws of classical physics. These have been known since the end of the 19-th and the beginning of the 20-th century, therefore it is clear that major content changes are not possible. Starting with high school physics curriculum includes also some elements of »modern physics« which includes new findings, especially in quantum mechanics and relativity theory. However, due to conceptual difficulties and demanding mathematics an approach that would explain chapters of »modern« physics in an accessible and satisfactory way has so far not been found (Michelini in Stefanel, 2003).

The standard approach is to introduce and explain physical quantities and basic laws of physics, which are nothing else but relationships between some most basic physical quantities. Calculation exercises, when applied to specific practical problems, help one understand the meaning of physical quantities, how they are related, how to "manipulate" them, and get a sense of the magnitude order of quantities. Experiments demonstrate to students how phenomena actually happen. They also help them verify their ideas and gain new insights. This way students gain experience and insight into scientific research, i.e., the way connections between physical quantities are discovered.

Even though the content and basic concepts have not changed much in physics instruction, the need for new and more modern teaching methods is great, since the society that we live in has changed drastically (Etkina and Van Heuvelen 2001; Karelina and Etkina 2007; Viennot 2006, 2010a, 2010b). Nowadays students have fewer direct experiences with nature and nature phenomena, but they are more involved with computers, mobile phones and similar devices. Instruction in natural sciences should make up for a lack of practical experiences by science experiments, and use skills that students do have in a productive way.

Experiments are a fundamental element of physics instruction. In this article we would like to show how »real« experiments can be complemented by simulations, which by large are interesting to students and increase their motivation to study (Lowe, 2003; Mayer and Moreno, 2002). We want to right away emphasize that simulations can only be a complement but not the fundamental element in the demonstration of natural phenomena.

However, it is not possible to perform experiments for all phenomena being covered in school. There are cases where we can show the development of a phenomenon only by analogy; when it develops very rapidly we cannot follow it directly; many phenomena cannot be seen, or they are dangerous or inappropriate for the classroom, etc. In such cases simulations and animations can substantially complement the picture and help visualize the process. It is a general consensus that the "real" experiment is better, when it is possible to carry it out, than an "imitation". Despite that, a simulation can be a good complement even in a case when a "real" experiment can be performed since it can reveal details or hidden parts of the experiment. In order to produce such simulations one needs to know physical laws, which is another reason why students themselves should create them. Therefore an important element in physics instruction is a "demonstration toolbox". Technological, especially computer capabilities enable us to clearly present in the classroom phenomena that are not directly accessible.

In what follows we will briefly describe a few examples of simulations that we consider to be good complements to real experiments, or substitutes in cases where it is not possible to perform experiments in the classroom.

Simulations

Observations and experiments are the fundamental tools in the research of natural phenomena and laws. Students of science have to develop skills of independent observation and the ability to perform (at least simple) experiments. Observations and performance of experiments are basic skills without which a true science cannot exist. In order to help visualize phenomena, drawings, images, sequences of images can be helpful. (Some authors (for example, Kuščer in Moljk, 1977) liked in their textbooks the simplest possible pictures that would emphasize the "essence" of a phenomenon; today's youth wants »rich«, graphically perfect pictures, that they are used to in computer graphics.) However, computers are capable of much more. Animations, simulations, 3-dimensional representations, are very important tools in science instruction.

Falling stick

As our first example of simulation we consider a falling stick. First we put a stick (or a pencil) in a vertical position on a table and then let it fall. This is an interesting example of motion that is difficult to observe because it happens so quickly. Therefore it is not easy to notice details. We are interested, for example, if the stick slides; if it slides, in which direction and what the direction of the slide depends on?

It is not difficult to write basic equations of motion for a falling stick. It is harder or impossible (and not worth trying in school) to find analytical solutions. We can get a good picture of the motion that tells us a lot about the physical background of the phenomenon (the effects of gravity and friction, the dependence on the static friction coefficient) if we draw a sequence of pictures (Figure 1). However, a simulation is a much more effective presentation of the motion. We can follow in detail positions of the stick either frame by frame or in slow motion (Figure 2).

