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Computer Simulations and their Influence on Students' Understanding of Oscillatory Motion

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Abstract. Nowadays, the use of information technology (ICT) in education is nothing new. But the question is where the limit is when the use of ICT does not have the desired effect.

In the paper we discuss the use of simulations in the teaching process that can positively influence students' achievements. At the beginning of the paper we present the results of a research aimed at exploring the impact of the use of computer simulations on secondary school students' understanding of oscillatory motion. The aim of the research was to explore the effect of the use of simulations on students' abilities to work with graphs and to find out relevant information. In the conclusion, the possibilities of integration of simulations into the teaching process are discussed.

Keywords: simulation, physics education, oscillatory motion, graph.

1. Introduction

Before 2008, prior to the Educational Reform in the Slovak Republic, there was a number of calls regarding the integration of active and innovatory methods within the teaching of physics. Once the reform was put in force, the state education programmes had taken these calls into consideration, ending up in new physics curricula for ISCED 3A. *"Methods of active learning and systematic research, individual student work, i.e. activities aimed at actions leading to new knowledge construction..."* should be incorporated in physics lessons at upper secondary schools. Nevertheless such activities do require a certain time to prepare and due to the time allocated for physics they are hardly done.

It is then important to seek such means that will simplify the implementation of the aforementioned methods into practice. It is possible to use a variety of ICT's that facilitate the experimental data collection and shorten the time needed to prepare the experiment, which enables the effectuation of the experiment – the discovery and postulation of the problem, postulation of hypotheses, and analysis and interpretation of obtained data, etc. The possibilities offered by computer-supported laboratories allow the effectuation of real or simulated experiments.

The paper will give a closer look at simulations that represent the object of simulated experiments. Their use comes with an undeniable advantage – the input parameters can be modified to watch the course of simulations in changed conditions. This will allow students to postulate their own hypotheses, envisage the course of the simulation according to the input parameters, or even ask a question: "*What happens if...?*" Additionally, computer simulations may allow students to visualize objects and processes than are normally beyond the user' control in the natural world (do Jong, Linn and Zacharia, 2013).

Research oriented on the use of computer simulations has a long history as it is showed by a review of de Jong and van Joolingen (1998). Researches on computer simulations in physics education conducted in the last decades can be divided by research questions into two groups (Rutten, van Joolingen and van der Veen, 2012):

1. How can traditional science education be enhanced by the application of computer simulations?
2. How are computer simulations best used in order to support learning process and outcomes?

That simulations might positively influence students' knowledge and skills has been proven by multiple studies. For example *Huffman, Goldberg and Michlin* (2003) proved a positive effect of simulations on students' results. Some similarities may be found in the research carried out by *Jimoyiannis and Komis* in 2001. They concluded that the use of simulations within the teaching process could help students dispel misconceptions and ameliorate the comprehension of the respective concepts. The impact of simulations on students' understanding of mechanics, thermodynamics and optics was studied by *Zacharia and Anderson (2003)*, with the target group being the future teachers of physics. Once the research had been done, the authors agreed that the use of simulations had a positive impact on students' being able to predict and explain the phenomena.

Other research studies show that the use of computer simulations appears to make easier student's conceptual understanding (Zacharia, 2007), (Stern, Barnea and Shauli, 2008), (Sarabando, Cravino and Soares, 2014), requires less time as traditional methods (Gibbons *et al.*, 2004), and improves the ability to predict the results of experiments (McKagan *et al.*, 2009).

Further researches showed importance of instructional support in facilitating discovery learning through simulation-based learning For example *Veermans, van Joolingen and de Jong (2006)* found out that students' self-regulation was best facilitated by providing heuristics explicitly instead of implicitly. Lazonder *et al.* (2009) confirmed that it was necessary for learners to have a basic understanding of the variables that were involved.

Based on the previous studies, we assumed that the simulation would have a positive impact on students' learning outcomes. Thus, to verify the didactic effect of the simulations, the hypothesis: "*The use of simulations within the physics teaching process will contribute to better achievements of experimental class students in each level of*

Niemierko's taxonomy (remembering, understanding, specific and non-specific transfer)" was postulated. In the next step we wanted to know whether the use of simulations impact on improving experimental class students' skills to work with graphs.

