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Exploring of students' knowledge using the Concept Inventory Test at Technical University

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Abstract

The Force Concept Inventory (FCI) test has been widely used to investigate students' concept and understanding of introductory mechanics. It can be used to monitor the preconceptions, misconceptions and development of the students' conceptual understanding on mechanics. The purpose of this study is to evaluate the entering engineering students' prior knowledge in key concepts of mechanics in introductory physics using Concept Inventory Test at Technical University.

Our findings have revealed absence of basic knowledge in the field of physics. Due to the fact that the testing revealed that students have problems with reading comprehension, graph interpretation, mathematical relationship, it is necessary for the future to pay attention not only to physics as a subject but also to skills related to maths and to overall engineering studies – to STEM education. Video analysis and simulations (VAS method) of problem tasks using interactive programme Tracker is one of the methods that considerably helps to form conceptual thinking and to develop manual skills and intellectual capabilities of students and finally at the same time eliminates misconceptions. Using videos and other multimedia aids affects in a positive manner the level of the students' knowledge and understanding of physical phenomena.

Keywords: Conceptions, video-analysis, paired student´s t-test, F-test,reliability, validity, VAS method.

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1. Introduction

Modern interactive methods utilizing multimedia DVD teaching tools in education (Kristak, Nemec, Stebila & Danihelova, 2013) or a project-based learning where learners mutually interact with teachers (Chovancova, 2014) increase the effectiveness of the learning process and help with establishing true picture of the real functioning world. Many teachers and researchers deem necessary to start motivating learners to study science already in the pre-primary or primary education (Rochovska, 2012). While it is the acquisition of science literacy fundamentals being aimed in the pre-primary education, pupils should systematically develop this competence in the primary education. In case the science literacy is not developed in this period, students face difficulties in solving science tasks at higher degree schools, perhaps even during university studies.

Research has proved true that students do not have appropriate level of the science literacy. International PISA study presents that the level of science literacy of Slovak pupils at the end of the compulsory study period is below standard (Rochovska, 2012). Therefore it is necessary to start forming physics (natural) apprehension, in a sufficient extent, sooner than during university studies.

It is not a new issue that we mention; physics teachers often face students lacking the ability to understand and interpret physics graphs. It happens quite often when students studying mechanics have significant problems understanding and interpreting kinematic graphs, therefore understanding motion and force concepts. (Beichner 1996, Hake 1998, Halloun & Hestenes, 1985, Hestenes, Wells & Swackhamer, 1992). We should not ignore the fact since many physical phenomena (e.g. velocity and acceleration) are defined as slopes (gradients) of line graphs (Planicic, Milin-Sipus, Katic, Susac & Ivanjek, L 2012). Another issue significantly influencing effectiveness of physics instruction is the spatial visualization ability; as Kozehnikov declares: “it plays a central role in conceptualization processes in physics and in scientific discoveries” (Kozhevnikov,Motes & Hegarty, 2007), so it requires high visual resources.

Experiments and visualization tools play an important role in science education. Interactive and dynamic computer animations, simulations and video analysis, in particular, are one of the effective ways of learning abstract concepts. Computer animations help concretize abstract, complex concepts and phenomena in science education, thus helping students to learn more easily and more effectively. The dynamic quality of animations and videos may promote a deeper encoding of information than that of static pictures. This teaching method may also add depth to their learning. Usually, prepared animations are designed to help students learn abstract phenomena and to construct mental models of these concepts more easily and permanently.

There are many studies that widely apply such computer animations and simulations, Physlets, and other computer-assisted tools in science education. (Akpınar, 2014; Brown & Cox, 2009; Eadkhong, Rajsadorn, Jannual & Danworaphong, 2012; Gröber, Klein & Kuhn, 2014; Malgieri, Onorato, Mascheretti & Ambrosis, 2014; Phommarach, Wattanakasiwich & Johnston 2012; Rodrigues & Carvalho, 2013; Suhonen & Tiili, 2014; Tiili & Suhonen, 2013; Vozdecký, Bartos & Musilova, 2014; Wieman, Adams, Loeblein & Perkins*,* 2010; Zacharia and Constantinou, 2008) As Akpınar (2014) has proved by his study, the use of animation in education increased conceptual understanding by promoting the formation of dynamic mental models of phenomena. Williamson and Abraham (1995) reported in their study that computer animation had a more positive effect on students’ conceptual understanding than traditional instruction. Ardac and Akaygün (2004) informed that the group of students who were instructed to use multimedia and animation received higher scores than the control group Kelly and Jones (2007) showed that animations improved some students’ concepts scientifically; however, some prior misconceptions of the students sustained. And moreover, new misconceptions appeared. Zacharia and Constantinou (2008) used Physlets to investigate the effects of experimenting with physical or virtual manipulatives and found out that both modes of experimentation were equally effective in enhancing students’ conceptual understanding. Chen et al. (2013) explored the effects of predict-observe-explain (POE) method and simulation-based learning strategies on correcting misconceptions and improving learning performance. The study proved improvement in learning performance and abatement of misconceptions.

As Akpınar (2014) declared, when the POE and other technology-enhanced learning environments are used together, learning is facilitated; learning of abstract concepts is enhanced and it results in permanent knowledge, so problem solving tasks can build knowledge of a concept while minimizing the risk of misunderstanding. The studies on Physlet-based learning material, including animations, graphics and videos, simulations, demonstrations and models, indicate that if such materials are properly designed, they help students visualize phenomena therefore they contribute to understanding by augmenting abstract concepts with concrete mental images. Visualization techniques help students see how the phenomena occur, thus facilitating their ability to effectively grasp the fundamentals of the phenomena and learn the concepts more easily (Cadmus, 1990). In addition, it has been demonstrated that humans are able to remember 10 % of what we read, 20% of what we hear, 30% of what we see, but we are able to retain 75 % of the information if we interact with it (practice by doing) (Kristak et al., 2013).

One of the new creative methods of teaching physics which makes natural sciences more interesting for the students is the video analysis using the programme Tracker (Open Source Physics) (Brown & Cox, 2009). It enables students to detect relationships between physical quantities and describes motion using time dependencies. It´s also easily applicable; all we need is a camera (mobile phone, tablet) to prepare motion files - video experiments. This method helps students study certain motion in detail, thus to observe its characteristics and to learn the basics of classical physics by providing students with a simple and easy way to understand the process of movement. This is made possible by integrated ICT tools that use videos (via point-tracking) to measure. Unlike tasks from printed textbooks, video analysis based tasks do not incorporate either all necessary data to solve a problem or a procedure and a way how to find a solution to a task. The role of students in video analysis is to realize necessary physical characteristics, to choose a suitable way to a problem solution and to find a solution to a task from the relations of physical quantities. 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. Many of the video analysis based tasks are suitable also for the Physics lessons at grammar or secondary schools as there is no need to be aware of the integral and differential equations to be successful in solving them. On the other hand, it is also possible to demonstrate secondary school students, by a simple mathematical analysis, the use of integrals and derivatives in physics. The use of video analysis based tasks in physics can significantly affect the differences in the knowledge when students solving traditional tasks from printed textbook.