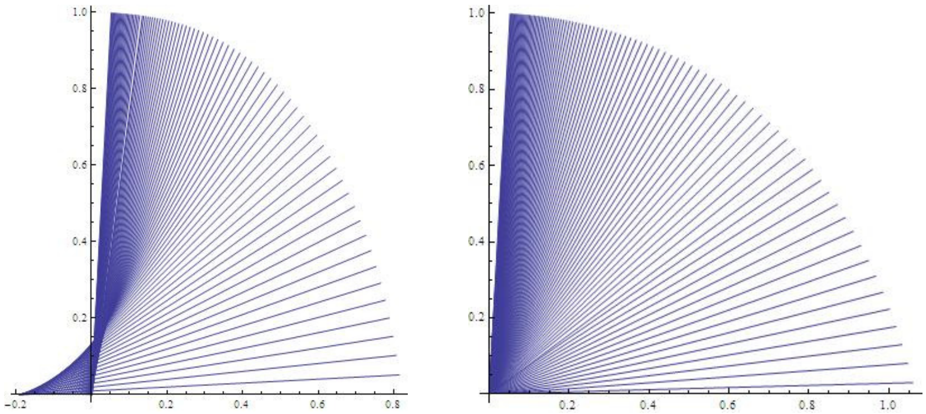

Figure 1: Left: Consecutive positions of the stick for small static friction coefficient: the stick slides "backwards", i.e., in the direction opposite to the direction of the fall. Right: consecutive positions of the stick for a large static friction coefficient: the stick slides "forward", i.e., in the direction of the fall.

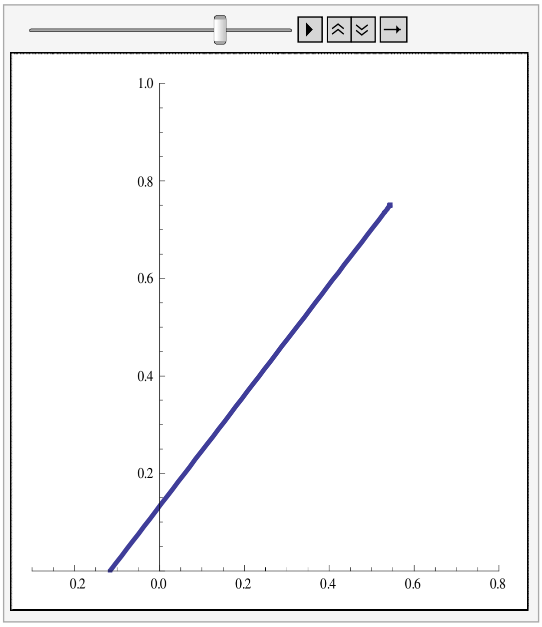

Figure 2: Simulating the fall of a stick. Positions of the stick can be observed frame by frame or watched in slow motion where we control the speed of simulation. The case of small static friction coefficient where the stick slides backwards is shown. The backward direction is clearly evident from the picture

Rings with balls

Suspend a tube forming a ring by a chord as shown in Figure 3. We position in the top of the tube, next to each other, two balls of a slightly smaller diameter than the inner diameter of the tube, so that we can assume that there is no friction.

We drop the balls. If there is no friction the balls lose contact with the tube one third of the vertical way down the ring. As soon as they detach themselves from the supporting surface they hit the outer wall of the ring. Since there is no friction, they act on the ring with a force perpendicular to the outer wall (= the new surface of contact). The two horizontal components annul each other, the vertical ones are added. Therefore the balls push the ring upwards so that it jumps up.

This phenomenon is interesting because it is unexpected. Its analysis is not complicated and it is useful, since it helps us understand the action of forces and their effect on the motion of bodies. Not only is the course of the motion (the sliding of the balls and the ring's jump) very fast, but it would also be difficult to carry out the experiment in a convincing way. Therefore a simulation offers convenient means of presenting and spurring of students' interest.

