Theses of PhD Dissertation

The application of motion simulation programs and measuring their effectiveness in high school physics education

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Introduction

In the 21st century, digitalization of education is inevitable, an increasing number of lessons contain computer-based teaching material. Some of them are essentially just the modernized forms of old methods, while some are completely new. Such is the case with simulation software, which are used to supplement classroom experiments in physics classes. Their biggest advantage is that, with minimal equipment requirements, they can support complex experiments that are either difficult to accurately perform or cannot be carried out without the help of the teacher. Only the most dedicated students or those who receive a lot of parental support can complete the experimental homework tasks. Sadly, this can only widen the difference in understanding level between better and worse performing students. This gap can be bridged by the using a simulation software, which makes it much easier for less dedicated students to perform complex experiments by themselves. Students can use the simulation programs intuitively and by paying attention to the settings, they can model physical reality with great accuracy, they are able to draw graphs showing the forces and the time dependence of the movement, thus deepening their understanding.

In my present work, in addition to using these programs, I focused on examining how useful these programs are in learning physics, whether students who use a motion simulation program while learning mechanics learn the curriculum more effectively. To study this, I conducted a large-scale educational experiment, the results of which I present in detail in the thesis.

Methods

My doctoral research is related to the work of a methodological research group, which has already planned educational experiments. When designing the educational experiment that forms the basis of this study, I used the methodology of Design-Based Research (DBR). One of the basic features of the DBR methodology is the iterative design, so the first step when designing an experiment was to use the experiences of the previous ones, to eliminate the errors that arose, and then to take into account the feedback of the participants during the experiment during the evaluation. To analyze the data, I used the SPSS program, with which I performed the following tests: Cronbach's alpha, Shapiro-Wilk test, Mann-Whitney, correlation, tercile, ANOVA and ANCOVA analyses.

Theses

1. Determining the magnitude of the forces acting on the vehicle during acceleration and thus calculating the acceleration when the vehicle starts its accelerating motion is an easy high school task if the car is considered to be point-like and the coefficient of friction between the ground and the wheel is sufficiently large. Reality is more complicated than this and cannot be easily investigated experimentally within the framework of a classroom. In the thesis, I presented how the acceleration of vehicles can be processed with Algodoo as a teaching material in physics classes. Using a simple simulated car model, I developed a step-by-step methodological recommendation that handles the details of the accelerating movement of a car at a high school level. With the help of simulation, I showed the parameter values at which the car's acceleration was determined by the engine torque or the friction coefficient between the ground and wheel and I also verified by calculation that these values are in line with reality. I showed that the program handles details correctly such as the net torque acting on the vehicle. As a result, vehicles exert more force on their rear axle during acceleration. I verified by calculation that the extent of this deviation is the same as what we would expect.

I used a simulation to show the role of traction control systems. [1]

2. In this work, I described the details of an experiment measuring the effectiveness of learning the dynamics curriculum. In the experiment, 700 students took part in a ratio of half to experimental and reference groups. The students of the experimental group learned dynamics with the help of a motion simulation program, while the members of the reference group learned in the traditional way. I developed teacher's material for the educational experiment. The students of both groups wrote tests before and after learning the topic (pre-test and post-test). When evaluating the results, I showed that the students of the experimental group learned the curriculum better overall than the members of the reference group. Evaluating the results of the post-test and using the results of the pre-test as a covariate, I found that the results of the experimental group on the post-test were: 50.7 ± 0.9 %, while the result of the reference group: 44.9 ± 0.9 %. [2]

3. During a more detailed examination in the theses, I showed that the difference between the two groups depends on the school the

students attend. Students belonging to the experimental group attending weaker schools showed much greater progress compared to their peers in the reference group attending the same school, while in stronger schools this difference was significantly smaller. The difference can be assumed to be explained by the fact that students from weaker schools are usually less motivated to learn, so the new method, which on the one hand attracts the student's attention more, and on the other hand allows more independent experimentation, resulted in them being more involved with the subject than if they had studied in a traditional way. [2]

4. I also examined the results of the post-test for each task. I showed that the students of the experimental group performed better than the students of the reference group for each type of task. The difference between the two groups, however, differed by question type. In the case of purely theoretical questions, the difference was comparable to the value of the standard error of the mean (SEM), however, in the case of tasks that were related to some common dynamic misconception (net force is needed to maintain motion, and no force acts on freefalling bodies) or

required graphic problem solving the difference was significantly larger (3-7 times larger than SEM). [2]

5. After the course material was completed, we carried out a follow-up examination to measure the deep understanding of the course material. The students both in experimental and reference groups filled out Hestenes' Force Concept Inventory (FCI). By evaluating the results, I showed that the difference between the experimental and reference groups, which appears in the traditional tests, cannot be detected in the FCI, which contains questions quite different from the regular school tasks. Based on the FCI analysis, I showed that the students of the experimental group performed better in the case of graphic tasks, and that, while the students at the stronger schools achieved better results in the traditional school tests, the students of the lower and middle terciles performed the same within the margin of error for the comprehension questions.

6. During the evaluation of the results of Force Concept Inventory, I developed a method with which these tests can be evaluated effectively, I used this method in another study, where

I examined the change in the performance of first-year university students, using the Mechanics Baseline Test (MBT) also compiled by Hestenes. During the investigation, I showed that both the reduction of the introductory physics course material and the introduction of mandatory homework significantly improved the level of students' development, and that this effect was exceptionally large in the case of students in teacher training program. [3]

Conclusions

During my doctoral work, I showed that motion simulation programs can and should be used in high school physics classes. Simulations help to understand complex phenomena that are difficult to investigate with real experiments. Overall, the students learn the material better by using the programs, one of the reasons being the program's display functions, which can help correct certain misconceptions, and on the other hand, the increase in the students' independent experimentation time, as a result of which they engage more with the course material and become more committed to physics. These two effects are much stronger for students with lower performance in general, who are fundamentally less motivated to learn. The follow-up study showed that the way we incorporated the use of the program into the education only gave the students an advantage in understanding and solving classic classroom tasks compared to traditional methods, and no difference could be detected between the two groups when it came to tasks testing deeper understanding.

Publications on which theses are based

[1] T. Radnai, T. Tóthné Juhász, A. Juhász, and P. Jenei, "A simulation experiment using Algodoo: what force makes a car accelerate and what does the acceleration depend on?", *The Physics Teacher* , vol. preprint.

[2] T. Radnai, TT Juhász, A. Juhász, and P. Jenei, "Effect of motion simulation programs in teaching force concept ”, in *Journal of Physics: Conference Series* , 2021, vol. 1929, no. 1, p. 012042.

[3] C. Wiener, T. Radnai, and P. Tasnádi, "Investigation of first-year university students' performance", *J. Phys.: Conf. Ser.* , vol. 1929, no. 1, p. 012089, May. 2021, doi: 10.1088/1742-6596/1929/1/012089.

Publications not directly related to theses

[4] T. Radnai, T. Tóthné Juhász, A. Juhász, and P. Jenei, "Educational experiments with motion simulation programs: can gamification be effective in teaching mechanics?", *J. Phys.: Conf. Ser.* , vol. . 1223, no. 1, p. 012006, May. 2019, doi: 10.1088/1742-6596/1223/1/012006.