Our previous research confirmed that the students´ competencies were developed and their knowledge was increased when working with the program Tracker and PhET sims, so the application of VAS method (Video Analysis and Simulations) has significantly influenced the level of students' knowledge. Research findings have shown that the traditional method, regardless of the lecturer, leads only to a limited increase in students' knowledge. We performed various surveys at technical universities confirming that using video analysis and simulations in the educational process results in enhanced knowledge compared to that gained through teaching by traditional methods (Hockicko, Kristak & Nemec, 2015). This research also showed that active learning develops student's communication and cooperation. We observed that the class attendance and the students' participation in the learning process were significantly higher when using active learning methods compared to the traditional teaching-based classes. We found out that students taught with the use of interactive methods liked teamwork more, they enhanced their communication skills, we felt stronger motivation; this led to good better atmosphere in the class (Hockicko, 2012), so in the end to better teacher-student cooperation resulting in better results at both sides.

We have demonstrated that watching video recording process of braking and subsequently performing video analysis using these videos in an appropriate and attractive way forms correct students' conceptions about car braking distances. Using videos and other multimedia aids affected the level of the students' knowledge and their understanding of physical phenomena in a positive way (Hockicko, Trpisova & Ondrus, 2014).

This paper aims to continue with the VAS research on the development of conceptual thinking and elimination of misconceptions. We analyze a test, its validity and students´ answers so that we find possible alternatives on how to help students, during lectures, eliminate wrong apprehension of physics processes. At the same time, we test the experiment group that has utilized video-analysis method and compare it with the control one that has followed standard way in calculation seminars in a way so students´ conceptual understanding was encouraged as much as possible.

2. Purpose of the study

Student's first year of university can be critical and difficult time in their education, many students withdraw from courses or drop out university (Bone& Reid, 2011; Cook & Leckey, 1999). Students need to become more self-reliant and more self-motivated. First-year courses cover a large amount of broad subject areas, which can make them troublesome for students without background knowledge. Students need to develop active and independent learning skills (Bone et al., 2011). Students' perception of teaching quality and generic skills development were found to be most influential in terms of attitude towards study and motivation (Ning & Downing, 2011). Effective studying requires not only that the students possess knowledge of appropriate study skills but also positive attitude towards learning with motivation and self-regulation (Reason et al. 2006).

In previous contributions we have already presented that the students´ conception of the real physical processes is not correct (Hockicko & Rochovska, 2013). This led us to the production of a video set, by means of which we explained physical laws in lectures and realized video analysis in seminars (Hockicko, 2013). We decided to test the effectiveness of the given teaching method using standard statistics methods. We designed a test (see appendix) which covered such questions that grammar school students (secondary school graduates), as well as students applying for the university studies, could answer (questions were taken from the former Monitor tests). The test was given to students both at the beginning and at the end of the semester. First year students of the Faculty of Civil Engineering at the University of Zilina had the possibility to participate in physics lectures in the summer semester and to receive tuition in mechanics (kinematics, dynamics, rigid body, liquids, oscillations), gravitational field, thermics and thermodynamics, while not explicitly discussing answers to the test questions. At the same time students participated in laboratory and calculation seminars; they were divided into two groups in the calculation seminars; the control group (solving equations by a standard method), and the experimental group (solving equations by means of video analysis). The following section provides statistical processing of results.

This study aimed to investigate the effects of using video analysis as a tool to improve student comprehension of physics-related concepts. At the beginning, we had to identify existing misconceptions and to take the pre-test in order to start the experiment. The teaching process in the control groups was performed in the traditional way, i.e. 13 lectures and 13 seminars within a semester. The lectures focused on individual physics topics and were subsequently followed by the seminars aimed at quantitative task solving.

The students of the experimental groups, aged 19–20, also took part in 13 lectures and 13 seminars (the amount of teaching time for both groups was the same); however, the interactive method based on the increased focus on problem solving was used during the seminars. Video analysis and interactive simulations were used as the method (VAS method) to enhance student understanding while explaining the laws of nature.

3. Analysis and test evaluation

The pre-test was carried out at the beginning of the summer semester of 2013 and 2014. 123 and 121 students took part in the test during the introductory seminar; the test took 20-30 minutes. 109 and 100 students took part in the same test, the post-test, at the end of the semester. Students were answering by means of computer, each student solving the same number of questions; however, to avoid cheating, the order of questions as well as the order of multiple choice answers was generated at random. Test results were collected and subsequently stored for further processing. Lecturers were acquainted with the pre-test results the next week, mostly with wrong answers, so afterwards they could adapt their lectures so that they were able to interact with students´ misconceptions.

To statistically evaluate collected data, we used paired Student's t-test (part 3.3), i.e. we considered only those students who took part both in the pre-test and post-test. After having paired the tests, there were 155 student samples left. The number indicates huge student fluctuation during semester as it corresponds only to 64% of students entering the course. It also betokens that many of those taking the course are not seriously interested in its successful completion. On the other hand, our experience shows us that some students re-taking the course become more involved after the first third of the semester.

The same test was conducted among students in the last year of grammar school studies because we expect students entering university education to have knowledge at the level of grammar school students. However, the fact is that many students do not reach the level, mostly due to the fact many of them are not grammar school graduates, i.e. they do not pass physics leaving exam. Moreover, Slovak education system allows schools to adjust number of lessons per week in order to satisfy needs of their students, so the average number of physics lesson during the secondary school studies vary. Thus graduates can enter university education with only 4 lessons a week per whole secondary school studies, while others even with 12. We see this as a key problem why many students face difficulties passing introductory course of physics at universities.

3.1. Test Reliability and validity

In the process of test evaluation, we have determined fundamental characteristics of a didactic test, such as validity, reliability and difficulty level of the given task. Reliability or accuracy of a didactic test is in our case expressed by a coefficient in the scale from 0 to 1, where 0 represents complete unreliability and +1 maximum reliability and accuracy of a didactic test. When constructing the test, we followed the condition for contextual homogeneity of test tasks. On the basis of the above mentioned, we decided to choose Kundera-Richardson formula as a suitable method for calculating reliability coefficient,

$$r_{\mathrm{KR20}} = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} p_i q_i}{s^2}\right) \tag{1}$$

where k expresses number of test tasks, p is a relative number of students who solved the particular task right, q relative number of students who solved the particular task wrong and s expresses the standard deviation for the overall students´ test results.

Test validity states whether particular test questions examine that knowledge that is aimed to be examined. Content validity is used to monitor and check whether didactic test content follows the topics that we aim to examine. To determine test validity, *correlation coefficient r* stating statistically significant dependence of the observed data is often used. Some authors state the minimum correlation coefficient of 0.3. To determine test validity, we have used *biserial correlation coefficient rbk* that is considered to be a suitable tool for determining content validity of particular question of a didactic test (Chraska, 2007).

We calculated the reliability coefficient for the students of the Faculty of Civil Engineering of the University of Zilina (FCE UZ) and for the students of the chosen grammar schools. Test reliability coefficient of the first year undergraduates of FCE UZ has increased from 0.13 to 0.58 from the beginning to the end of the 2012/2013 summer semester, and from 0.43 to 0.67 in the 2013/2014 summer semester. The coefficient for the students of grammar schools was of the 0.76, which is over the recommended value and so we can say that the test designed to evaluate the knowledge level of students is reliable and accurate enough. Recommended minimum value of the coefficient for the test including fewer questions is of 0.6, so we can state that the test taken at the end of semester is reliable and we can consider it appropriate to assess the knowledge level of students.