2. Simulations as a Part of Experiments

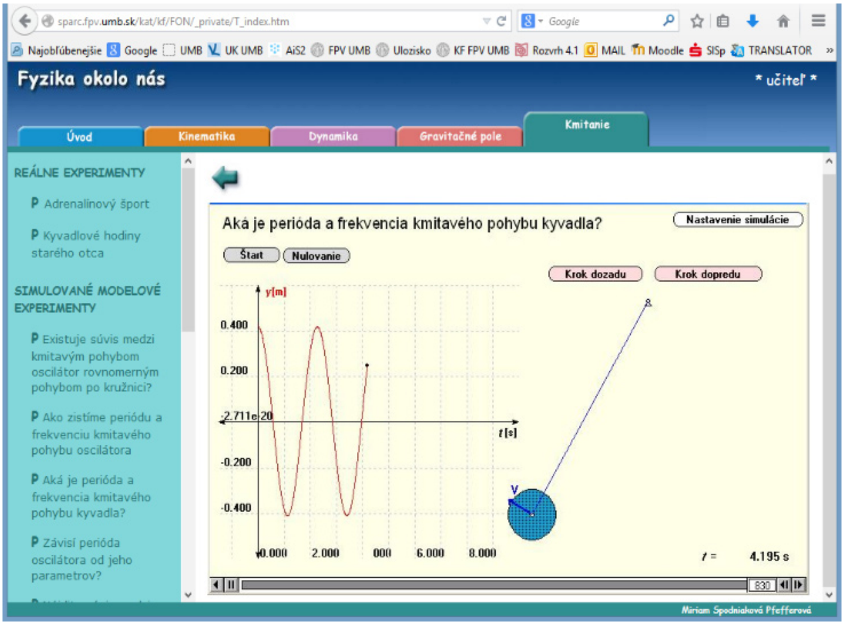
Nowadays there is a huge number of simulations on the Internet that might be applied within teaching (web portals with physics simulations: *PhET – Interactive simulations, OSP – Open source physics, Physlets, Modellus, Easy Java Simulations, etc.*). However, it is important to examine always the simulation prior to its use; firstly to verify its physical aspect, secondly to confirm its method within the teaching process. The language of simulations might be sometimes also considered as a disadvantage since simulations are not usually offered in Slovak and therefore their using in the teaching process can bring many problems. Based on our experiences with the use of non-Slovak simulations in physics lessons at the secondary school the teacher had to translate the English text in the simulation before its using during explanation. Nevertheless most of students were more focused just on English in simulations instead of the essence of the physical phenomena and for this reason it was rather problematic to fulfil a teaching goal.

These difficulties actually made us to create a set of simulations designed directly for secondary school physics in Slovak conditions. It means that the simulations have been designed mainly to complement the real experiments that have been identified as useful in explaining the physical topics by the state physics curricula. Some of the created simulations were also designed to provide possibility to explore physics phenomenon which cannot be realized in school conditions (for example – dangerous, too long or too short experiments, etc.).

The simulations have been designed in the Interactive Physics program and have aimed at different fields of mechanics – kinematics, dynamics, the gravitational field and the motions in it, and oscillations. The complete set of the simulations of different fields of mechanics is available at the website called *Physics around us* (Fig. 1):
`<http://sparc.fpv.umb.sk/kat/kf/FON/>`.

The set of 13 simulations focused at oscillatory motion was used in the pedagogical experiment. These simulations have covered all physics phenomena of this field which had to be explained during physics lessons at the secondary school according to the state educational program. The most of them were combined with real experiments.

