USING VIDEO-ANALYSIS OF MOTIONS IN PHYSICS TEACHING AND LEARNING

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Abstract: This paper describes using video-analysis based tasks in the educational process of the students at the technical university. The attention is paid to university students and their knowledge of physics and conception/misconception.
The role of students in video analysis is to realize necessary physical characteristics, to choose a suitable way to a problem solution and from the relations among physical quantities to find a solution to a task. The tasks can be considered being the problem-solving tasks with a well-defined problem and according to Bloom´s taxonomy of cognitive domain they require higher level solution – mostly application, analysis and synthesis. On the other hand, it is also possible to demonstrate students, by a simple mathematical analysis, the use of integrals and derivatives in physics.
Using the method of video-analysis by interactive program Tracker the level of knowledge of students can be increased and some misconceptions can be eliminated.
Keywords: STEM education, FCI test, program Tracker

Introduction

We have already presented students' understanding of the real physical processes in previous works that is not correct (Hockicko et al, 2013). Many authors confirmed that during the last decades, entry-level engineering students' basic abilities in Physics (and Mathematics) have decreased dramatically (Pinxten et al, 2017). Physics are often considered to be difficult subjects. The fundamental laws are expressed in the language of mathematics. Teachers constantly work on improving students´ understanding of various phenomena and fundamental laws. One of the creative methods of teaching physics which makes natural sciences more interesting for students is video-analysis (VAS method) using the program Tracker. Collaborative projects based on digital video-analysis provide an educational, motivating and cost-effective alternative to traditional course-related activities in introductory physics (Laws et al, 1998).

The traditional teaching of Newtonian mechanics in the early years of university studies eliminates the wrong perception of students acquired during their secondary school studies only to a small extent. It was also shown that traditional lectures help to acquire only basic knowledge without deeper understanding and the ability of problem solving; students do not show conceptual understanding of the subject which should result from a sufficient number of solved quantitative tasks and from logically clear lectures (Redish, 2003).

This led us to producing a video set, by means of which we explained physical laws in lectures and realized video-analysis in seminars (Hockicko, 2013). The tasks can be considered being the problem-solving tasks with a well-defined problem and according to Bloom´s taxonomy of cognitive domain they require higher level solution – mostly an application, an analysis and a synthesis. Many tasks based on video-analysis are suitable to demonstrate a simple mathematical analysis, the use of integrals and derivatives in physics. The use of tasks based on video-analysis in physics can significantly affect the differences in knowledge when students solving traditional tasks from printed textbook (Hockicko et al, 2015).

We try to prepare our students for teamwork and collaboration with scientists and engineers, so they can work in interdisciplinary fields at the interface between Physics and technical departments. As a result, we consider theoretical training not as the goal but to an end, and therefore it should always be followed by practical application.

It is very important to use the multimedia tools also in other subjects including basic education to make science and technology more appealing and to address the scientific apathy crisis of young people (Bussei, 2003). Game provides many examples that can bring physics to life in the classroom. Especially, the kinematic and dynamic characteristics of motions are worth a physics classroom discussion. It enables the students to work in much the same way as sport scientists do (Heck 2010). Therefore, we decided to support freshmen by interactive lectures using video and video analysis and find out whether interactive lectures are more effective in increasing students prior knowledge level of Physics than traditional lectures.

Methodology of teaching physics

Using the program Tracker students can detect the relationship between physical quantities and describe a motion using time dependencies. Tracker offers time dependencies of 22 physical quantities (+ we can define other), data processing by means of graphs and tables. From the number of frames per second (30 fps or 120 fps usually) the time is deduced ($\Delta t = 0.033$ s or $\Delta t = 0.0083$ s) while the position can be measured in two dimensions (x, y) using a video image after calibration. The function autotracking in this program allows for accurate tracking without mouse. The studied motion can be divided into two parts: the horizontal component and the vertical component. These two components can be analysed independently of each other and afterwards the results can be combined to describe the total motion ($x(t)$, $y(t)$, $v_x(t)$, $v_y(t)$, $a_x(t)$, $a_y(t)$).