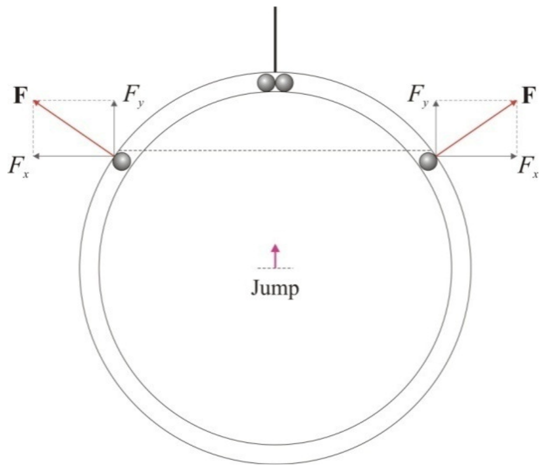

Figure 3: A tube forming a ring is hung by a rope. Two balls are dropped from the top, moving in opposite directions in the tube. When they drop by one third of the vertical distance they lose contact with the tube and hit the outer wall. The ring jumps up.

Waves

Waves, especially the longitudinal (important, for example, because they include sound) are hard to visualize. It is particularly difficult to see how two travelling waves moving in opposite directions create standing waves. Static pictures that show the situation in consecutive moments can help a better visualization (Figure 4) (Kranjc et al., 2007).

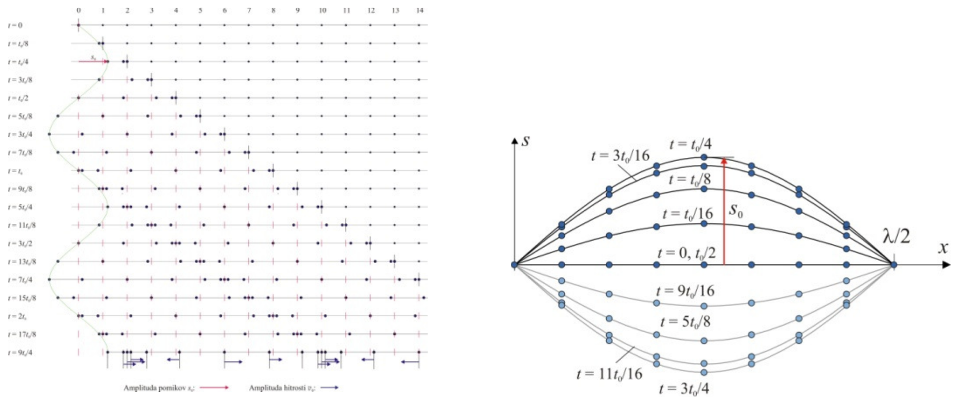

Figure 4: A "textbook" presentation of travelling and standing waves. Left: the beginning of the propagation of longitudinal waves through a sequence of consecutive moments. Right: a graph of displacements from the equilibrium position in case of standing waves (the lowest mode). The graph is the same for transverse and longitudinal waves.

Figure 4 right shows a sequence of motions of parts of a medium in case of standing waves. If one understands the quantities involved the picture can serve for both transverse and longitudinal waves. A simulation (Figure 5, longitudinal waves) makes it possible to follow, in detail, the motion of parts of the medium during the creation of standing waves during the interference of two propagating waves, and is able to convince students that standing waves really are the result of two waves travelling in opposite directions (Kocijančič, 2001).