In order to define quality of a didactic test, we analyzed the difficulty level of test questions. The difficulty level characterizes either the group of students being right in their answers or those being wrong (it is possible to express it also in the form of percentage). The difficulty level index P was calculated on the basis of the relationship: $P = (n_s/n)\cdot 100$; where n_s expresses number of students being right, n expresses the total number of students taking a test. Tasks with index lower than 20 are too difficult and those with index above 80 are too easy. A test should not include either too many difficult or too many easy questions.

As presented (Table 1), some questions indicate extreme values *P*. After deeper research, we have found out these extreme values presented within some questions were caused by the fact that not all of the FCE test groups were delivered the topics in the same extent and that many of the students did not attend lectures regularly.

Table 1. Difficulty index and biserial correlation coefficient of particular test questions

		2012/2013		2013/2014			2012/2013		2013/2014	
Q.	GS	FCE-pre-	FCE-post	FCE- pre	FCE-post	GS	FCE- pre	FCE-post	FCE- pre	FCE-post
	P	P	P	P	P	r_{bk}	r_{bk}	r_{bk}	r_{bk}	r_{bk}
1	66.1	13.8	29.4	24.3	30	0.7	0.3	0.5	0.6	0.4
2	85.5	24.4	49.5	40.9	50	0.4	0.4	0.6	0.7	0.7
3	56.5	30.9	22	18.2	23	0.7	0.4	0.5	0.2	0.5
4	70.9	39	45.9	37.9	39	0.6	0.2	0.3	0.5	0.4
5	45.2	6.5	32.1	26.5	26	0.3	0.4	0.3	0.7	0.3
6	20.9	14.6	36.7	30.3	30	0.6	0.2	0.5	0.3	0.4
7	37.1	25.2	31.2	25.8	38	0.7	0.5	0.4	0.4	0.5
8	50	12.2	29.4	24.3	38	0.8	0.3	0.5	0.5	0.7
9	58.1	11.4	29.4	24.3	26	0.6	0.3	0.3	0.1	-0.1
10	54.8	19.5	44	36.4	44	0.5	0.3	0.6	0.4	0.7
11	29	4.9	31.2	25.8	27	0.6	0.6	0.5	0.8	0.6
12	35.5	5.7	18.3	15.1	21	0.8	0.4	0.6	0.4	0.6
13	24.2	13	28.4	23.5	40	0.2	0.4	0.5	0.1	0.5
14	75.8	43.9	68.8	56.9	84	0.3	0.3	0.3	0.3	0.3
15	59.7	25.2	13.8	11.4	18	0.6	0.2	0.4	0.4	0.4
16	27.4	17.9	38.5	31.8	37	0.2	0.2	0.5	0.5	0.4
17	22.6	4.1	7.3	6	17	0.8	0.2	0.6	0.5	0.7
18	24.2	4.9	6.4	5.3	17	0.6	0.6	0.03	0.3	0.5
19	74.2	6.5	21.1	17.4	20	0.5	0.4	0.5	0.7	0.6
20	30.6	17.9	26.6	21.9	40	0.5	0.4	0.3	0.4	0.5

In case the test shall be used again, it is necessary to consider some tasks should be left or modified and that the task order should follow the "easy-medium-hard" scheme in order to improve conditions for weaker students enfeebled by time limit.

3.2. Relationship between students´ success in a particular task and the overall test results

The content validity of post-test tasks ranged to maximum value of 0.6 which represents middle value of correlation coefficient. The task reaching 0.62 correlation coefficient can be said to have middle content validity and therefore it can averagely distinguish students according to their knowledge. The minimum correlation coefficient is of value ±0.1; one question (no. 18) was of value 0.03 which signals its really low content validity. We can conclude that this task is not suitable to assess students´ knowledge of the given topic. We suppose that the students took a guess in answering the question. The maximum coefficient for the pre-test was of 0.61, more tasks reached value around 0.2.

The difficulty index (*P*) values in bold indicate very difficult questions; however, such phenomenon occurs only with the FCE students! The fact that the task is difficult was not proved true with the students of grammar schools, so the tasks are suitable to assess the knowledge at the level of grammar schools. When talking about the FCE students, low post-test values were caused by the fact that some of the topics relating to some tasks were not presented in the lectures or practiced in the seminars in a sufficient extent. All other questions achieved the difficulty index in the 10-90 interval, so we consider the test to be reliable.

Question no. 13 proved lower content validity with grammar school students when compared with the FCE students (2012/2013); this fact indicates that the task is not suitable for the grammar school students. This finding was also proved by discussions with grammar school teachers who claimed that the topic being tested in the question was not lectured in the lessons.

3.3. Analysis of students' conceptions

The multiple choice answers of the test questions are in such order, that A option is right, see the appendix.

Although there has been an increase in the knowledge of the FCE students (question 1: from 17% to 30% of correct answers), there is still a very high percentage of students who have erroneous conceptions of accelerated motion. The answers to the question no. 1 and 2 have given as the impression that students simply do not accept different relationship for the velocity definition than the one for the uniform motion that they acquired in the secondary school studies, although it is clear from the task assignment that they shall have the accelerated motion in mind.

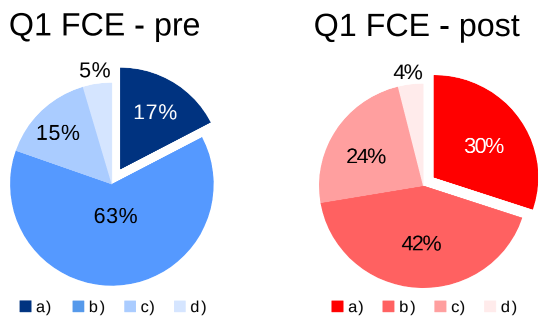

Figure 1: Overall response rate - Question 1

The answers to the question no. 2,3 (*Figures 2,3*), 15, and 19 (*Figure 11*) indicate very important fact, namely that students have problems understanding graphical dependences of physical phenomena. Simply said, they cannot read from graphs. The overall test response rate for the question no. 15 is almost the same for all the choices, so it can be assumed that students just guessed the right answer.

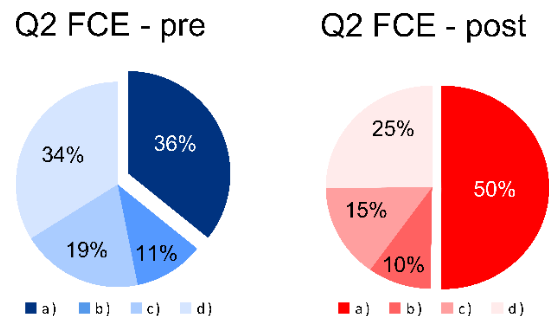

Figure 2: Overall response rate – Question 2

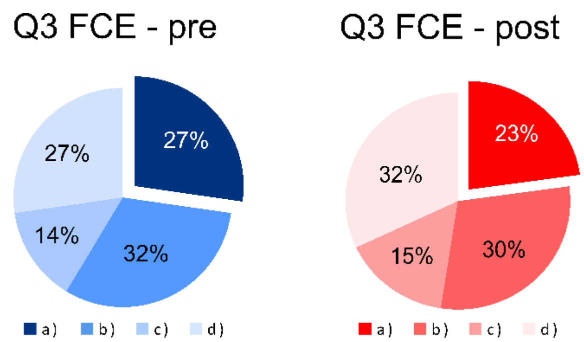

Figure 3: Overall response rate – Question 3

Question no. 6 is not suitable for the grammar school students because it tests the knowledge of a topic not being lectured (information by grammar school teachers). However, although the FCE students did have lectures followed by practice seminar on the moment of inertia, only 34% of them were right in their answers.

