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To cite this article: T Radnai *et al* 2021 *J. Phys.: Conf. Ser.* **1929** 012042

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# Effect of motion simulation programs in teaching force concept<sup>1</sup>

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**Abstract.** The most important concept in dynamics is force. Teaching forces in secondary schools has many difficulties, due to the fact that when students start learning dynamics, they have already developed a force concept based on their everyday experiences. This concept is usually simplified and often confused with impulse. However, the concept taught on physics lessons, is a much more complex, based on a vectorial quantity, with a time-dependent direction and magnitude. This confusion of concepts can be largely eliminated by the visualization of force vectors during the motion of an object. This opportunity is available in motion-simulation software, which work as a digital sandbox, allowing users to create their own scenes and display force vectors during the simulations. Connecting kinematics by motion visualization and dynamics by force visualization is a powerful tool that helps students to develop deeper understanding in mechanics. In our educational research, we investigated the positive effect of using such a program. With the participation of 700 students, divided into experimental and reference groups, we measured their development in understanding mechanics. The results proved that students who used the simulation program reach a better functional understanding of the concept of force than those being in the reference group.

## 1. Introduction

Mechanics is divided into two main subtopics: kinematics and dynamics. Kinematics deals with the motions themselves, but doesn't discuss the reasons behind these motions, therefore in this topic students are mainly expected to solve equations or analyse and explain different parts of functions. Usually students cope well with solving equations, because by this age they have had broad experience in solving equations in maths. Functions, on the contrary, prove to be a challenge for most of them, therefore it is advantageous to use motion-simulation computer programs that both visualize the motion and at the same time draw the position-time, velocity-time or acceleration-time graphs. The best-known such program is Algodoo, whose applicability in teaching physics has already been tested by different teams of scientists [1-4]. Our previous researches also confirmed [5,6] that such programs help the understanding of several concepts such as displacement, velocity and time in teaching kinematics.

The most important physical quantity and concept in dynamics is force this statement is confirmed by many researchers in the past decades. Hestenes et al. created the Force Concept Inventory [7] to measure knowledge of students in the topic of mechanics putting the main emphasis on the concept of force. This article is listed in the collection of A Literary Canon in Physics Education Research by Thompson and Ambrose [8], who refer to it as one of the most important articles in Physics Education Research (PER). Viennot [9] showed that even university students think that there is a linear relationship between force and velocity. Gunstone and White [10] conducted a research among first-year physics

<sup>1</sup> This study was funded by the Content Pedagogy Research Program of the Hungarian Academy of Sciences.



students, that demonstrated that students tended to observe their misconceptions related to gravitational force regardless of what happened in the experiment. Clement [11] made video interviews with students in which videos they were solving physics problems. Clement concluded, that many students believe, that motion implies force even after studying introductory mechanics at the university.

The greatest problem for students is the fact that mathematical models describing dynamics involve solving equations as well as vector operations. While students are familiar with equations (whose solution requires to same logic as those learnt in kinematics), they often struggle with vector operations. Although they have already encountered vectors in kinematics (displacement, velocity, acceleration), but the vector quantity of force is the first, where operations (addition, subtraction and multiplying by a scalar) are involved. The conceptual understanding of forces (and vectors) can be helped by building up a physical model based on drawing and investigating forces in different positions during the motion. We hypothesized that these static “snapshots” are not enough: it’s even better if a simulation program can visualize the forces while showing the motion of the object and also drawing the graphs of motion, thus connecting the motion to kinematics and dynamics at the same time.

In this paper we present examples showing how motion simulation software can be used in teaching the force concept, then introduce an educational research, whose results prove quantitatively that this method can be used effectively in the topic of dynamics.