The use of simulations within the teaching process must follow some rules to be effective (Spodniaková Pfefferová, 2008), (Spodniaková Pfefferová *et al.*, 2009): (1) simulations must be used in the phase of the learning process they are necessarily a part of (i.e. simulation, as cognitive objects, models physical reality that is the lesson subject matter), (2) if the simulation models a multitude of physical phenomena, it is appropriate to present only the one directly related to the topic (the simplicity of the simulation is related to its comprehension and graphicness), (3) it is important not to use excessive amounts of simulations, otherwise students are less likely to follow the presented physical phenomena, they are less concentrated and interested in the topic.



Aká je perióda a frekvencia kmitavého pohybu kyvadla?

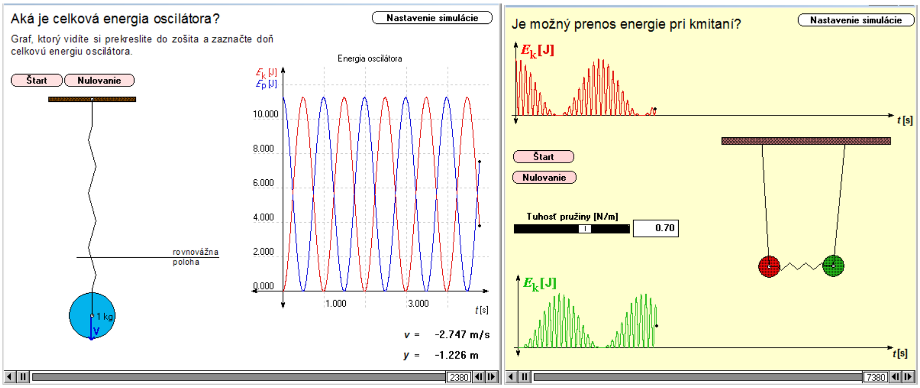
Fig. 1. Website “Physics around us” contains a set of simulations in different fields of physics (Menu of the website: Introduction, Kinematics, Dynamics, Gravitational field, Oscillations).

These simulations were used in the teaching process in such a way so as an increased activity of students was achieved. Respecting the aforementioned aim (and the rules described above), at the beginning all the students together with the help of the teacher made a few steps before using the simulation – an introduction to the motivational situation from real life, an identification of the problem, a formulation of the problem, a formulation of the hypothesis. Subsequently the students worked with the simulation and explored the physical phenomenon in different initial conditions individually or in small groups (2 or 3 students). After finishing the work with the simulation students analysed obtained data and interpreted results with the teacher’s assistance. The final step in this process was a common discussion of the results. Each simulation was prepared together with a guide for both the student and the teacher, aiming to simplify the use of simulations within the teaching process (Holec and Spodniaková Pfefferová, 2006).

Just a sample of simulations used within the pedagogical experiment is presented in this paper due to the limited range. As was already mentioned all of these simulations are available at website *Physics around us*, section *Oscillations*.

The simulation ***What is the total energy of the oscillator?*** (Fig. 2 (1)) aims at the examination of energy transformations of a mechanical oscillator, i.e. from potential energy to kinetic energy. It was important for the students to realise that its total energy remained unchanged.

The simulation ***Is the energy transfer possible even during oscillation?*** (Fig. 2 (2)) is to show that the energy transfer takes place when two oscillators oscillate and are interconnected, with the speed of transfer being based on the type of binding.


Aká je celková energia oscilátora?

Graf, ktorý vidíte si prekreslite do zošita a zaznačte doň celkovú energiu oscilátora.

v = -2.747 m/s

y = -1.226 m

Je možný prenos energie pri kmitaní?

Tuhosť pružiny [N/m] 0.70

(1) (2)

Fig. 2. Sample of simulations used in the pedagogical experiment
(1) What is the total energy of the oscillator?
(2) Is the energy transfer possible even during oscillation?

Both of these simulations were used with combination of real experiments by which students explored basic characteristics of oscillatory motion (experiments with a spring oscillator and coupled magnetic oscillators). By the simulations the students explored energy transformation in the both of oscillators.

3. Results of Pedagogical Experiments

The simulations were tested within a pedagogical experiment at a 4-year secondary grammar school with 3rd year students in the school year 2008/2009 (Table 1). An important criterion was to compare the physics knowledge level of the students from an experimental class (EC) and a control class (CC). As they were 3rd year students, the grades obtained in the 1st and 2nd year as well as the first term grades from the 3rd year in physics were used to compare their assessment.