The students can fit the time dependencies of position, velocity, acceleration and other using a data tool which provides a data analysis including automatic or manual curve fitting of all or any selected subset of data. The position and the velocity can be plotted and fitted to see the correlation between the real data and the kinematic equations. For example, students have found that the trajectory of the free fall ball is always a parabola (Hockicko 2011).

The example of the task for students:

The cylinders with different mass are rolling down an incline that is placed at a certain height above ground. What will be the horizontal distances of the points at which the cylinders hit the ground from the end of the incline? (Length of the black square segment: 1 cm, frequency of taking pictures: 120 fps, masses of cylinders: m1 = 1.807 kg, m2 = 0.640 kg, m3 = 0.264 kg)

The solution using video-analysis using program Tracker:

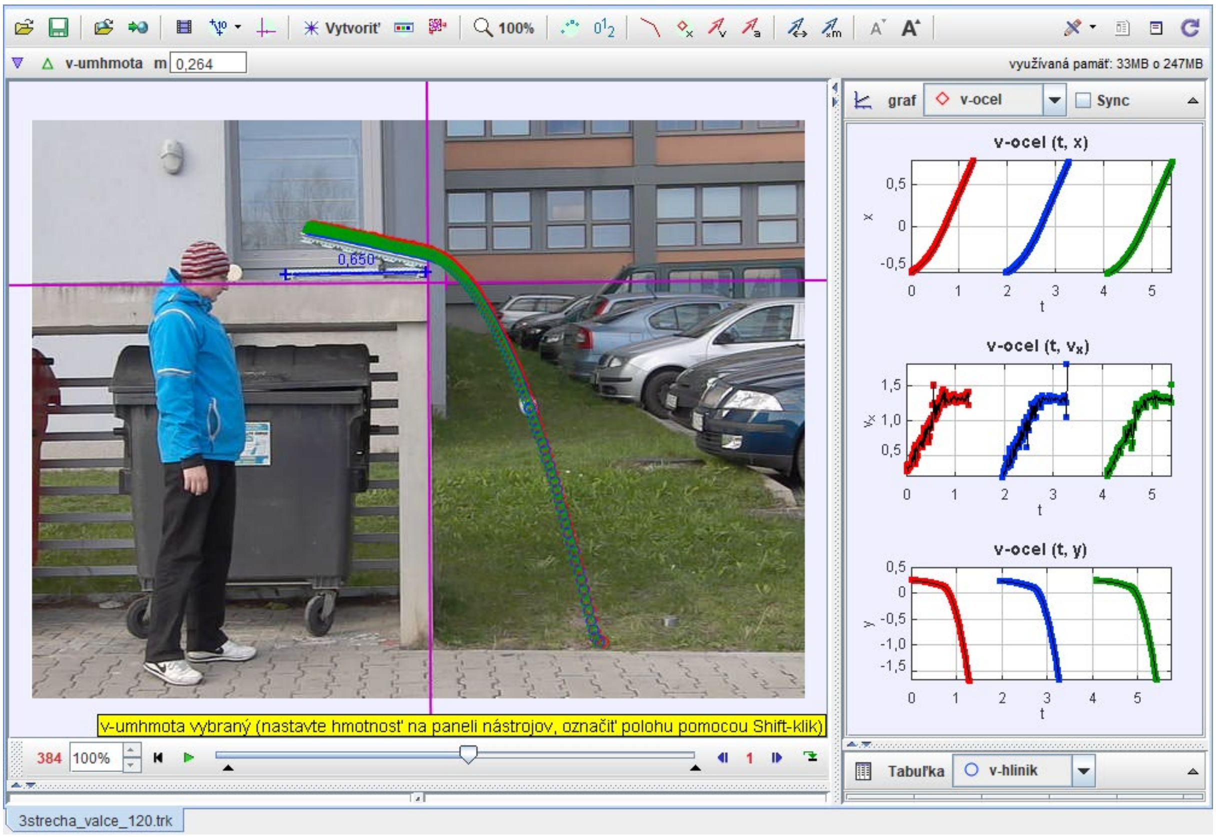

Figure 1. The analysis of motion using program Tracker. Red – a metal cylinder, blue – aluminium, green – plastic.