Figure 4 shows that the grammar school students are much more oriented in the issue of friction than the university students. We find the fact that there has been only little increase (from 19% to 34%) in the knowledge very bad; the response rate in the post test reveals 66% of wrong answers. Although the FCE students passed the basic Physics course, their conceptions of the relating facts are erroneous. When analyzing, we shall also point to the answer option d, with overall response rate in the pre-test of slightly more than 50% and only slightly less than 50% in the post-test.

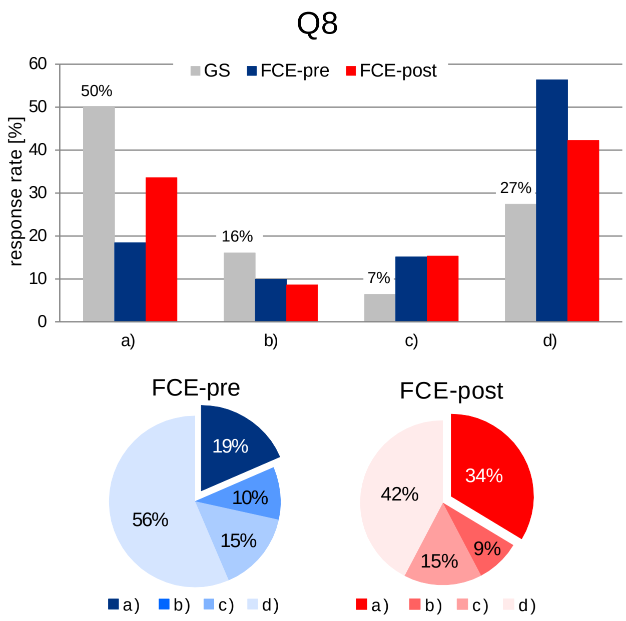

Figure 4. Overall response rate – Question 8

The analysis of question 9 indicates that the university students do not have satisfactory knowledge in the field of the rotary motion and they cannot apply right-hand rule to determine the bearing of the moment of inertia. As seen in *Figures 5* and *6*, it is obvious from the tests that the grammar school students as well as the university students do not have satisfactory knowledge in the field of fluid dynamics. There has been overall improvement at the end of semester; however, 70% (Q.11) and 80% (Q.12) of all answers were wrong, which proves the students still have inappropriate conceptions. Although most students stated in question 11 that the speed of fluid will decrease in case of pipe flaring-out, however most of them could not apply continuity equation in a right way. Similar situation occurred in question 12 where the results show that more than two thirds of students cannot apply Bernoulli equation (even at the end of semester and in the final exam).

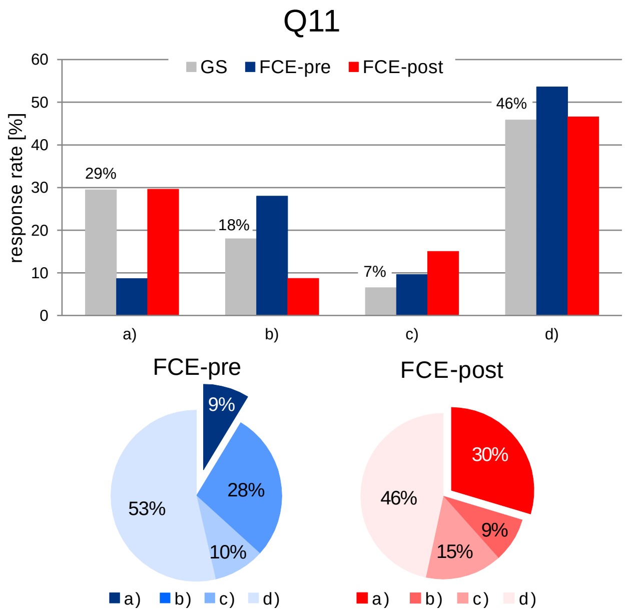

Figure 5. Overall response rate – Question 11

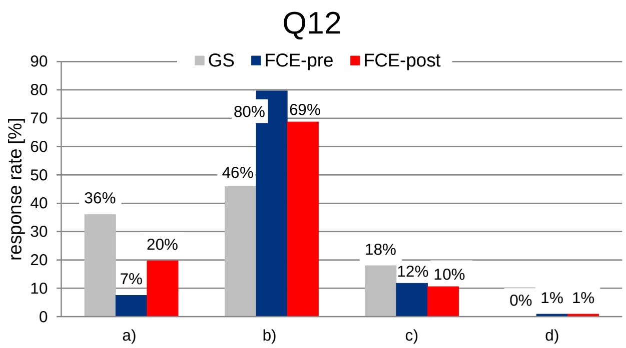

Figure 6. Overall response rate – Question 12

Really shocking test results were revealed in question 13. Due to the fact the task is practically oriented to civil engineering; it is difficult to understand why 65% of FCE students answered right in the pre-test, but only 50% in the post-test.

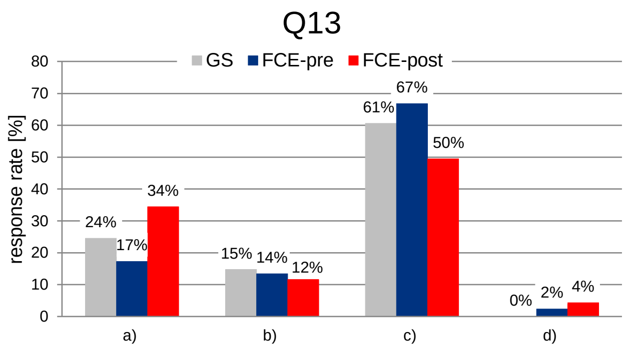

Figure 7. Overall response rate – Question 13

Test results of the question 16 proved that grammar schools students as well as university students do not have appropriate conceptions of the actions in gasses *(Figure8*); the analysis of question no. 15 has proved our assumption that students cannot read dependences of physical phenomena from graphs. They also have erroneous conceptions of the oscillatory motion (*Figures 9* and *10*); notice the high percentage of FCE students who opted answers b and c both at the beginning and end of semester. The analysis of question 19 (Figure 11) shows that the grammar school students have better knowledge in the field of oscillation than the university students both in the pre-test and post-test. Therefore it is necessary to place greater emphasis on the understanding of basic physical phenomena such a s frequency and cycle.