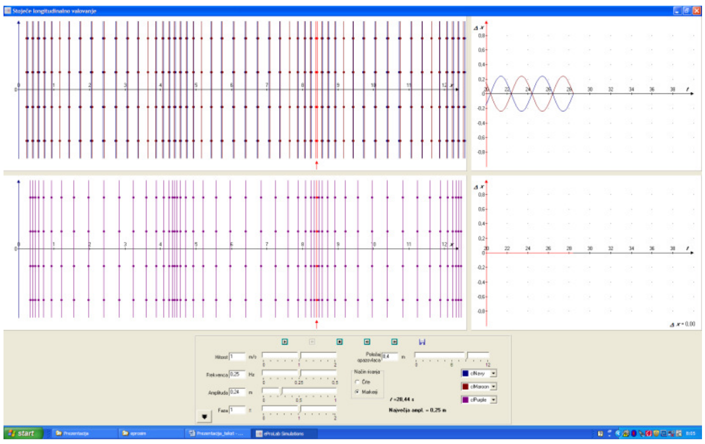

Figure 5: A simulation of a creation and the course of development of longitudinal standing waves.

Lunar phases

In school, astronomy is probably the most popular natural science. Despite this it is again and again clear that students are not familiar with some basic phenomena and notions that they see practically every day. Such are the sequence of days and nights on Earth, seasons, and lunar phases. Students have a weak knowledge of characteristics and explanations of these phenomena, and they are not very familiar with the pertinent terminology. Let us focus on lunar phases.

Lunar phases are an interesting but not completely simple phenomenon, although known to everybody (Kranjc in Razpet, 2010; Unsöld, 1969). Some superstitions are also tied to it, which is an additional reason for a more detailed treatment and an effort to gain a better understanding. Because of the definiteness and attractiveness of the phenomenon the respective "everyday" terminology is quite accurate: waxing crescent, first quarter, waxing gibbous, full moon, waning crescent, new moon, etc. It is interesting that this terminology is not well known to students nowadays.

Looking at the Moon we see that it is constantly migrating in the sky and that the lighted region of its surface is changing. How the phenomenon should be explained and presented for students to understand it? "To understand" means that they have a pretty good picture about it, for example, that they know that the waxing crescent cannot be seen early morning or waning crescent late afternoon, that they know when and where the Moon rises during different phases, etc.

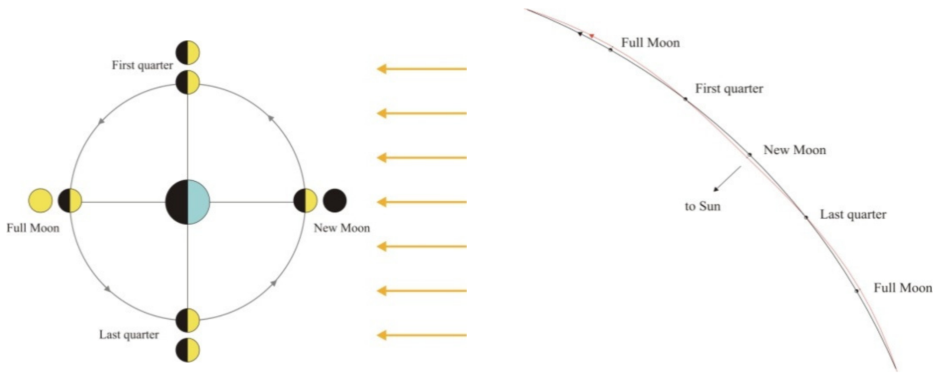

Figure 6: Left: A schematic illustration of the illumination of the Earth and the Moon which can be used to figure out the sequence of lunar phases. Right: a more "realistic" illustration of the Moon's motion around the Earth, which includes the motion of the Earth around the Sun.

Simple astronomical observations, of the Moon in particular, are accessible to everybody. In order to follow the motion of the Moon no special measuring devices are necessary. Despite that there is an obvious "inconvenience", typical of astronomy: observations are long and require persistence and consistency. Besides, we only see a part of the phenomenon; the whole picture has to be created based on the data collected during observations. For a "comfortable" presentation of the whole phenomenon we need an accelerated presentation of the motion which "in nature" can not be seen in a short time.

