The knowledge of Hungarian students in the light of the Mechanics Baseline Test

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Abstract. In the introductory courses in physics at Loránd Eötvös University (ELTE) students with very different physics knowledge can be found. It seems the core problem is the undeveloped thinking skills and the deficiency in conceptual understanding. The investigation of the conceptual understanding is not simple, however, there are some reliable instruments for it such as the Mechanics Baseline Test which was constructed by Hestenes and Wells. In this paper the results of this test obtained in Hungary (mainly at ELTE) are presented. The test is universal in the sense that it is limited to the concepts that should be addressed in introductory physics at any level from secondary schools to universities. In 2016 at the Faculty of Science of ELTE students enrolled in introductory physics courses were tested. The students' majors were Biology, Earth Sciences, Physics and Physics Teaching. The same test was given as a post test for the students of Physics major and Earth Sciences. The results were compared to those of obtained previously in Hungarian secondary schools, at ELTE courses and at the universities in the USA (Arizona State University, Harvard University). It can be stated that at ELTE the test scores of the students of physics major has decreased significantly in the last 20 years. (Maybe it is the consequence of the implementation of Bologna Process due to which the number of the students entering into the University highly increased.) It was also revealed that there are difficult topics in kinematics and dynamics the understanding of which shows serious deficiencies at any level. (For example the dynamics of the curvilinear motion.) Finally on the basis of the results some proposal for the improvement of the instruction strategy is presented.

1. Introduction

It is a worldwide tendency that students' interest in science is decreasing [1] and especially their attitude towards physics is negative [2]. Physicists and physics teachers have been made high efforts to reverse this trend. The Pisa 2015 investigation detected that in the OECD countries the average enjoyment index of the broad sciences has slightly improved. [3]. (Unfortunately Hungary was among the countries where this index highly decreased.)

The unpopularity of sciences has influenced the knowledge of the students enrolled to universities. The introductory courses in physics at Hungarian universities have shown that the prior knowledge of students is very different. Besides highly qualified students there are very weakly educated ones whose preparedness is not enough to pursue university studies. The problem originates partly from the

enrolment policy. In Hungary the admittance of physics students to universities is primarily based on the results of their high school final exams in two subjects of their choice from the following list: biology, chemistry, geography, informatics, mathematics, and physics. That is, students can be accepted to universities (including the most prestigious ones) without significant background in physics. Moreover, the minimum score for admission to the physics-related courses is rather low, enhancing the differences at the level of knowledge.

To overcome this problem "physics criteria courses" were introduced in physics program at Loránd Eötvös University (ELTE) for those students who do not reach the minimum score in a test written right after their admittance to the university. These criteria courses are obligatory for students with poor knowledge, while optional for the others. Usually more than 60% of the students have had to attend these courses, where, on a high school physics level, kinematics and dynamics are taught only for one semester merely for two credits.

To find students with deficient physics knowledge the basic concepts and laws of the physics that are essential for the fulfilment of a university course should be investigated. Besides, it is important to map these basic concepts since they provide information not only on the physics knowledge level of the students determining the most important concepts to be developed, but they also characterize the difficulty of the different basic concepts. Since the difficulty of a concept also depends on the teaching method, this kind of mapping provides information on physics education in Hungary.

We found that Mechanics Baseline Test (MBT) [4] designed by Hestenes and Wells to assess qualitative understanding of the basics in kinematical and dynamical concepts in mechanics is suitable for this kind of investigation. Firstly, the introductory course in physics at universities is concerned mainly with mechanics and covers the topics treated in MBT. Secondly, the test is universal in the sense that it can be addressed to introductory physics at any level from secondary schools to universities. In addition, mechanics is an important prerequisite for many other physics courses and the concepts introduced in mechanics are very significant and expressive, therefore they help with the understanding and usage of the advanced mathematics (like differential calculus). Test results of basic concept of mechanics can consequently predict later problems e.g. in electrodynamics. And last but not least, it is used worldwide for the investigation of the conceptual understanding of physics [4-6], so results obtained at ELTE can be compared with those of other countries, thus relevant information can be achieved about the Hungarian teaching methods.

2. Results and discussion

The MBT was first used in Hungary in 1995 to measure the effectiveness of the Hungarian public education in physics. It was a post-test for 2220 students of third and fourth grade of 30 different grammar schools in the western (more developed) region of Hungary. (The teaching of mechanics is finished at the second grade in grammar schools.) The results of the top two schools were evaluated separately as well (table 1., rows 8-9). In the time period 1996-2003 university students at the Faculty of Science of ELTE were tested occasionally (table 1., rows 6-7). Due to deteriorating performance in physics of the students in Hungarian universities, students enrolled in introductory physics courses at ELTE were also tested in 2016. The students' majors were Biology, Earth Sciences, Physics and Physics Teaching. The test was applied as a pre-test in order to map the general deficiencies in mechanics, therefore the students remained anonymous. (table 1., rows 1-5) The lectures were delivered in conventional way in one group for each major subject, while the practice lessons were organized in groups of 25-35 students according to the common practice of ELTE. That is the students are given problems and solve it individually according to teaching instructions followed by a common discussion of the solutions. The instructors varied from group to group.

The effectiveness of the instructions of introductory physics courses can be measured by testing the same students both before and after the course. We gave the test to the same students mentioned above at the beginning of the second semester, 1 to 4 weeks after their exam. (table 2.)