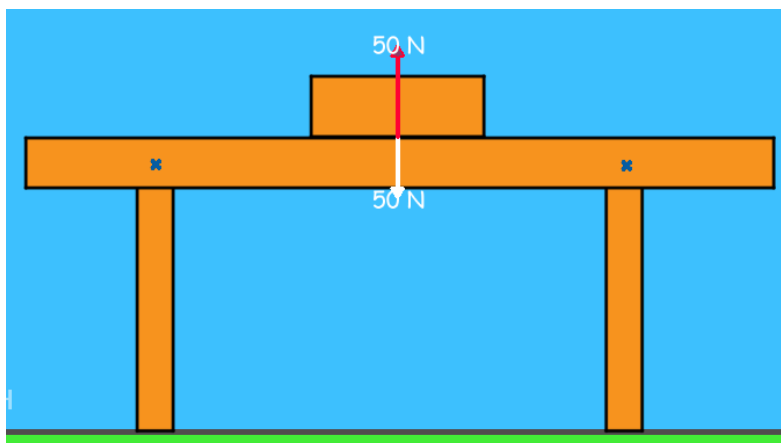
## **2. Teaching the force concept with the help of motion simulation software**

### *2.1. Introducing the employed program*

FIZIKA [12] is an English-language simulation software that is very similar to Algodoo in a way that it is also a digital sandbox, where students can create their own scenes from various elements. In dynamics one of the best features of the program is the visualization of forces in vectorial representation. This allows students to see and investigate something they don't know yet: the invisible forces “in action”. Traditionally students would be given detailed formal explanation of how each type of force (eg. gravitational force, normal force, friction) behaves and this would be backed by some free-body diagrams and problem-solving. In our learning-activities students had the opportunity to discover the properties of these forces along the way by themselves through creating scenes and playing with the simulation. The software was run on laptops and smartphones in classes, students were sometimes given ready-made simulations, but sometimes were asked to create their own scenes. All projects could be saved and further investigated at home.

### *2.2. The concept of normal force*

A recurring problem that we have noticed about normal force is that if it’s not introduced with care, students will soon develop a misconception that its magnitude is always equal to  $mg$  and it points vertically upwards. This is true in case of objects resting on horizontal surfaces (Fig.1).



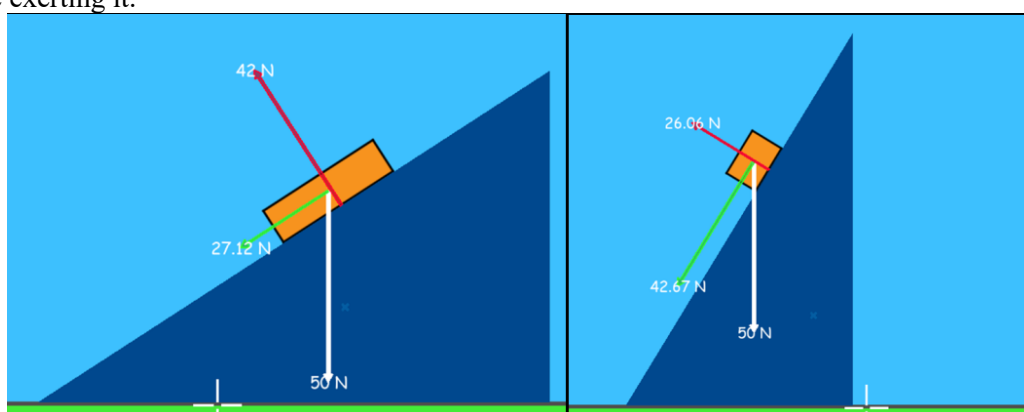
**Figure 1.** Visualization of the normal force (drawn in red) acting on an object being at rest on a horizontal surface.

Since dynamics and drawing of free-body diagrams should be introduced through easy examples, it is natural that students will first encounter situations, where this is the case and therefore might soon arrive to the conclusion that the magnitude of normal force is always  $N = mg$ .

However, in general, the normal force changes according to the circumstances (the support exerts it to prevent the object from falling through the surface). This property of the normal force plays an essential role in everyday situations such as the rebound of a ball from the floor or a person standing in an accelerating elevator. In order to help our students understand the true nature of normal force, it is crucial that they should discuss problems where  $N \neq mg$ .

Drawing a few free-body diagrams of such situations would definitely help some students, but the majority needs something more powerful tool, and this is where computers can help. If students have the chance to discover these properties through playing with simulations, they will achieve a deeper level of understanding.

The direction of the normal force can be investigated easily through objects placed on frictionless inclined planes. If students are asked to draw three of four inclined planes of different slopes with an object on top, they will soon discover by themselves that normal force is always perpendicular to the surface exerting it.