A presentation can be made through drawings or pictures with suitable comments. Figure 6 shows a standard schematic presentation of the mechanism of lunar phases. With a *suitable knowledge* it is possible to read from Figure 6 all their main characteristics. By »suitable« we mean a knowledge that is necessary for a "correct reading" of the picture. This includes, for example, the knowledge that the Moon circles the Earth in about the same plane as is the plane of the Earth's motion around the Sun, that the direction of the Moon's movement is the same as the direction of the Earth's spinning around its axis, and that it takes about 27 days for the Moon to circle around the Earth (and of course one day for the Earth to spin once around its axis). One also has to have some idea what an observer sees from a given point on the rotating Earth.

Computer simulations can give a much better presentation than static pictures (Figure 7). They can also show a better picture of what is seen by an observer, and how it depends on his/her position and the position of the Moon. The ability to change the observer's position and different configurations of the Earth and the Moon gives a much more complete idea about the functioning of the lunar phases phenomenon.

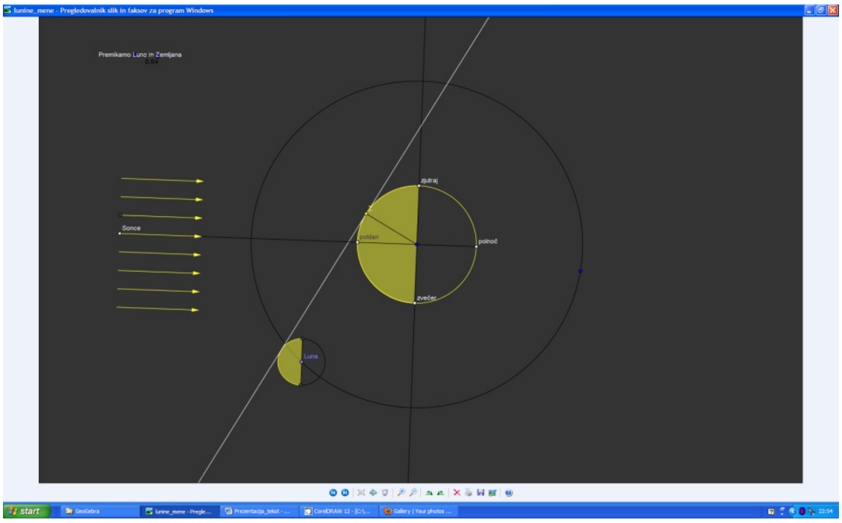

Figure 7: Computer animation allowing the change of the observer's position and the configuration of the Earth and the Moon.

Falling "quantum cards"

For decades there have been attempts to present basic concepts and laws of quantum mechanics already at the pre-college level (Michelini in Stefanel, 2003). According to our judgment this has not (yet) been done successfully. There are several reasons. On one side quantum mechanics and the behaviour of quantum systems are foreign to our experience and intuition, therefore a special effort is needed to get used to them and to adopt them. On the other hand, to get "familiar" with the new concepts and laws, and with this new "behaviour patterns", substantial time is needed—a time that is even lacking for the presentation of the classical physics content.

Despite our preceding observations we believe that some basic facts from quantum physics have to be included in the physics instruction early enough so that students at least encounter them, even if they cannot yet gain a real understanding. We believe that correct explanations have to be given, not just explanations with nonexistent analogies (see e.g. Feynman, 1992). Simulations can play a motivational role in performing macroscopic "thought experiments" that cannot be performed in reality, but they are realistic (insofar as there are macroscopic phenomena that behave that way), and attractive and interesting to students. One of such "experiments" (besides the experiment with "Schrödinger's cat") are falling "quantum cards" which demonstrate two basic quantum principles—the superposition and the collapse of a wave function.