The next task: *Compare the motions of cylinders with different mass and the same diameter. If they all start moving from rest at the same elevation and roll down without slipping, which of them reaches the bottom as the first? Which reaches it as the last? Try to compare the velocities at the end of an incline.*

Using Data Tool in Tracker which provided a data analysis including automatic or manual curve fitting of all or any selected subset of data, the students can fit the time dependencies of the position, velocity (Fig. 1), acceleration and other. The position and the velocity can be plotted and fitted to see the correlation between motions of different cylinders. Using the fit function, the students can find that all cylinders are rolling down an incline with basically the same acceleration and velocity of their centres of mass. For the students during the lecture and watching the video these results were quite interesting since both the speed and the acceleration of the centre of mass of the cylinder were independent of their mass.

Using this video (http://hockicko.uniza.sk/Priklady/video/strecha_valce_120.avi), we can change the misconception that *"heavier objects fall faster"* and show that the time of free fall does not depend on mass of body. We can analyse velocity and the position of cylinders in x-direction and show that the results do not depend on mass of cylinders in rolling motion, too.

Methodology of Evaluating

At the beginning of the second semester of academic year 2018/19, the Force Concept Inventory (FCI) (Hestenes el al., 1992) was administered to students at the Faculty of Electrical Engineering and Information Technology (FEEIT) University of Žilina (UNIZA) to find out their prior knowledge level of Physics. The pre-test was carried out at the beginning of the second semester during the first week, post-test was carried out at the end of the semester (the 13th week, after the semester course 'Physics') and it was attended by 64 students who participated in the both pre- and post-test.

The students were assigned to two groups – the experimental (attended by 44 students) and the control group (attended by 20 students). Only those students who participated actively in the lectures took part in the experimental group. Students who did not attend lectures took part in control group.

The lectures were conducted in an interactive way aimed at clarity - using real-life videos related to the topic. All videos were analysed with the help of the program Tracker (using VAS method). Students from both groups attended compulsory computational Physics seminars. The subject 'Physics' consists of 3 - 2 - 1 (lectures - exercises - labs) lessons per week, presence study. The semester consists of 13 weeks. The only difference between the experimental and the control group was that students from experimental group actively attended 13 interactive lectures while students from control group did not attend lectures.

Results and Discussion

These results (Fig. 2, Tab. 1) indicate that there is no statistical difference in the mean pre-test FCI score between the experimental and the control group at the beginning of the semester.