**Figure 2.** Simulations of inclined planes with two different slopes. Normal force (drawn in red) is always perpendicular to the surface exerting it.

In addition to their discovery about the direction of normal force, most students also realize that the magnitude of normal force on an inclined plane is equal to the component of the gravitational force directed perpendicular to the inclined plane ( $N = mg \cos \theta \neq mg$ ).

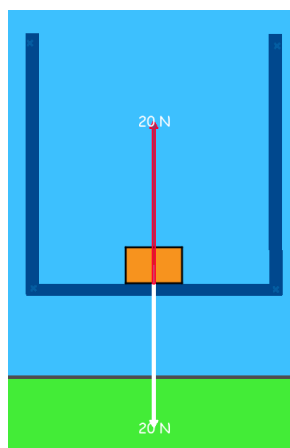
In order to strengthen their understanding of the magnitude of normal force, students should investigate more simulations. The one that we introduce here is based on a typical problem that students certainly come across during their secondary school mechanics course: the normal force acting on a person standing in an accelerating elevator.

Although the first step in understanding this situation is to actually stand on a scale in an elevator, simulation has an important role here too, as it allows students to investigate the situation at different accelerations of the elevator, thus creating a whole set of experiment. Observing important features while playing with these simulations help students understand the basic characteristics of normal force.

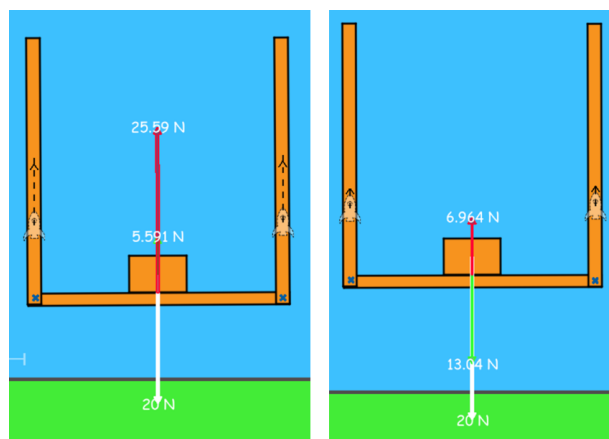
The simulation that students are asked to investigate consists of a frame (representing the elevator) and an object inside it. As an introduction to the elevator-problem, the forces acting on the object in a stationary elevator should be investigated.

After the introduction, the forces acting on an object in an accelerating elevator should be analyzed. In this case the elevator has three forces acting on it (Fig.4): the downwards gravitational force and two symmetrical external forces (represented by rocket symbols) pointing upwards. The reason for using two external forces instead of only one is to avoid rotation, which would easily happen in case of an asymmetrically positioned single force.

By changing the external forces, students can set the acceleration of the elevator to different values and examine the behavior of normal force in all cases.



**Figure 3.** Forces acting on an object in a stationary elevator. There is no vertical acceleration, therefore the normal force is equal in magnitude to the gravitational force (20 N).



**Figure 4.** Forces acting on an object in an accelerating elevator. Gravitational force is drawn in white, normal force in red, net force in green. (The green arrow of 5.59 N in the left figure is not visible, because it's behind the red one of the normal force.)

The figure above shows two different situations: in the former the elevator accelerates upwards, in the latter it accelerates downwards (the rockets still exerts upwards forces, but since their sum is less than the downward forces acting on the elevator, it will accelerate downwards.)

By investigating how the normal force changes in case of different accelerations, students soon realize that in case of an upward acceleration

$$N = mg + ma,$$

and in case of the downward acceleration

$$N = mg - ma.$$

Note that these two equations are actually two forms of the same vector equation ( $ma = N + mg$ ).

The general conclusion of this simulation is that normal force changes according to the circumstances such that it prevents the object from falling through the surface.