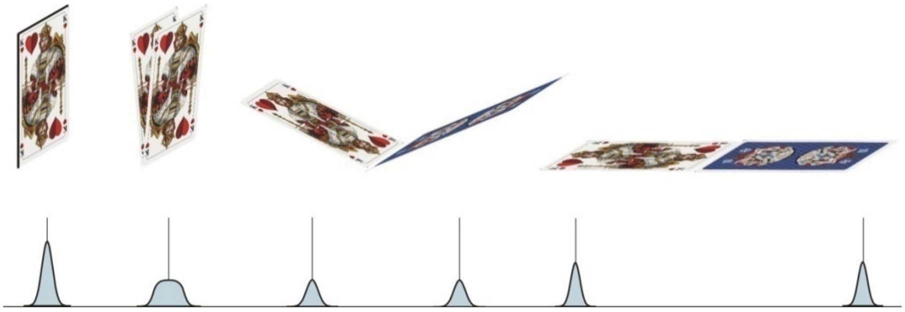

Figure 8: A quantum card put vertically on a horizontal surface falls in superposition to both sides. Its state is described by a wave function which is different form zero where the card can be found.

Suppose we have an isolated card (it could be a stick as well) that has one end attached to a horizontal table so that it can freely move around it (Figure 8). We would like to know how the card moves if we put it in a vertical position and drop it, given that we treat it as a quantum object (Tegmark and Wheeler, 2001; Batista and Peternelj, 2008; Scully and Walther, 1991; Zurek, 1991). Its motion is described by the Schrödinger's equation.

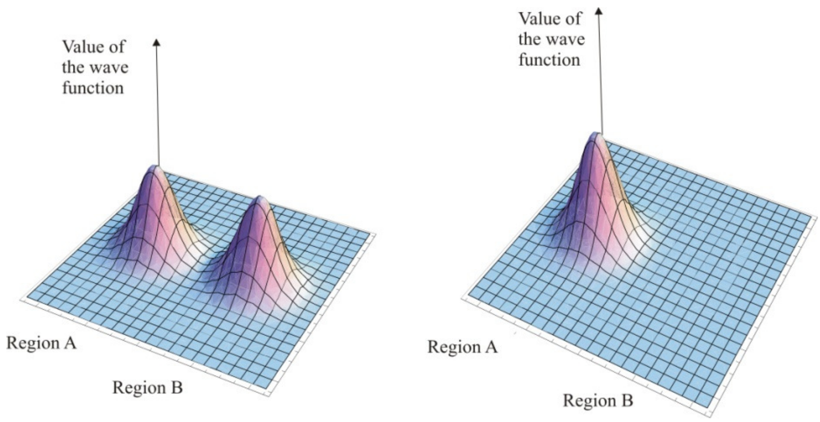

Figure 9: Left: The wave function (ψ) which is a superposition of states of the system (say a particle) in regions A and B ($\psi = \psi_A + \psi_B$). Right: With an experiment we determine that the particle is inside the region A. This CHANGES the wave function which is now $\neq 0$ only in the region A, $\psi \rightarrow \psi_A$. A *collapse* of the wave function occurred.

The answer to this question was presented by Tegmark and Wheeler in the article "100 years of quantum mysteries" (Tegmark in Wheeler, 2001) where they wrote "...You take a card with a perfectly sharp edge and balance it on its edge on a table. According to classical physics, it will in principle stay balanced forever. According to the Schrodinger equation, the card will fall down in a few seconds even if you do the best possible job of balancing it, and it will fall down in both directions – to the left and to the right – in superposition."

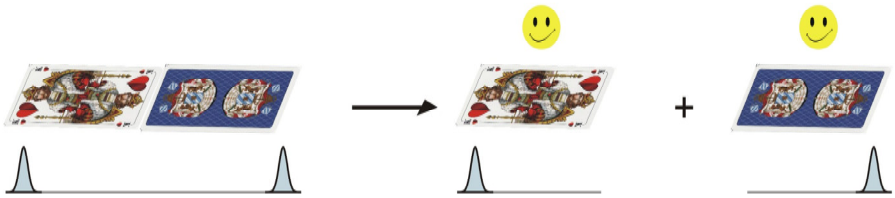

Figure 10: A quantum card put on a horizontal surface falls on both sides. Its state is described by a wave function. Before the process of determining with an experiment where the card is, it is in superposition on both sides. When the observation (experiment) is performed we find the card on one or the other side. During observation a collapse of the wave function occurs.