Based on the aforementioned data, we can conclude that the knowledge levels in physics of both the experimental and the control class students were nearly the same. However, the arithmetic average of grades did not reflect the actual distribution of the

Table 1

Overall comparison of EC and CC students' achievements in physics

	Experimental class	Control class
Students in total	32	31
1st year	2,35	2,38
2nd year	2,22	2,25
3rd year	2,51	2,45

knowledge level as such. Thus, diagrams were created to show the number of the respective grades obtained (Fig. 3)

Simulations, as used within the teaching process in experimental class, were a part of the teaching unit *Oscillation and Waves*. In both classes, the same methods were utilised, i.e. explanation, demonstrative real experiments, and solution of problems of a type. The students of the experimental class used simulations in addition, and as already mentioned in the part above, students worked with simulations individually in small groups. Teaching in both classes was performed by the same teacher.

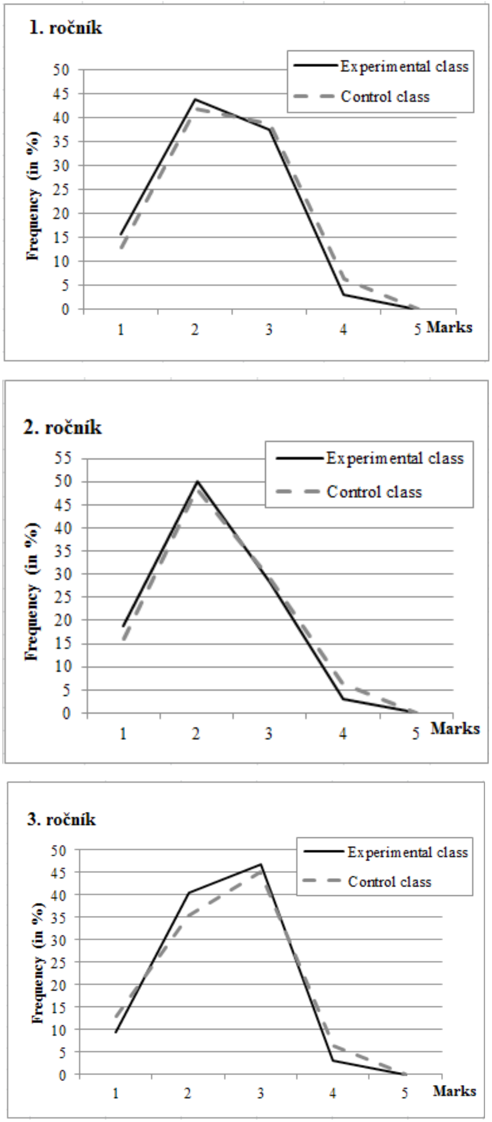


Fig. 3. Distribution of student performance in physics in both classes during three school years.

To identify experimental and control class students' knowledge in the thematic unit, a non-standardised didactic test was used. It was to prove the level of remembering, understanding of the subject matter, and ability to solve tasks of varying degrees of difficulty (specific and non-specific transfer). On the basis of belonging to particular categories, the tasks were assigned their significance weights, e.g. tasks requiring comprehension were valued twice as much as tasks requiring only memorisation.

After the evaluation of tests, the level of students' knowledge was expressed by means of relative weighed score. In addition to essential characteristics of the individual tests, arithmetic averages were submitted to the test on its difference (t-test), with the level of significance being set at $\alpha = 0.05$.

Based on previous research (Zacharia and Anderson, 2003), (Holec, Spodniaková and Raganová, 2004), (Finkelstein *et al.*, 2005), (Spodniaková Pfefferová, 2006) we assumed that the use of simulations would have a positive impact on the experimental class students' knowledge level. The analysis of results proved our expectations and confirmed hypothesis mentioned above. The experimental class students' performance was significantly better (relative weighted score: $p^{v}_{average} = 62{,}8$ %) than that of control class students (relative weighted score: $p^{v}_{average} = 49{,}7$ %). The distribution of student performance in both classes is shown in a diagram (Fig. 4).

