Early Identification of Problems in Physics Learning and Suggestion of Intervention Tools for the Freshman Students in STEM Education

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INTRODUCTION

Many researches have 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 (Rochovská, 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 that students studying mechanics have significant problems understanding and interpreting kinematic graphs, therefore understanding motion and force concepts. (Beichner 1996, Hake 1998, Halloun et al.1985). We should not ignore the fact since many physical phenomena (e.g. velocity and acceleration) are defined as slopes (gradients) of line graphs (Planicic et al. 2012). Another issue significantly influencing effectiveness of physics instruction is the spatial visualization ability; as Kozehnikov

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declares: “it plays a central role in conceptualization processes in physics and in scientific discoveries” (Kozhevnikov et al. 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 concretise 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 (Wieman et al. 2010; Brown and Cox, (2009), Tiili and Suhonen (2013), Gröber et al (2014), Suhonen and Tiili (2014) and others). 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 et al. 2014).

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 et al. 2014). 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.

This paper aims to continue with the VAS research on the development of conceptual thinking and elimination of misconceptions. We analyse a 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 experimental 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.

1 PURPOSE OF THE STUDY

In previous contributions we have already presented that the students´ conception of the real physical processes is not correct (Hockicko, Rochovská, 2013). This led us to the production of a video set, by means of which we explained physical laws in lectures and realised 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 (http://hockicko.uniza.sk/pre-post-test.pdf) 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 (FCE) at the University of Žilina 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. Number of students in experimental group was limited by possibilities for using the computer room.

2 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, 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. 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.

3 ANALYSIS OF STUDENTS' CONCEPTIONS

Because of limitation of this paper, we'll analyse only chosen questions:

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

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

2) The shown graph (Fig. 1) represents the movement of a train before entering the station. What was the velocity of the train during braking?

   (A) 30/8 m.s^{-2} (B) 30/12 m.s^{-2}

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

3) What distance did the train travel during braking? (see the Fig. 1)

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

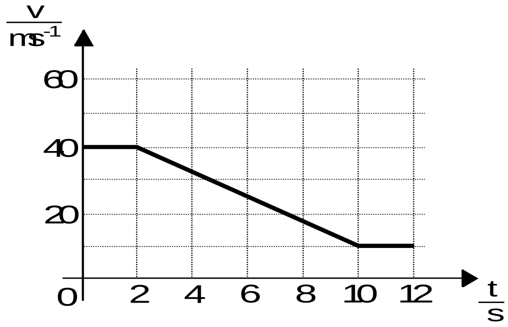

Fig. 1. Graph for questions 2 and 3

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

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.

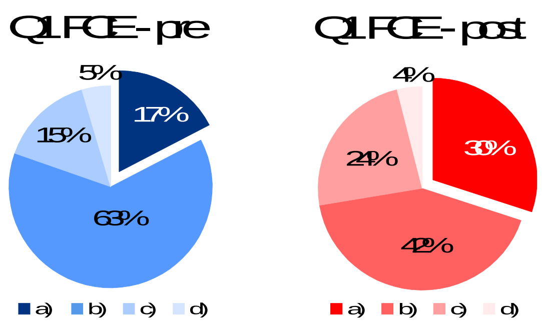

Fig. 2. Overall response rate - Question 1

The answers to the question no. 2, 3 (Figure 3a), b)), indicate very important fact, namely that students have problems understanding graphical dependences of physical phenomena. Simply said, they cannot read from graphs.

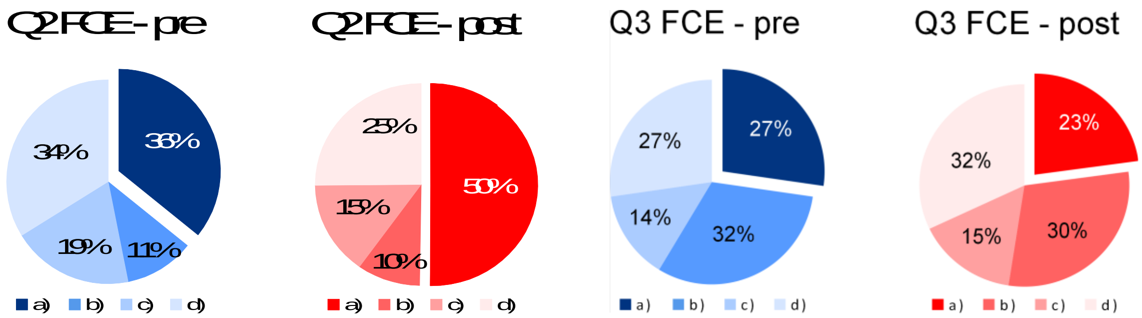

Fig. 3. Overall response rate - Question 2 (a) and Question 3 (b)

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 analysing, 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.