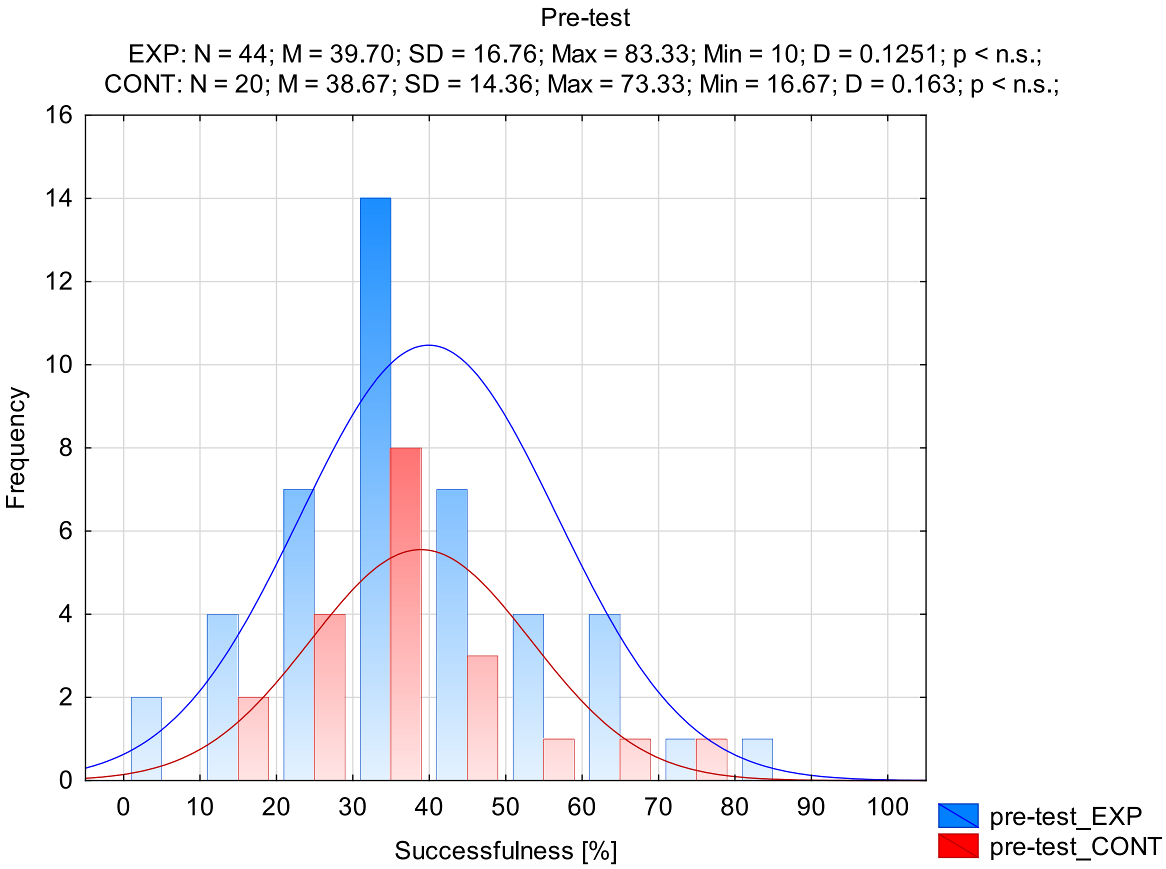

Figure 2. FCI score of pre-tests for the experimental and the control groups.

Table 1: Pre-test: F-Test Two Sample for Variances and t-Test: Two Sample Assuming Equal Variances.

	Experimental group	Control group
Mean	39.70	38.67
Variance	281.04	206.32
Observations	44	20
df	43	19
F	1.36	
P(F<=f) one-tail	0.24	
F Critical one-tail	2.02	
Pooled Variance	258.14	
Hypothesized Mean Difference	0	
df	62	
t Stat	0.24	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.00	

But results in Fig. 3 and Tab. 2 indicate that there is a statistical difference in the mean post-test FCI score of the experimental and the control group at the end of the semester.