When the pedagogical experiment was being carried out, we were concerned only with the impact of the use of simulations on the students' knowledge level. After a certain time, we treated the results differently. Since the tasks of the didactic test were weighed according to which individual categories they were a part of – remembering, understanding, specific and non-specific transfer (taxonomy of educational objectives as described by B. Niemierko) – it was possible to examine the effect of simulations on these different levels. Experimental and control class students' assessment of particular categories is shown in the diagram (Fig. 5)

The diagram clearly shows that experimental class students' results were assessed better in all categories. A statistically significant difference might have been observed in two categories only – understanding ($\bar{p}_{EC} = 74{,}2\ \%, \bar{p}_{CC} = 61{,}4\ \%$) and non-specific transfer ($\bar{p}_{EC} = 43{,}7\ \%, \bar{p}_{CC} = 29{,}5\ \%$). Other categories did not prove any significant

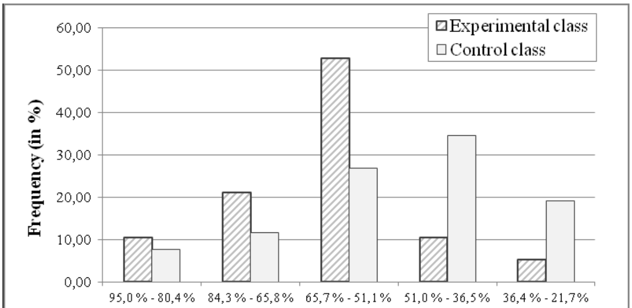


Fig. 4. Distribution of student performance in both classes.

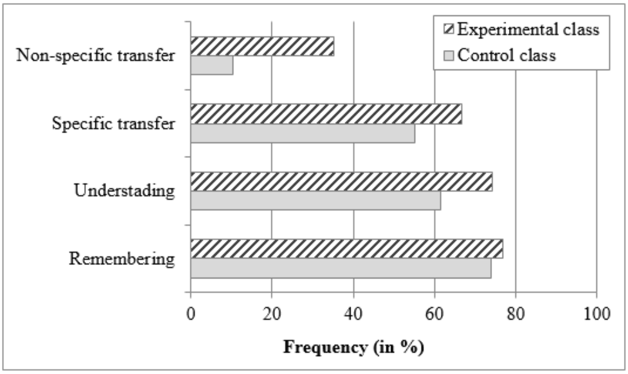


Fig. 5. Successfulness of students in particular categories.

difference. It is possible that the control class students acquired knowledge only on the basis of memory, without their being able to comprehend the laws of oscillation. This postulation is proven by the control class students' assessment within the category *non-specific transfer.* This category required both acquired knowledge and creative approach regarding the solution of the task results, which assumes proper understanding of the phenomena.

The tasks requiring a work with diagrams as a part of the category *understanding* were an object of our further analysis. The students' assessment of the tasks is shown in the diagram (Fig. 6).

As the diagram shows, the achievements are comparable. The test concerning the difference of arithmetic averages did not approve any significant differences, yet that the category *understanding* showed statistically significant differences regarding the achievements of classes.

Based on these results regarding the use of simulations, we can conclude that we recorded a positive result in understanding the phenomena as well as in problem solving (non-specific transfer), but the impact on the students' ability to work with graphs was not proven. This phenomenon may be due to the fact that the dependency diagrams were only a complement to the simulations, not the dominant part that students should concentrate on.

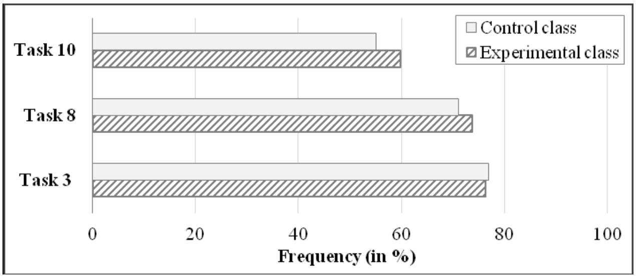


Fig. 6. Successfulness of students in particular tasks.