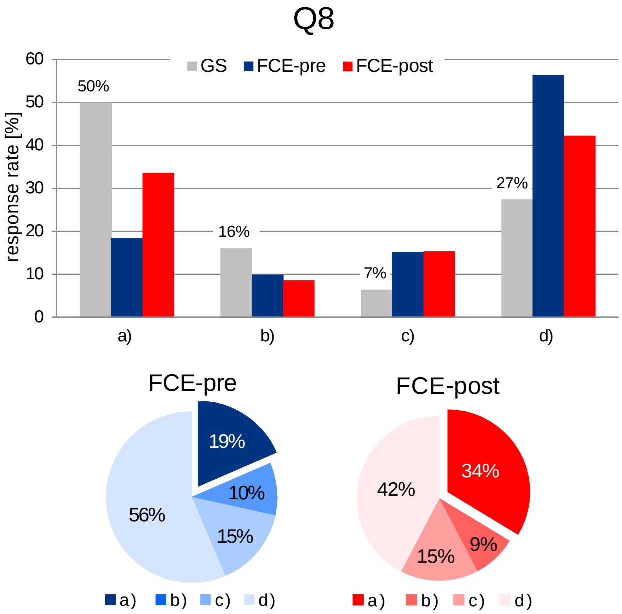

Fig. 4. Overall response rate – Question 8

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:

H0: average test percentage at the beginning and at the end is the same so H0: $\mu_1 = \mu_2$ (versus H1: $\mu_1 \neq \mu_2$); 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 $\alpha = 5\%$

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 $D < D_{max,\alpha}$).

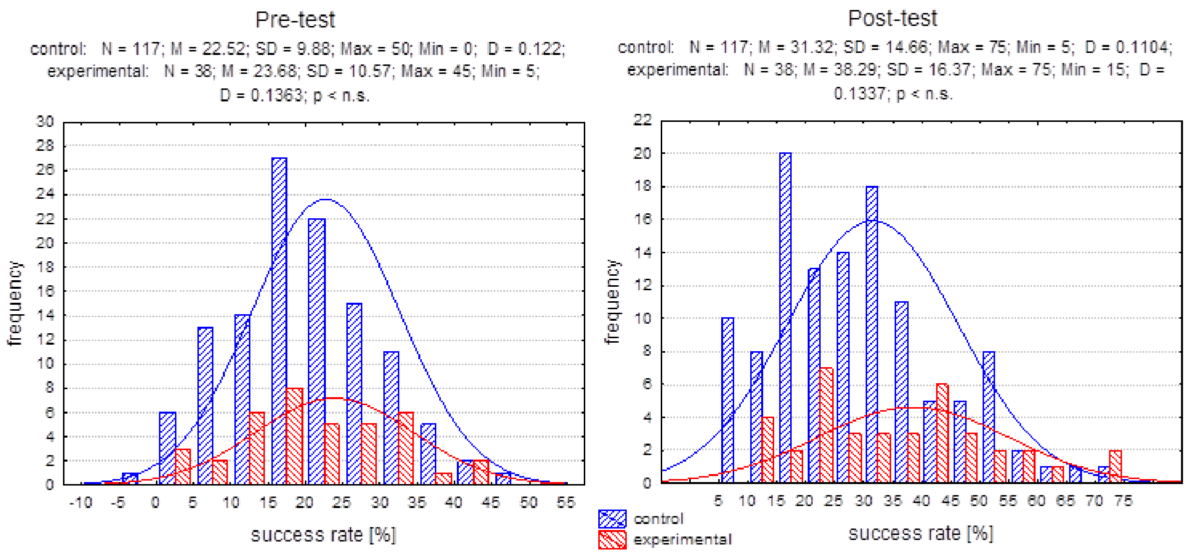

Fig. 5. Pre-test and Post-test for control and experimental groups

5 DISCUSSION

The pre-test results revealed no significant difference between the experimental (EG) and control group (CG) (M_{CG} = 22.52, M_{EG} = 23.68). After application of VAS method, the experimental group achieved significantly better scores than the group educated under tradition approach (post-test: M_{CG} = 31.32, M_{EG} = 38.29).