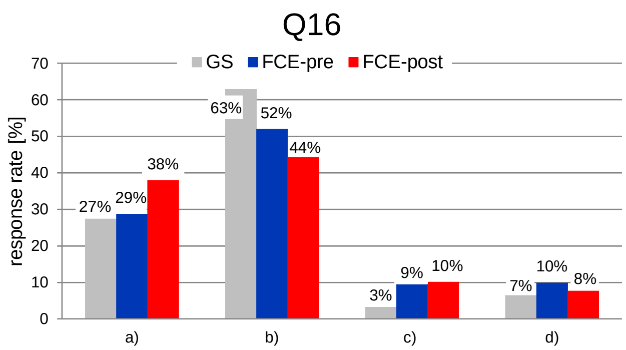

Figure 8. Overall response rate – Question 16

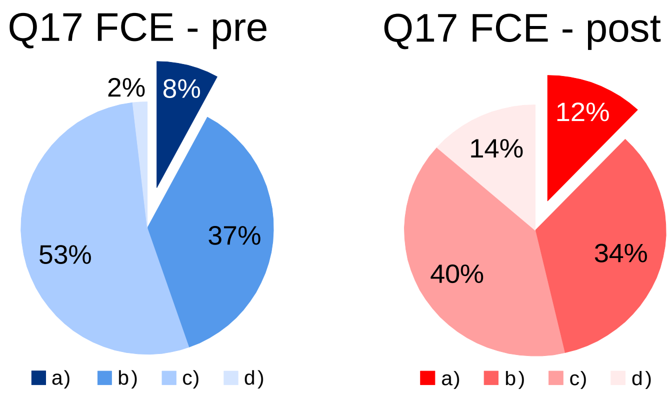

Figure 9. Overall response rate – Question 17

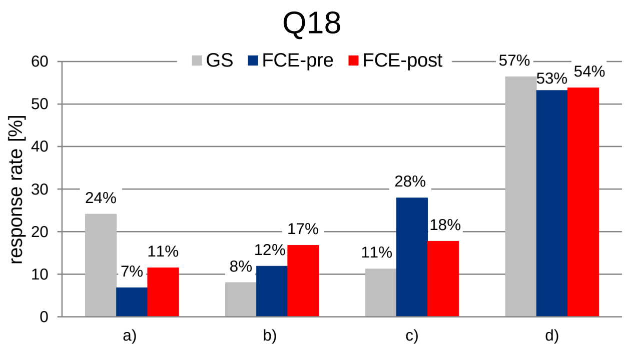

Figure 10. Overall response rate – Question 18

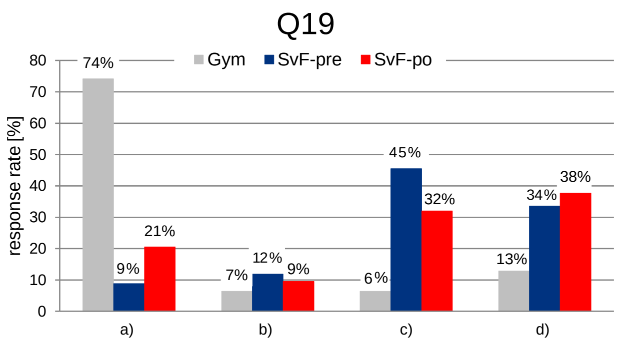

Figure 11. Overall response rate – Question 19

After closer analysis of answers on the question 20, we have found out that incorrect answers were not most likely caused by ignorance of the term „spring stiffness“ but by incorrect unit conversion. Unfortunately this is not surprising, since we know from experience that freshman students do not attach importance to physical phenomenon units.

3.4. The use of video-analysis to enhance students' conceptual understanding

The initial question was whether students would achieve increase in knowledge at the end of the semester and whether this increase would be statistically significant. We stated the null hypothesis:

H_0: average test percentage at the beginning and at the end is the same so H_0: $\mu_1 = \mu_2$ (versus H_1: $\mu_1 \neq \mu_2$); while the difference in means $\mu_1 - \mu_2$ of two normal distributions, where $N(\mu_1, \sigma_1^2)$ and $N(\mu_2, \sigma_2^2)$, is considered equal 0 for both examined groups.

To verify the stated hypothesis, we used the test for a difference in arithmetic mean (two-sample paired t-test for the mean value for each group and two-sample t-test to compare control and experimental group); we tested at a significance level of α = 5% and we suggested that the difference in arithmetic means $\mu_1 - \mu_2$ of two normal distributions $N(\mu_1, \sigma_1^2)$ and $N(\mu_2, \sigma_2^2)$ will fall into $100\cdot(1-\alpha)$ % of two-sided confidence interval. At the beginning of testing we were detecting the concordance between the tested sample and the theoretical distribution, assuming the normal (Gaussian) distribution using the one-sample nonparametric Kolmogorov–Smirnov test (K–S test). The concordance proved the normality of the distribution (calculated data were lower than the critical values for K-S test of the normality at a significance level of α = 5% specified by the program Statistica, where $D < D_{max,\alpha}$).

As shown in *Table 2*, the average student test percentage in the given test was around 33% at the end of the semester (post-test), while being 23% percentage at the beginning of the semester.

Table 2. Paired t-test for the mean value (all students).

	Post-test	Pre-test
Mean	33.03	22.81
Variance	235.23	100.68
Observations	155	155
Pearson Correlation	0.33	
df	154	
t Stat	8.31	
P(T<=t) one-tail	2.36E-14	
t Critical one-tail	1.65	
P(T<=t) two-tail	4.72E-14	
t Critical two-tail	1.98	

Since calculated parameter $|t| > t_{critical(two\text{-}tail)}$ for the two-sided confidence interval, the hypothesis H_0: $\mu_1 = \mu_2$ was rejected and the alternative hypothesis H_1: $\mu_1 \neq \mu_2$ was accepted. Based on these, we stated new hypothesis: H_0: $\mu_1 > \mu_2$ (for $100\cdot(1-\alpha)$ % left-sided confidence interval for the difference $\mu_1 - \mu_2$). Since $t \in \langle t_{critical(one\text{-}tail)}, \infty)$, the hypothesis H_0: $\mu_1 > \mu_2$ has been accepted. Statistical testing by means of paired Student's t-test has confirmed statistically significant difference in the knowledge at the end and at the beginning of the semester. The next phase of testing focused on the individual groups: the experimental and control ones; we have observed an increase in the knowledge of the individual groups (*Table 3* and *4*). We have also proved statistically significant difference in the knowledge at the end and at the beginning of the semester. The tables below, acquired by Excel spreadsheet, show the final statistical values:

Table 3. Paired t-test for the mean value – experimental group

	Post-test	Pre-test
Mean	38.29	23.68
Variance	267.94	111.74
Observations	38	38
Pearson Correlation	0.21	
df	37	
t Stat	5.12	
P(T<=t) one-tail	4.79E-06	
t Critical one-tail	1.69	
P(T<=t) two-tail	9.58E-06	
t Critical two-tail	2.03	

Table 4. Paired t-test for the mean value – control group

	Post-test	Pre-test
Mean	31.32	22.52
Variance	214.82	97.68
Observations	117	117
Pearson Correlation	0.37	
df	116	
t Stat	6.65	
P(T<=t) one-tail	5.03E-10	
t Critical one-tail	1.66	
P(T<=t) two-tail	1.01E-09	
t Critical two-tail	1.98	

Correctness of the decision on the acceptance of the alternative hypothesis of inequality of mean values is also proved by the p-value (P(T<=t)) which is significantly lower than the opted significance level of $\alpha = 0.05$ ($P < 0.001$). We focused our attention also on the statistically significant difference in the knowledge of the experimental and the control group at the end of the semester. Before we started testing of the null hypothesis H_0: $\mu_1 = \mu_2$. It was necessary to apply the F-test (Fisher-Snedecor test) for the equality of two normally distributed populations (H_0: $\sigma_1^2 = \sigma_2^2$ versus H_1: $\sigma_1^2 \neq \sigma_2^2$). After specifying the equality (or inequality) of the variances, to test the hypothesis H_0: $\mu_1 = \mu_2$ we used two-sample Student´s t-test for the unequal sample sizes but with equal (eventually unequal) variance. Since calculated parameter F verifies the condition $F_{critical1-\alpha/2} < F < F_{critical\alpha/2}$ (for two-sided interval F in the range of 0.567 - 1.638), the assumed hypothesis of the equality of variances for the experimental and the control group at the beginning of the semester H_0: $\sigma_1^2 = \sigma_2^2$ has been accepted (Table 5).