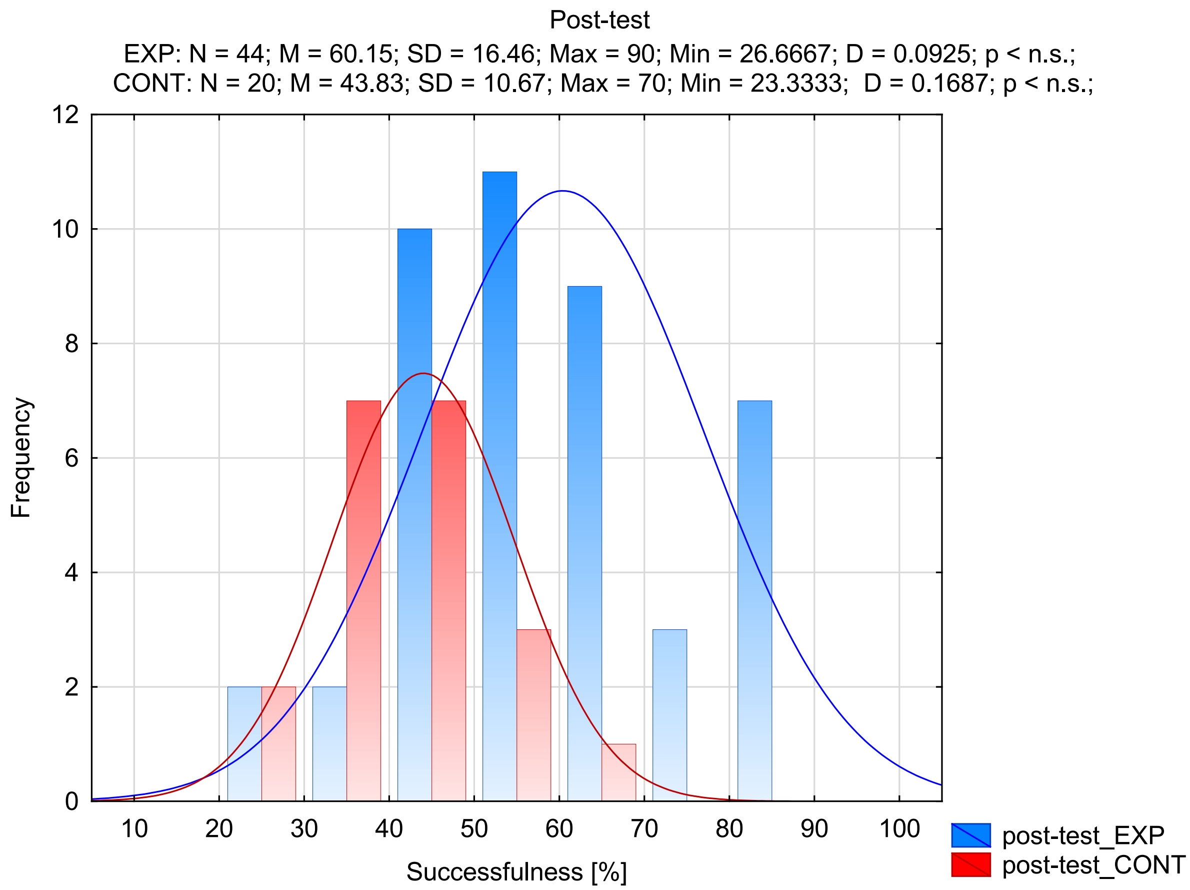

Figure 3. FCI score of post-tests for the experimental and the control groups.

Table 2: Post-test: F-Test Two Sample for Variances and t-Test: Two Sample Assuming Unequal Variances.

	Experimental group	Control group
Mean	60.15	43.83
Variance	270.78	113.77
Observations	44	20
df	43	19
F	2.38	
P(F<=f) one-tail	0.02	
F Critical one-tail	2.02	
Hypothesized Mean Difference	0	
df	54	
t Stat	4.74	
P(T<=t) one-tail	7.94E-06	
t Critical one-tail	1.67	
P(T<=t) two-tail	1.59E-05	
t Critical two-tail	2.00	

After that analysis we try to use Student t-test and compare pre and post-test results of experimental and control groups (Fig. 4, 5).