### 3. Educational research

Based on the results of our previous researches and our experiences in teaching, we hypothesised that those students, who use simulation programs in school or at home or both, manage to arrive to a better understanding of the vector nature of forces and can apply them better in interpreting different situations. In order to prove this hypothesis, we organized an educational research with the participation of 17 secondary school teachers, who were taught how to use the simulation program and were also provided with readymade simulations and worksheets. These teachers then taught dynamics for 3 months to a total of 334 students using the simulation program. At the same time, each teacher chose a reference group, taught by another teacher from the school, where students of similar abilities were taught dynamics based on the method their own teacher comfortable with, which usually didn't involve any simulation. The only requirement in case of the reference groups was that students had to write the same final test (post-test) as those students being in the experimental group. The reference groups consisted of 351 students in total.

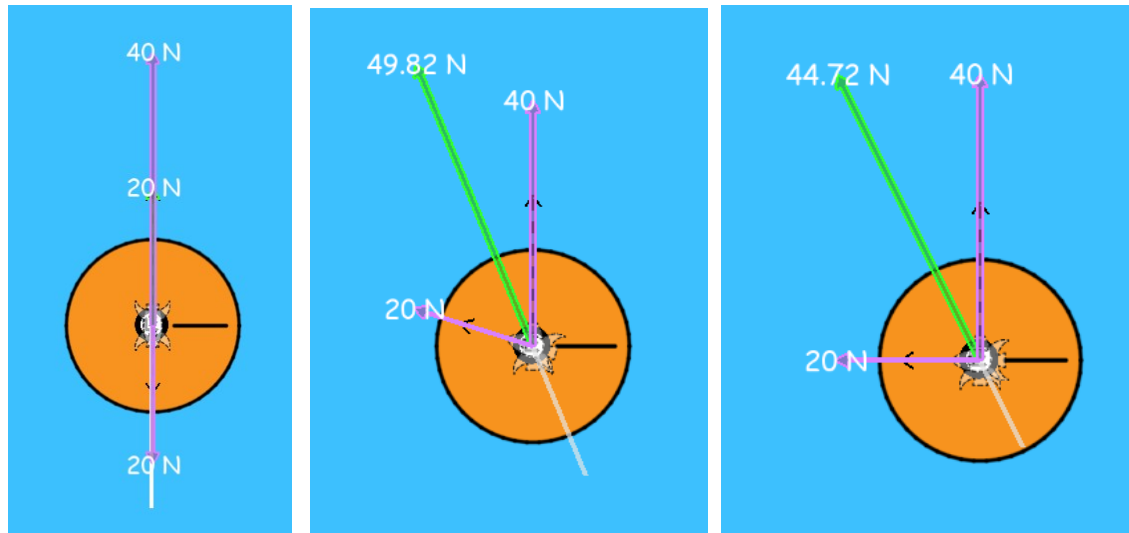
In order to be able to measure and compare the general abilities of students in the two main groups, we used a pre-test: every student wrote the same test in kinematics, which is the topic taught before dynamics. In this way we had a measurement of the level of knowledge and ability of the two groups before starting the experiment, which could then be compared to the results of the final post-test. Only students who completed both tests were included in the final evaluation process. With this methodology, that the content of the pre-test was learned from the same teacher we also tried to measure, if there is any selection bias in the results. This could be come from the fact that the teachers participating in the experiment were volunteers and maybe were generally more efficient in teaching physics, than the teachers teaching in the control groups. Table 1 below shows that the students in the reference groups performed the pre-test with better results, but the difference was not significant. This result represents, that if there is any systematic error in the results of the post-test, coming from selection method of participating teachers, the effect is probably small.

#### 3.1. Background work of research

In order to make teachers successful in applying the simulation program in their lessons, we organized a teacher training, where they learned the use of the software. The course focused on the use of simulation, but teachers were also given a total of 25 auxiliary teaching materials which consisted of one or more simulations and a methodological guide on how to analyse and apply them in lessons. Figure 5 shows screenshots of such simulations that were intended for helping the teaching of adding vector. In this auxiliary material there were several simulations, one for every situation shown below. The methodological guide gives recommendation on the order in which these simulations should be used, points out the important tricks of each simulation and also offers ideas for homework. It is a great advantage of this software that the actual forces acting on the body and the net force are visually distinguishable: they are drawn in different colour and the net force can be set to show or hide with a click of a button. Furthermore, by starting the simulation, it's possible to check whether the object accelerates in the direction of the net force. At the end of the teaching experiment, we made a survey to

find out the number of the auxiliary teaching materials used by each teacher, and we found that an average of 14 materials were used, and the simulation helping the addition of forces were used by all teachers.