Table 5. Two-sample F-test for variances: pre-test

	Experimental group	Control group
Mean	23.68421	22.52137
Variance	111.7354	97.68273
Observations	38	117
df	37	116
F	1.143861	
P(F<=f) one-tail	0.290043	
F Critical one-tail	1.513534	

Thereafter, we used two-sample Student´s t-test the unequal sample sizes but with equal variance to test the hypothesis H_0: $\mu_1 = \mu_2$. It has confirmed the hypothesis on the equality of the entry knowledge level of both the experimental and the control group ($|t| < t_{critical(two-tail)}$) (*Table 6, Figure 12*).

Table 6. Two-sample t-test assuming equal variances: pre-test

	Experimental group	Control group
Mean	23.68	22.52
Variance	111.74	97.68
Observations	38	117
Pearson Correlation	101.08	
df	153	
t Stat	0.619448	
P(T<=t) one-tail	0.268271	
t Critical one-tail	1.654874	
P(T<=t) two-tail	0.536542	
t Critical two-tail	1.97559	

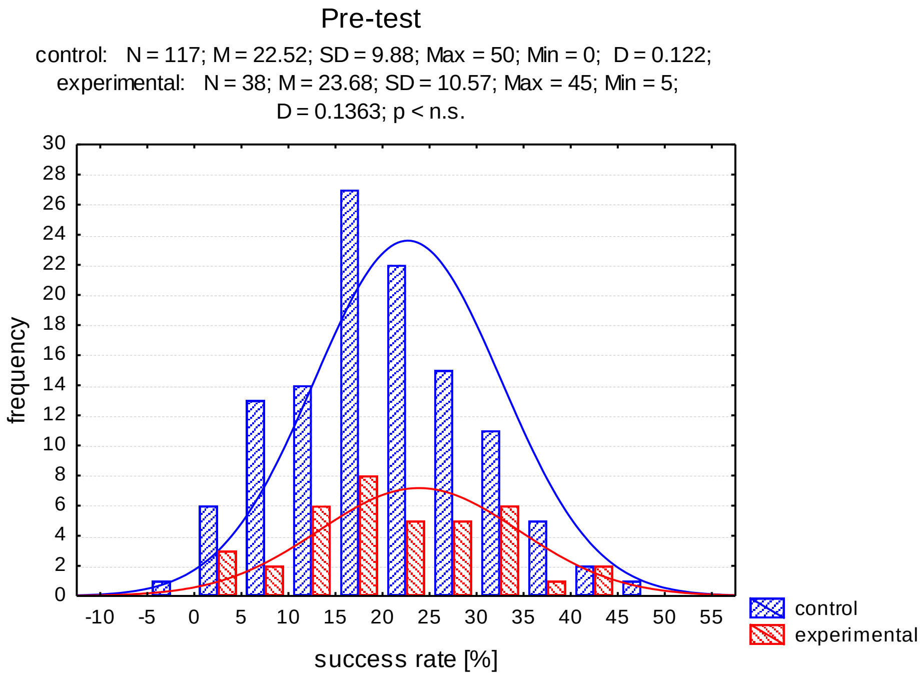

Figure 12. Result analysis of the experimental and the control group: pre-test

Similar analysis as above was done at the end of the semester. F-test has confirmed the equality of two normally distributed populations at the end of the semester. (*Table 7*) (H_0: $\sigma_1^2 = \sigma_2^2$).

Table 7. Two-sample F-test for variances: post-test

	Experimental group	Control group
Mean	38.28947	31.32479
Variance	267.941	214.8246
Observations	38	117
df	37	116
F	1.247254	
P(F<=f) one-tail	0.187889	
F Critical one-tail	1.513534	

Next we used two-sample Student's t-test for the unequal sample sizes but with equal variance to test the hypothesis H_0: $\mu_1 = \mu_2$. Based on the results ($|t| > t_{critical(two\text{-}tail)}$) we reject the null hypothesis on the equality of entry knowledge level at each significance level higher than 1,4 %.

Therefore we rejected the hypothesis H_0: $\mu_1 = \mu_2$ and stated the alternative hypothesis H_0: $\mu_1 \neq \mu_2$ for 100·(1-α) % left-sided confidence interval for the difference $\mu_1 - \mu_2$. Since $t \in \langle t_{critical(one\text{-}tail)}, \infty)$, the hypothesis H_0: $\mu_1 > \mu_2$ has been accepted. Statistical testing by means of Student's t-test has confirmed statistically significant difference in the knowledge of the experimental and the control group at the end of tuition. (*Table 8, Figure 13*).

Table 8. Two-sample t-test assuming equal variances: post-test

	Experimental group	Control group
Mean	38.29	31.32
Variance	267.94	214.82
Observations	38	117
Pearson Correlation	227.67	
df	153	
t Stat	2.47211	
P(T<=t) one-tail	0.007264	
t Critical one-tail	1.654874	
P(T<=t) two-tail	0.014527	
t Critical two-tail	1.97559	