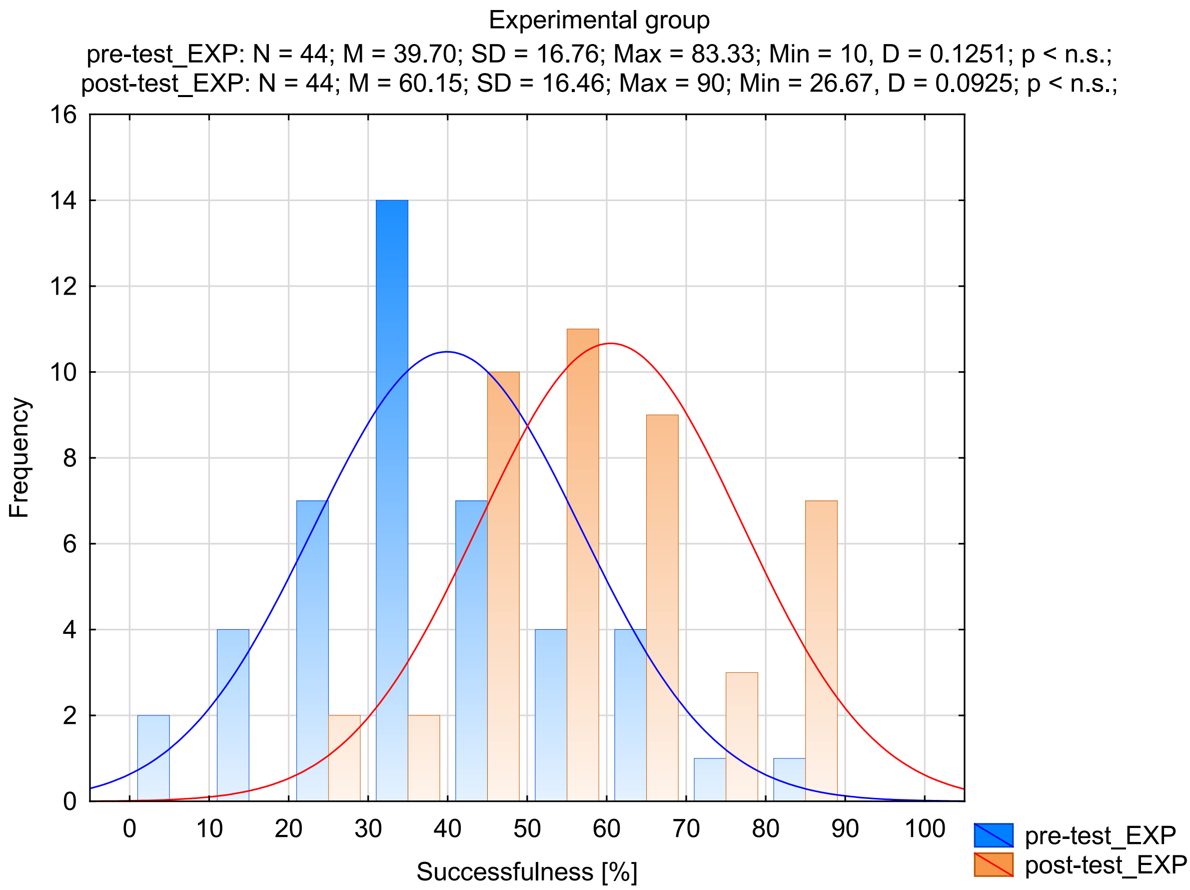

Figure 4. FCI score of pre and post-test for the experimental group.

Table 3: t-Test: Paired Two Sample for Means – Experimental group.

	Post-test	Pre-test
Mean	60.15	39.70
Variance	270.78	281.04
Observations	44	44
Pearson Correlation	0.53	
Hypothesized Mean Difference	0	
df	43	
t Stat	8.45	
P(T<=t) one-tail	5.47E-11	
t Critical one-tail	1.68	
P(T<=t) two-tail	1.09E-10	
t Critical two-tail	2.02	