[1]



**Figure 5.** Screenshots of the simulations from the material helping the teaching of vector addition.

### 3.2. Evaluating the results

We started the evaluation of the test results by applying the Cronbach's alpha method of reliability. Since both the pre-test and post-test proved to be reliable (0.83 and 0.86), we carried out a statistical analysis on both tests. There were a total of 17 schools involved in our research, and these schools were very different in their profile, geographical position, and the social situations of their students. Due to this fact we expected some unevenness in the results, but wanted to minimize the effect of external factors. As a first attempt to that, we made sure that every experimental group had a reference group from the same school, however this didn't ensure the same number of students from the given school, since group sizes can slightly differ even inside the same school. Furthermore, we used data from a website [13], where the strengths of all Hungarian schools were compared. This comparison is based on the results of several different national tests and a final score is assigned to every school. The score of schools involved in our research varied between 368 and 573 (higher score meaning stronger school). These school scores were handled as covariate in our analysis. In case of the test results modified by the covariate, we calculated the mean and standard deviation of both the pre-test and post-test and used the ANCOVA method to check whether there is a significant difference in the results of the two groups in case of each test. The results are shown in table 1.

**Table 1.** The mean and standard deviation of the test result (in percentages) and the significance between the two groups in case of each test. It should be noted that the results of pre-test and post-test are not comparable to each other individually, because the two tests were different (see section 3.)

	Pre-test (%)		Post-test (%)	
	Mean	SD	Mean	SD
Reference group (n=351)	50.0	20.9	45.0	19.2
Experimental group (n=334)	49.1	21.0	50.5	19.2
p-value	0.578		<0.001	

The results in the table above show that in case of the pre-test, there wasn't a significant difference between the two groups, which means that teachers made a good decision when selecting experimental

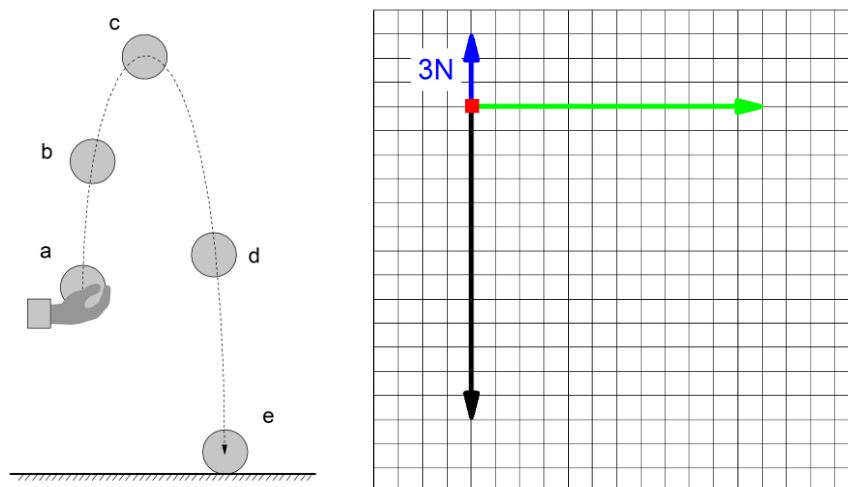
and reference groups for the research and managed to work with students of the same average abilities in both groups. The post-test results, however, show that students in the experimental group scored significantly better, which means that teaching was more effective in this group. Since the only difference between the groups was the method of teaching, we can conclude that using simulation software in teaching dynamics has positive effects and therefore their application in teaching is advantageous.

It should be noted that the objective score of a school correlates with the results of the students both in the pre-test and the post-test. In case of the pre-test the correlation coefficients of the two groups were practically the same (0.384 and 0.395 for the reference and the experimental groups, respectively). In the case of post-test the correlation coefficient of the experimental group was much lower (0.194), than the reference group (0.284). Hence, we can assume, that motion simulation software helped more for students in weaker schools.

### 3.3. Evaluation of test questions one by one

Besides the mean scores of the test, we were also interested in the performance of students in individual questions where the force concept was tested. The post-test consisted of 9 questions, 2 of which required students to work with force vectors.