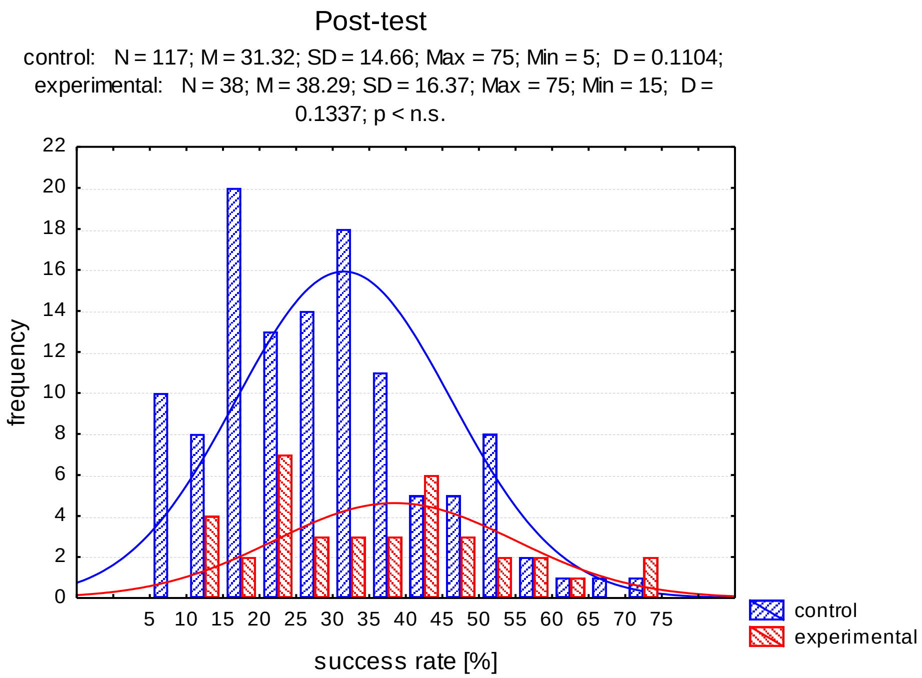

Figure 13. Result analysis of the experimental and the control group: post-test

Thanks to grammar school teachers, we could also use the same test with the grammar school students; results are shown in *Figure 14*. The overall success rate was 46%, higher than the success rate of the experimental group represented by the university students. On the other hand, it is necessary to point out to the largest group represented with the success rate interval from 15 to 20%. Noticing that the entry knowledge of both the control and experimental groups was of 22%, we can assume that grammar school students enrolling for studies at technical universities are the ones, with the weakest knowledge of Physics. We suggest we shall prove this hypothesis within bigger test sample (in the future). However, it is obvious that many of the students studying at technical universities did not have adequate extent of Physics at secondary schools; Physics is often taught for only one or two years within 4-year secondary school study period.

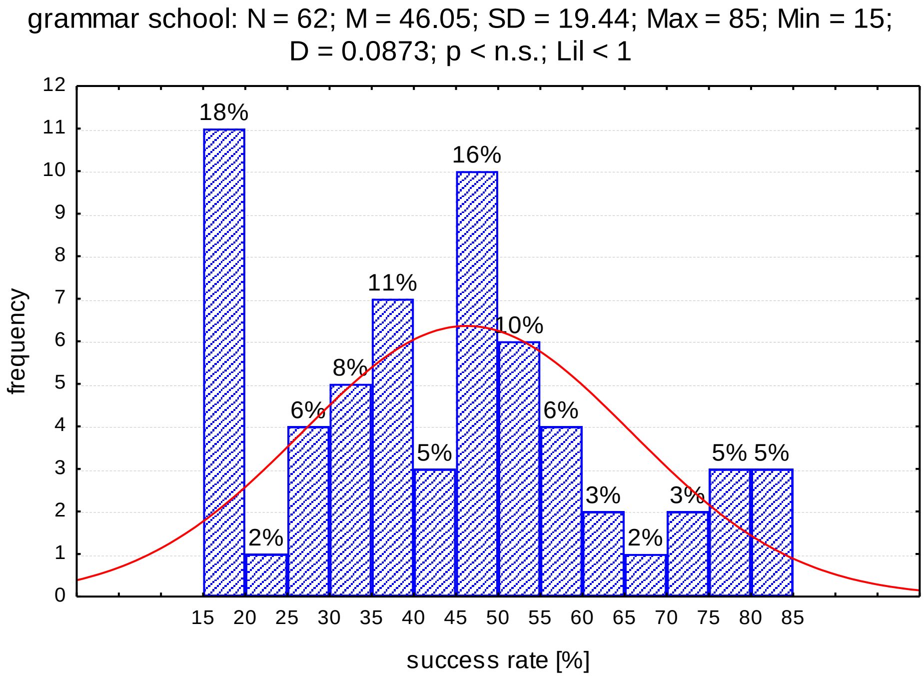

Figure. 14 Pre-test: grammar school students

4. Discussion

The pre-test results revealed no significant difference between the experimental and control group. After application of VAS method, the experimental group achieved significantly better scores than the group educated under tradition approach.

The testing itself also confirmed that if we want to achieve better results with current student quality, it is necessary to start using new, interactive methods and to focus more on active and creative approach. Our findings also support many other authors Annetta et al. 2013; Bekele 2010; Francis & Shannon, 2013; Gavin 2011; Gröber et al. 2014; Hake, 1998b; Hestenes et al., 1992; Kristak et al., 2013; Macho-Stadler & Elejalde-García, 2013; Madhuri,Kantamreddi & Prakash Goteti, 2012; Mazur, 1997; Oliveira & Oliveira, 2013) who have already dealt with the issue; they all have proven that problem-based learning, project-based learning, Internet-supported learning, video-based problems, P&E method, conceptual question application, Interactive engagement methods, model-based introductory physics curriculum, and other inquiry-based teaching methods enhance higher order cognitive skills and that students do better than those attending traditional lecture-lab type instruction.

Due to the fact that the testing revealed that students have problems with reading comprehension, graph interpretation, unit conversion and mathematical relationship, it is necessary for the future to pay attention not only to physics as a subject but also to skills related to maths and to overall engineering studies – to STEM education.

Our research has also pointed to the fact that students do have difficulties understanding conceptions. Knowledge of relationships between conceptions, physical principles and real world is often very weak. The graph analysis has shown that students often do not differentiate speed and acceleration; they associate motion with force application; force is often associated with speed and not with speed change; higher body mass and faster moving object are associated with acting force;

free fall of heavier objects shall be, up to students, faster; and that the lower speed of free falling objects depends on their lower mass. Students cannot define oscillation period in case of the oscillatory movements of a spring, the confuse oscillation period with frequency. There is a considerable absence in the knowledge of gasses and the actions running in them, dependence among pressure, temperature and gas volume. Most of grammar school students as well as FCE students do have misconceptions about properties and applicable laws of a fluid flow, not only at the beginning of semester; were these misconceptions not even eliminated after lectures on the topic. They also cannot apply continuity equation or to use Bernoulli equation in practice. Detailed analysis and observation of students have also revealed that a certain percentage of students cannot properly use a calculator when calculating particular values, which may also have influence on the test results and so we have to mention the absence of this skill.

To change students´ conceptions, a teacher´s lecture as well as quantitative issue solving is often not enough; it is necessary to involve students in activities themselves by quantitative issue solving and to constantly repeat and connect physical formalism with real world. VAS method of problem tasks using interactive programme 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 (Hockicko et al., 2015), which was also proved by the testing we conducted.

5. Limitation of this study

The main drawbacks of this study and therefore its limited parameters come from the fact that the research was conducted only at one Slovak technical university, i.e. one faculty; in the future we would like to confirm these results by means of Force Concept Inventory (FCI) tests (Halloun *et al*. 1985, Hestenes et al., 1992, Martín-Blas *et al*. 2010). The authors plan to conduct the research in the future again, this time at different Slovak technical universities, the ones with more physics lessons in curriculum and mixed-ability students with different entry knowledge coming from different types of secondary schools (electrical engineering, mechanical engineering, other grammar school, etc.), with the aim to ask more universities for the cooperation.

6. Conclusion

Testing we realized has shown the following:

- There has been an increase in the knowledge both in the experimental and in the control group.
- Increase in the knowledge in the experimental group, the one solving equations by means of video analysis, was higher than in the control group.
- The difference in the knowledge level between the experimental and control group was statistically significant, at the significance level of $\alpha = 5\%$.
- Success rate of grammar school students was higher than the one achieved at the end of semester by FCE students
- Reliability coefficient was of values in the interval 0.58-0.75, so the test can be regarded as reliable.
- Further task analysis shown that although there is an increase in the number of correct answers at the end of semester, a very big group of students whose conceptions of the physical actions is erroneous still remains in existence; their misconceptions remain.
- The use of video-analysis and action simulation in the lectures is one of the options that may improve visualization and help create right physical conceptions of the action around us.