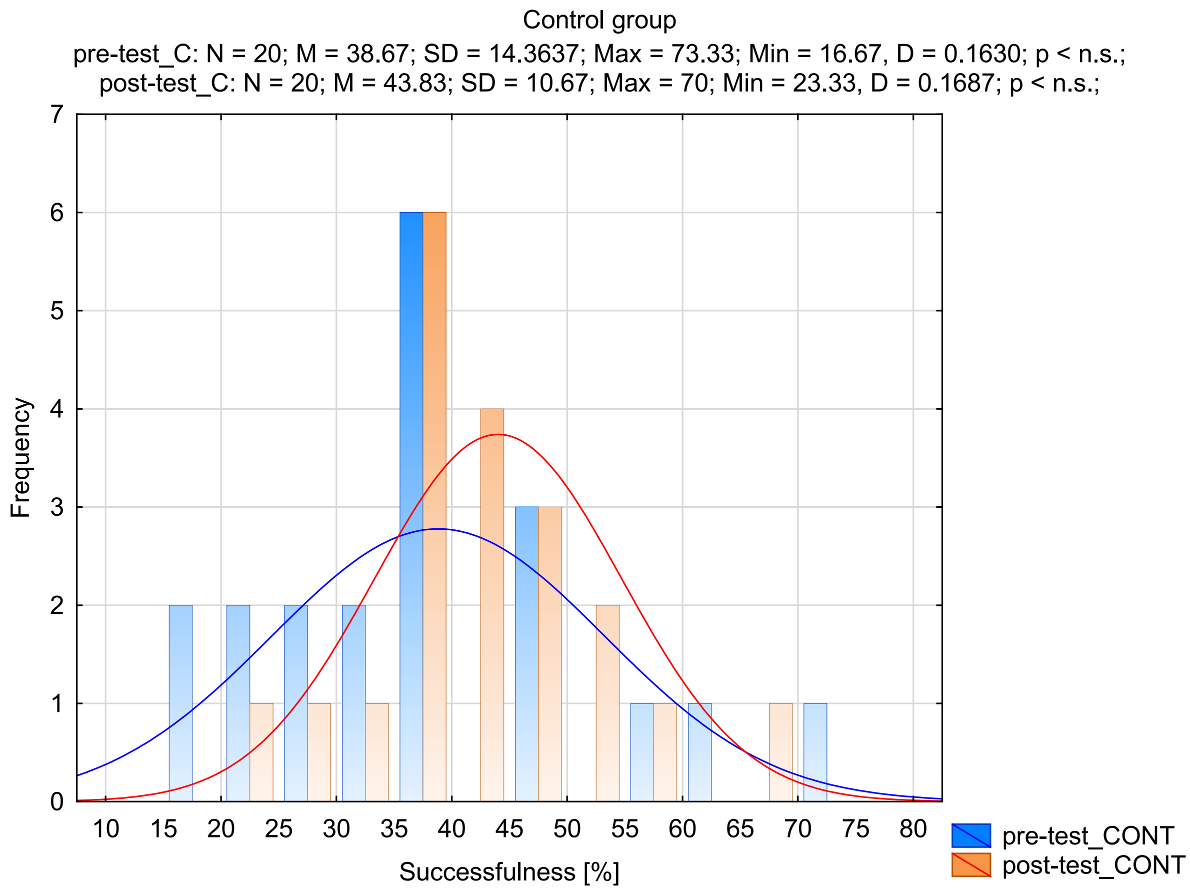

Figure 5. FCI score of pre and post-test for the control group.

Table 4: t-Test: Paired Two Sample for Means – Control group.

	Post-test	Pre-test
Mean	43.83	38.67
Variance	113.77	206.32
Observations	20	20
Pearson Correlation	0.83	
Hypothesized Mean Difference	0	
df	19	
t Stat	2.87	
P(T<=t) one-tail	0.0049	
t Critical one-tail	1.73	
P(T<=t) two-tail	0.0098	
t Critical two-tail	2.09	

The evaluation of pre-test and post-test of the experimental group at the beginning and at the end of semester (Fig. 4, Tab. 3) confirmed statistically significant difference between mean at the beginning and end of semester ($p < 0.001$).