For a description of the card's motion we need to introduce a wave function (Feynman 1992; Scully et al., 1991; Zurek 1991), Figure 9. Through the (thought) experiment with cards we can explain what the superposition of states is and what the collapse of the wave function which occurs due to the measurement procedure is (Figure 10). Using a simulation we present the time development of the wave function of the falling card (Figure 11). Seeing the unusual behaviour of the falling card students get the first experience and the first knowledge about the nature of quantum systems.

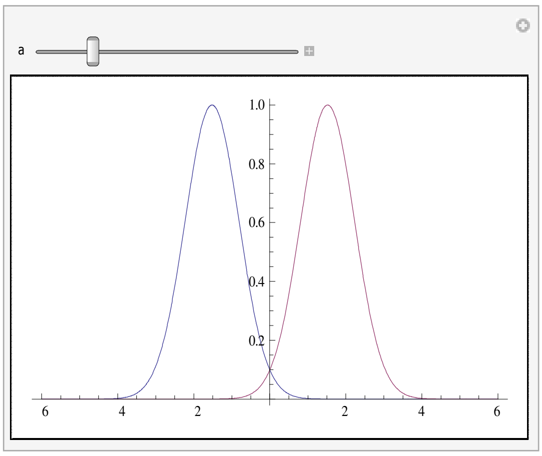

Figure 11: A simulation of the time development of the wave function of a falling card.

Conclusion

Included in the modern teaching methods is the use of teaching tools made possible by the modern technologies, which are mostly well known to students, even though in different contexts. One of these tools can be simulations that can in some cases significantly help the visualization and understanding of natural phenomena.

In this article we presented a few simulations that can be used in the classroom. They were chosen only as illustrative examples; every teacher has to decide on his/her own which simulations are appropriate in his/her classroom.

In general we find that simulations most of the time attract attention and interest. Students talk about them, which means that some degree of motivation has been reached. It also means that a step towards a better remembering has been made and it leads to a clarification of details and with that to a better understanding.

Sometimes students want to know how to make animations and some succeed to make their own. This way they not only acquire knowledge about a phenomenon represented by the simulation but also other "accompanying" knowledge (that physical statements, equations, and relationships between quantities indeed give the expected result) and skills, a satisfaction from the achieved results, and with that an additional motivation.

Of course, even with the help of simulations studying (i.e., a learner’s personal effort) is still necessary: unless we immerse ourselves into the process, we cannot understand it regardless of the way they are being presented (including simulations). Even with the help of a computer a time and (mental) effort investment, and the process of repetition and solidification of knowledge are necessary. Computer simulation does not give knowledge, it only make its acquisition easier.

References

Batista, M., Peternelj, J. (2008). Quantum cards and quantum rods. *Central Eur. j. phys.*, y. 6, No. 1, p. 171-177.

Etkina, E. and Van Heuvelen, A. (2001). *Investigative Science Learning Environment: Using the processes of science and cognitive strategies to learn physics*, Proceedings of the 2001 Physics Education Research Conference. Rochester, NY, PERC publishing, 17-21.

Feynman, R. P. (1992). *The Character of Physical Law*, Penguin Books.

Karelina, A. and Etkina, E. (2007). Acting like a physicist: Student approach study to experimental design, Phys. Rev. ST Physics Ed. Research 3, 020106.

Kocijančič, S. (2001). eProLab, Ljubljana.

Kranjc, T. et al. (2007). Fizika za srednje šole, Rešitve nalog, II. del, DZS, Ljubljana 2007

Kranjc, T., Razpet, N. (2010). »Po kakšnem tiru se giblje Luna?« Presek, letn. 37, št. 3, 22-25.