4. Conclusions

The findings of this study indicate that using of simulations in physics education brings significantly better results of experimental class students in comparison with control class students. The results show that the use of simulations in the teaching process has a positive impact on the students' knowledge levels. A deeper look at the results underscores the positive impact of simulations on the understanding of physical laws as well as on the solution of tasks requiring a creative approach (*non-specific transfer* by Niemierko's taxonomy).

Our results show:

1) The use of computer simulations helped students' better comprehension of basic features of oscillatory motion.
2) Students were able to use their knowledge to solve creative tasks required combination knowledge from different fields of physics.

On the other hand, though students of the experimental class obtained significantly better results in knowledge level *understanding* their ability to work with graphs was comparable with control class students.

The results regarding tasks requiring a graph utilisation might call for a deeper reflection. These results show no impact on students' being able to work with graphs. As mentioned, this state might actually be caused by the construction of simulations, graphs not being a dominant part. We suppose that to familiarise students with graphs, it would be better to use quantitative simulations created in a table calculator or in the program Coach. Students could work only with graphs, being able to change the input parameters to observe the change on it. When used, these simulations are supposed to improve students' abilities to work with graphs and to acquire relevant data, which might be a point of departure for further research.

Even though our research had been carried out prior to the Educational Reform the results are still valid as they show the impact of the simulations on students' performance without taking into consideration the subject matter of the teaching process. We approved the benefits of the use of simulations in the classroom, but how to integrate them into the school curricula? The Educational Reform in Slovakia came with two significant changes regarding teaching of physics at secondary schools. The first one was concerned with the time allocated for physics, reduced to 50 %, the second one was connected with the restructuring of the then-curriculum of physics, reduced and divided into several thematic units. There were also debates on the use of activation and innovative methods in the teaching of physics. Their implementation in the educational process needs time, notwithstanding that the curriculum and time allocated for physics at secondary schools is not sufficient.

One way to combine all these factors and to achieve this goal is the use of simulations. As mentioned simulations are a tool that helps to examine different situations with different input parameters, which determines their intensive use within the teaching process. The use of simulations within the teaching process is connected with its availability. We do not want to indicate a shortage of simulations on the internet. Admittedly, it is the opposite. The problem might be a need to devote a long time finding a suitable simulation of the physical phenomenon.

The way out of this situation would be to create a gateway containing a database of various materials for teaching, including instructions for real experiments with or without the support of computer simulations, problem tasks, and many other activities that might somehow improve the learning process. Teachers would have the opportunity to find everything they need in one place.

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In 2006 she obtained PhD degree. Her dissertation work was focused on an integration of information technologies to physics education, specifically an application of computer based experiments and simulations into physics lessons. Her recent research interest is still oriented on implementation ICT to physics education as well as on different kinds of experimental activities and their exploitation in physics lessons.

Kompiuterinis modeliavimas ir jo įtaka mokinių supratimui apie virpamuosius judesius

Miriam SPODNIAKOVÁ PFEFFEROVÁ

Šiuo metu informacinių ir komunikacinių technologijų naudojimas švietime nėra jokia naujovė, tačiau kyla klausimas, kur yra riba, kai IKT neduoda norimo rezultato. Straipsnyje aptariama galimybė modeliavimą naudoti mokymo procese taip, kad jis teigiamai veiktų mokinių pasiekimus. Pradžioje pristatomi tyrimo, kuriuo siekiama išnagrinėti kompiuterinio modeliavimo įtaką vidurinės mokyklos mokinių supratimui apie virpamuosius judesius, rezultatai. Tyrimo tikslas – ištirti, kaip modeliavimo panaudojimas veikia mokinių gebėjimą dirbti su grafikais ir surasti aktualią informaciją. Pabaigoje aptariamos galimybės modeliavimą naudoti mokymo procese.