The evaluation of pre-test and post-test score of the control group at the beginning and at the end of semester (Fig. 5, Tab. 4) confirmed statistically significant difference between mean at the beginning and end of semester, too, ($p < 0.005$) but p-value is lower in the case of the experimental group.

Discussion

We used Force Concept Inventory (FCI) test to verify students' knowledge of Physics (Kinematics and Dynamics). FCI test contained 30 qualitative multiple-choice tasks that focused on conceptual understanding of Newtonian mechanics (Hestenes et al., 1992).

As the authors of FCI test claim (Hestenes et al., 1992) it is necessary to point out that 60% of FCI test, for empirical reasons, is minimal threshold so that a student could continue in understanding Newtonian mechanics effectively. Below this threshold, a student's grasp of Newtonian concepts is insufficient for effective problem solving. Otherwise a student is not able to overcome difficulties which caused him/her misconception and thus s/he learns physics by heart. 80 – 85% FCI score represents the mastery level when a student thinks in terms of intentions and Newtonian physics. As the authors state such an outcome does not depend on what teacher, in what country and what kind of school s/he teaches. The results of pre-test (Fig. 2) reveal that only 14% of students in the experimental and 9% in control group reached the level of 60% or higher from FCI score.

In post-test (Fig. 3) the results reveal that 44% of students in the experimental and only 18% in control group reached the level of 60% or higher from FCI score. 16% of students in experimental group reached the mastery level from FCI score in post-test.

We also try to compare the pre-test results of students from other Slovak and foreign universities. Other research results using FCI tests reveal that the input knowledge level of UNIZA students concerning force, mass point kinematics and dynamics is at lower level in comparison with the students from university from Finland (Tampere University of Applied Sciences (TAMK)) (Mean(UNIZA) = 23 %, Mean(TAMK) = 45 % in academic year 2014/15) (Hockicko et al., 2015). There is also statistically significant difference between the average pre-test FCI score of the students in Slovakia and Russia (UNIZA and RSREU) at the beginning of the winter term 2018/2019 (Mean (UNIZA) = 32 %, Mean (RSREU) = 46 %) (Hockicko et al., 2019).

The video analysis and simulations (VAS method) of problem tasks using interactive program Tracker is one of the methods that considerably helps to form conceptual thinking and at the same time eliminating misconceptions, to develop manual skills and intellectual capabilities of students and increase the level of knowledge of students and the results in post-test, too (Hockicko et al. 2014, Hockicko et al. 2016).

If we want to achieve better results with current student quality, it seems to be necessary to use more effective, interactive methods and to focus more on an active and creative, more conceptual approach in order to enhance the students' expertise rapidly in the beginning of their studies. The video-based problems, problem-based learning, project-based learning, inquiry-based teaching methods, internet-supported learning, conceptual question application and other enhance higher order cognitive skills and students do better than those attending a traditional lecture-lab type instruction (Hockicko, 2010, Hockicko et al., 2014, 2015, 2016).

Conclusion

Our results confirmed that the difference in the knowledge level between the experimental and control group was statistically significant, at the significance level of $\alpha = 5\%$ (the experimental group consisted only from those students who actively participated in the lectures from Physics in comparison with the control group – consisted of the students who did not attended lectures).

Watching real physics concept videos and their subsequent video analysis had a positive impact on the growth of knowledge and improving of conception of Newtonian mechanics at the end of the semester in the experimental group. The methods of video-analysis using the program Tracker presented in this contribution make learning physics easier for the students, they can set individual pace for their work and they have fun when analysing videos. We assume that with the help of interactive way of teaching physics it would be possible to eliminate misconceptions of students, decrease of the dropout of the first-year students and also to improve students' level of knowledge in the introductory courses of general physics. A detailed analysis of FCI tests can help us to detect preconceptions and problems in the conception of physics basic principles and the work of this world.

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