Kuščer, I. in Moljk, A. (1977). Fizika, I., II. in III. del, DZS, Ljubljana.

Lowe, R. K. (2003). »Animation and learning: selective processing of information in dynamic graphics« Learning and Instruction, vol 13, 157-176

Mayer, R. E., Moreno, R. (2002). »Animation as an Aid to Multimedia Learning«. Educational Pshyhology Review, vol. 14, no. 1, 87-99.

Michelini, M. in Stefanel, A. (2003). *Avvicinarsi all teoria della fisica quantistica; una proposta per la didattica*, Università di Udine, Unità di Ricerca in didattica della fisica, Udine.

Scully, M. O., Englert, B.-G. and Walther, H. (1991). Quantum optical tests of complementarity, *Nature* **351**, 111-116.

Tegmark, M. and Wheeler, J. A. (2001). *Sci. Am.* **54** (February p 54).

Unsöld, A. (1969). *The New Cosmos*, Springer-Verlag New York.

Viennot, L. (2006). Teaching rituals and students' intellectual satisfaction, *Phys. Educ.*, **41**, 400-408.

Viennot, L. (2010a). Physics by inquiry: beyond rituals and echo-explanations, Menaaube & G. Santoro (eds.) New Trends in Science and Technology Education, Selected papers, CLUEB, Bologna.

Viennot, L. (2010b). Physics education research and inquiry-based teaching: a question of didactical consistency, in K. Kortland (ed.): Designing Theory-Based Teaching-Learning Sequences for Science Education. Utrecht:Cdß press, 39-56.

Zurek, W. H. (1991). Decoherence adn the Transition from Quantum to Classical, *Physics Today*, October 1991, 36-44.

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SIMULACIJE KOT DOPOLNILO IN MOTIVACIJSKI DEJAVNIK PRI POUKU FIZIKE

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Povzetek

Pri pouku naravoslovja in posebej fizike moramo poučevati tako, da med razlago vpletamo demonstracijske eksperimente in računske vaje ter dijake spodbujamo, da tudi samostojno raziskujejo—to pomeni, da izvedejo kakšen poskus in ga podkrepijo z računom; tako odkrivajo in ugotavljajo relacije med količinami, spremenljivke in konstante.

V prispevku prikažemo nekatere primere, ko simulacija nadomesti poskus, ki ga v resnici ni mogoče izvesti oz. ga dopolnjuje tako, da ga lahko opazujemo v drugačni časovni in prostorski skali. Med poskusi, ki jih ne moremo izvesti v učilnici, lahko prikažemo obliko luninega tira, lunine mene, prikaz razlike med sončnim in zvezdnim časom ter gibanje predmetov, ki odletijo z vesoljske postaje. Med poskusi, ki jih ne moremo natanko slediti, ker se odvijajo prehitro, lahko prikažemo padanje palice (za različne koeficiente lepenja med palico in podlago) ter zanimiv primer drsenja dveh kroglic po obroču in dinamiko obroča. Prikažemo tudi potek transverzalnega in

longitudinalnega potujočega valovanja ter nastanek stoječega valovanja, ko se potujoče valovanje odbije ter vpadno in odbito valovanje interferirata, vizualizacija česar je za študente zahtevna naloga.

Podamo še primer iz osnov kvantne fizike: padanje "kvantne karte", ki spočetka stoji v navpični legi na vodoravni podlagi. Prikažemo časovni razvoj valovne funkcije ter ilustriramo za študente nenavadno obnašanje in neklasični opis kvantnega sistema ter ga primerjamo s klasičnim opisom, kakor je bil prikazan pri padanju palice.

Omenimo možnosti, da študenti sami izdelajo simulacije in animacije.

Ključne besede: *poučevanje, simulacije, animacija, eksperimentiranje, mehanika, kvantna fizika.*