In question 5 students had to draw the force(s) acting on an object in different positions during a vertical projection. In question 7, there were 3 forces (of different magnitudes and directions) acting on an object with given mass, and students were required to calculate the net force and the magnitude and direction of the acceleration of the given object. Figure 6 shows the diagrams belonging to these questions in the test.



**Figure 6.** Figures belonging to questions 5 (left) and 7 (right).

The rest of the 9 questions were partly multiple choice questions testing the students on Newton's laws and partly problems requiring the understanding of force laws and solving equations. Below are one example of each type (question 1 and 9 in the post-test):

**1. A bus suddenly brakes, so passengers standing without holding on to handrails fall. Why does it happen?**

- a) Because the bus exerts the force of its brakes on the people, and that's what makes passengers fall backwards.
- b) Because the bus exerts the reaction force of its own brakes, which is a force pointing forward, and that's what makes passengers fall forward.
- c) Because the passengers not holding on can't exert a force that would change their velocity, therefore they continue to move with their original velocity.



**9. An object of mass 5 kg originally resting on a horizontal surface is pulled forward by a horizontal force of 25 N. Find the coefficient of kinetic friction between the surface and the object if it accelerates at  $3 \text{ m/s}^2$ ?**

When analysing the post-test results for individual questions, the score of school on the national list and the pre-test result were the covariates for each student. This way both the unevenness in the strength of schools and the difference between individual students could be smoothed and we measured the difference in their knowledge of dynamics only. The results of this analysis for questions 1, 5, 7 and 9 are shown in table 2:

**Table 2.** Results of analysis of covariance: mean, standard deviation for individual questions in case of each group, significance between the two groups and the difference of means divided by the statistical error.

	Question 1 (%)		Question 5 (%)		Question 7 (%)		Question 9 (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Reference group (n=351)	61.5	45.0	29.2	30.0	61.5	45.0	29.2	30.0
Experimental group (n=334)	64.4	45.7	39.7	29.2	64.4	45.7	39.7	29.2
p-value	0.392		<0.001		0.024		0.855	
diff ( $\sigma$ )	1.18		5.19		3.21		0.21	

The results show a significant difference in case of questions 5 and 7, which are the ones where the concept of vector nature of forces was tested. In case of questions 1 and 9, the experimental group also scored better, but the difference was not significant.

#### 4. Conclusions

In our research we investigated whether using a simulation software on the physics lessons helps the teaching of dynamics. Our results show that students using the software acquired deeper knowledge during the teaching experiment. The difference between the experimental and reference groups is small in case of theoretical or traditional calculation questions, but significant in case of problems testing the development of a correct force concept. This means that using the simulation software helps students effectively in the area that usually represents the most challenging part of the topic.

#### 5. References

- [1] Gregorcic B 2015 *Physics Education* 50 511
- [2] Euler E and Gregorcic B 2017 *Physics Education Research Conference* (Cincinnati) p 128
- [3] Çelik H, Sarı U and Harwanto UN 2015 *International Journal of Innovation in Science and Mathematics Education* 23 40
- [4] Cayvaz A and Akcay H 2018 *The Eurasia Proceedings of Educational & Social Sciences* vol 9 p 151-156
- [5] Radnai T, Juhász TT, Juhász A and Jenei, P 2019 *Journal of Physics: Conference Series* vol 1223 No. 1 p 012006
- [6] Juhasz TT, Juhasz A and Szigetlaki Z 2017 *Universal Journal of Educational Research* 5 2241-50
- [7] Hestenes D, Wells M, and Swackhamer G 1992 *The physics teacher* p 141-158
- [8] Thompson JR and Ambrose BS 2005 *APS Forum on Education* Fall p 16
- [9] Viennot L 1979 *European journal of science education* 1(2) p 205-221
- [10] Gunstone RF and White RT 1981 *Science education* 65(3) p 291-299
- [11] Clement J 1982 *American Journal of physics* 50(1) p 66-71.
- [12] Juhász TT 2015 *Proceedings of the 2015 Teaching Physics Innovatively* (Budapest Hungary) 249
- [13] <https://legjobbiskola.hu>