Acknowledgement

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APPENDIX (pre and post-test)

(1) A stone is falling in a free fall into the 45 m deep chasm. How long does it take to the stone to hit the ground? Neglect air resistance. (The velocity of the stone at the moment of hitting the ground is 30m/s)

(A) 3 s **(B)** 1.5 s **(C)** 4.5 s **(D)** 9 s

(2) The shown graph (Figure 15) represents the movement of a train before entering the station. What was the acceleration of the train during braking?

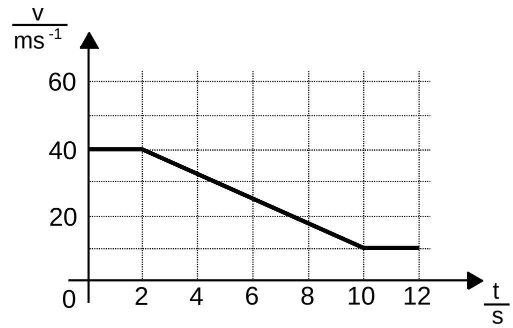


Figure 15

(A) 30/8 m.s^{-2} **(B)** 30/12 m.s^{-2} **(C)** 30/10 m.s^{-2} **(D)** 40/12 m.s^{-2}

(3) What distance did the train travel during braking? (see the previous graph)

(A) 200 m **(B)** 300 m **(C)** 400 m **(D)** 320 m

(4) A goalkeeper caught a ball of 0.5kg which was flying at the speed of 18 m/s. What average force did he exert on the ball if he stopped it in 0.06 s?

(A) 150 N **(B)** 36 N **(C)** 300 N **(D)** 600 N

(5) Which of the following is the unit of the moment of inertia?

(A) N.m **(B)** kg.m^2 **(C)** J **(D)** m.s^{-2}

(6) The rotary motion equation is expressed by the relationship:

(A) M = J.ε **(B)** F = m.a **(C)** L = J.ω **(D)** M = F.r

(7) A car is being on the way from point P to point Q (Figure 16), moving at a constant speed *v*. There are two bends on the road lying in the circles of the radii $r_B = 2.r_A$. For the angular velocities of ω_A and ω_B is valid that:

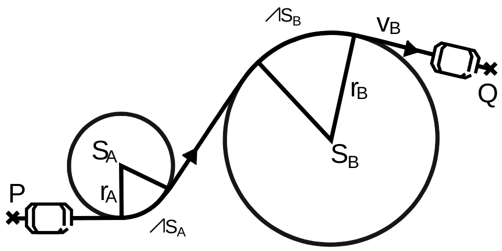


Figure 16

(A) $\omega_B = 0.5 . \omega_A$ **(B)** $\omega_B = 0.25 . \omega_A$
(C) $\omega_B = 2 . \omega_A$ **(D)** $\omega_B = 4 . \omega_A$

(8) What does not determine the amount of the frictional force?

(A) the size of the contact area, **(B)** a body´s mass, **(C)** the material of bodies being in contact
(D) the gravity of Earth

(9) We are facing the analogue clock in the direction perpendicular to its clock-face. What bearing does the moment vector causing the movement of the minute hand have?

(A) It is perpendicular to the clock-face´s plane and is heading away from us.
(B) It is perpendicular to the clock-face´s plane and is heading towards us.
(C) It lies in the clock-face´s plane and is perpendicular to the hand.
(D) It has the same bearing as the clock hand.

(10) A spherical buoy of a weigh *m* is lying stand-still on a liquid's surface with a density ρ. *V* is the volume of the whole buoy and *V*1 is the volume of the part of the buoy being immersed. Which of the following statements is true for the buoy?

(A) $V1\, \rho\, g = mg$ **(B)** $V\rho g < mg$ **(C)** $V1\rho\, g < mg$ **(D)** $(V + V1)\rho\, g < mg$

(11) Water is running through pipes of the radius *d* into a wider part of the radius 4*d.* What speed does the water running through the wider part have?

(A) *v/16* **(B)** *4v* **(C)** *16v* **(D)** *v/4*

(12) What happens to pressure in the closed pipe with a flowing liquid at the section where the pipe gets constricted?

(A) it decreases **(B)** it increases **(C)** it remains unchanged **(D)** it is still of a zero level

(13) For the coefficients of the thermal linear expansion of iron and concrete applies that:

(A)they are comparable **(B)** iron has a considerably lower coefficient **(C)** iron has a considerable higher coefficient **(D)** the coefficients are the same

(14) Air bubbles rising from the lake bottom to its surface:

(A) are getting bigger **(B)** are getting smaller **(C)** do not change their volume **(D)** do not change the lift force acting on them

(15) What work has an ideal gas done during a cycle shown in the Figure 17?

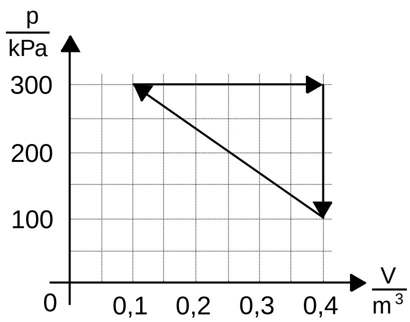
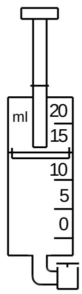


Figure 17

(A) 30 kJ **(B)** 60 kJ **(C)** 90 kJ **(D)** 120 kJ

(16) A valve a syringe is attached to is closed and the pressure under the piston is of value *p.* If we move the piston into the 5ml position (Figure 18), the value of pressure under the piston will be about:



(A) 3*p* **(B)** 2*p* **(C)** *p/2* **(D)** *p/3*

Figure 18

(17) The frequency of a mechanical oscillator is 81 Hz. What will its frequency be if its weight reduces 9 times?

(A) 243Hz **(B)** 729Hz **(C)** 9Hz **(D)** 27Hz

(18) A weight on the coil spring oscillates on Earth's surface at the frequency of 10 Hz. How would the frequency of oscillations change if we placed the system on Moon´s surface?

(A) it would not change **(B)** it would increase
(C) the weight would not oscillate at all **(D)** it would decrease

(19) There is a continuance of instantaneous oscillations deviation depending on the time shown in the figure 19 . How high is the frequency of the given oscillation?

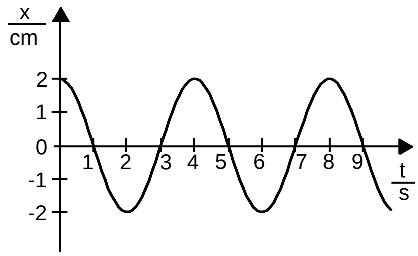
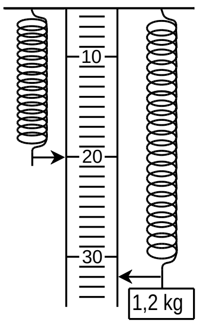


Figure 19

(A) 0.25 Hz **(B)** 0.5 Hz **(C)** 2 Hz **(D)** 4 Hz

(20) A weight of 1.2kg is hung on a spring lying next to the cm degree scale (see the figure 20). What is the approximate stiffness of the spring?



(A) 100 $N.m^{-1}$ **(B)** 10 $N.m^{-1}$ **(C)** 1 $N.m^{-1}$ **(D)** 1000 $N.m^{-1}$

Figure 20

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