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 (Francis et al. 2013; Gröber et al. 2014; Krišťák et al. 2013; Hake 1998 and others) 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. 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 at al 2014), which was also proved by the testing we conducted.

6 SUMMARY

Testing we realised 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 (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 $\alpha = 5\%$.
- 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 visualisation and help create right physical conceptions of the action around us.

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REFERENCES

[1] Beichner, R.J. (1996). The Impact of Video Motion Analysis on Kinematic Graph Interpretation Skills. *American Journal of Physics*, Vol. 64 (10), pp. 1272–1277.

[2] Brown, D., Cox, A. J. (2009). Innovative Uses of Video Analysis. *The Physics Teacher*, Vol. 47 (3), pp. 145–150.

[3] Francis, R., Shannon, S. J. (2013). Engaging with Blended Learning to Improve Students’ Learning Outcomes. *European Journal of Engineering Education*, Vol. 38 (4), pp. 359–369.

[4] Gröber, S., Klein, P., Kuhn, J. (2014). Video-based problems in introductory mechanics physics courses. *Eur. J. Phys.* Vol. 35(5), p. 055019.

[5] Hake, R. R. (1998). Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*, Vol. 66 (1), pp. 64–74.

[6] Halloun, I., Hestenes, D. (1985). The Initial Knowledge State of College Physics Students. *American Journal of Physics*, Vol. 53 (11), pp. 1043–1055.

[7] Hockicko, Peter, Trpišová, Beáta, Ondruš, Ján (2014), Correcting Students' Misconceptions about Automobile Braking Distances and Video Analysis Using Interactive Program Tracker. *Journal of Science Education and Technology*, Vol. 23, Iss. 6, pp. 763-776. ISSN 1059-0145

[8] Hockicko, Peter, Krišťák, Ľuboš, Němec, Miroslav (2015), Development of students' conceptual thinking by means of video analysis and interactive simulations at technical universities. *European Journal of Engineering Education*, Vol. 40, Iss. 2, pp. 145 – 166. ISSN 0304-3797

[9] Hockicko, Peter, Tarjányiová, Gabriela (2014), Testing and analysis of students' conception from physics, *Journal of Technology and Information Education*, 1/2014, Vol. 6, Iss. 1, 104 – 121. ISSN 1803-537X

[10] Kozhevnikov, M., Motes, M. A., Hegarty, M. (2007). Spatial Visualization in Physics Problem Solving, *Cognitive Science*, Vol. 31 (4), pp. 549–57.

[11] Krišťák, Ľ., Němec, M., Stebila, J., Danihelová, Z. (2013) Interactive P&E Method in Teaching Physics at Secondary Schools. *Journal of Technology and Information Education*, Vol. 5 (1), pp. 42 – 49.

[12] Planinic, M., Milin-Sipus, Z., Katic, H., Susac, A., Ivanjek, L. (2012). Comparison of Student Understanding of Line Graph Slope in Physics and Mathematics, *International Journal of Science and Mathematics Education*, Vol. 10 (6), pp. 1393–1414.

[13] Rochovská, Ivana (2012). Developing science literacy of pre-elementary and elementary pedagogy students. Ružomberok: Verbum, 2012. 267 p.

[14] Suhonen, S., Tiili, J. (2014). Active Engaging Video Assisted Physics Studies - Preliminary Results. *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2014*, pp. 1636-1644. Chesapeake, VA: AACE.

[15] Tiili, Juho, Suhonen, Sami. (2013). Combining Good Practices - Method to Study Introductory Physics in Engineering Education, *Proc. of the SEFI annual Conference 2013*, Leuven, Belgium.

[16] Wieman, C., Adams, W., Loeblein, P., Perkins, K. (2010). Teaching Physics Using PhET Simulations. *The Physics Teacher*, Vol. 48 (4), pp. 225–227.