Students were given 45 minutes to complete the test. MBT is a multiple choice test the right answer should be chosen from five options. The distractor choices are not common sense alternatives, but they

include typical student mistakes stemming from deficient understanding. It measures the conceptual understanding of the following topics: kinematical concepts of linear and curvilinear motion (displacement, velocity, acceleration); dynamical concepts of Newton's laws, momentum, momentum conservation; conservation of energy, work-energy principle and specific forces like gravity and friction force. In MBT the advanced concepts like torque and angular momentum are not considered.

Table 1. shows the results of the test written before the introductory courses at ELTE. For comparison the results of the MBT for Arizona Grammar School, Arizona State University and Harvard University are also presented. Although the MBT is widely used all over the world, the data of the results for different universities and grammar schools are not published in most cases. Therefore the test results of Hungary (1995, 2016) could have been compared only to the performances of the grammar schools and universities we could find in the literature [4]. Besides, we think that since the MBT is a current test independently from time in the sense that it concerns to basic concepts which are involved into physics curricula for a long time, thus the results obtained in different years can be compared. Accordingly, we think that comparing the data in table 1. makes sense. (Obviously, we suppose that the teaching methods have not changed too much in the last 20 years. In Hungary, except a small group of physics teachers, who introduce new methods to their physics courses in grammar schools, the main stream of the teaching methods have not changed much in the last 20 years.)

Table 1. Statistical data of the Mechanical Baseline Test written at ELTE and different schools in Hungary. For comparison the data in the literature [D. Hestenes et al. (1992) Phys. Teach. 30 159.] are also presented. The third column contains the percentage of students who chose the correct answer.

Students tested by MBT	Number of students	The year of writing	Results of MBT: Percentage of correct answers
ELTE, Physics BSc Regular (pre-test)	56	2016	0.52
ELTE, Physics BSc Honors (pre-test)	16	2016	0.77
ELTE, Physics Teachers (pre-test)	25	2016	0.58
ELTE, Biology BSc (pre-test)	212	2016	0.28
ELTE, Earth Sciences BSc (pre-test)	101	2016	0.37
ELTE, Physics Teachers (pre-test)	20/23	1999/2003	0.46/0.54
ELTE, Physics Honors (pre-test)	60/80	1996/1999	0.7/0.69
Grammar Schools, Hungary	2220	1995	0.35
Grammar Schools, top two in West HU	93	1995	0.58
Grammar School, Arizona Regular	600	1992	0.32
Grammar School, Arizona Honors	116	1992	0.37
Arizona State University	58	1992	0.61
Harvard University Regular	183	1992	0.66
Harvard University Honors	73	1992	0.73

The table shows that secondary grammar school students' performance on MBT is the same regardless of the different curriculum of the different countries. We have found, that comparing the performance of regular Hungarian university students to the data of the USA students the performance is very different. (See also Figure 1.) In Hungary even the regular Physics BSc students could not reach the conceptual threshold (which is 0.6 according to [4]).

As we mentioned in the introduction, many professors teaching introductory physics feel that the physics (as well as the math) knowledge level has declined. Supposing that the students on Biology BSc represent the average grammar school students, the results of the Biology BSc students confirm that the average physics knowledge has declined in the last 20 years in Hungary. Still, due to the peculiarities of the Hungarian education system which lays emphasis on the performance of top

students, the honors students' performance is very good, almost at a "master level" (threshold for that can be defined as 0.8 in average [4]).

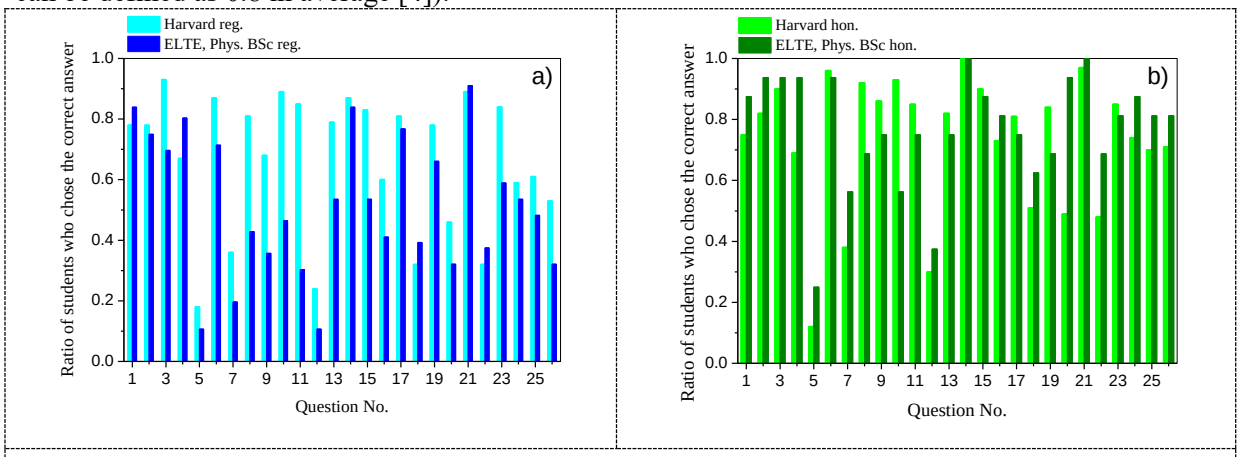

Figure 1. Comparison of the results for each question of the MBT for a) regular and b) honors students of Harvard University and Loránd Eötvös University.

To our surprise, the difference in knowledge is quite large when comparing regular students at universities (Figure 1.a.) The reason for the remarkable difference can be that universities in the USA can gain more students having the basic concepts of physics, while in Hungary we have to deal with students who could not reach the conceptual threshold.

Comparing the ratio of the students who chose the correct answer we found a gap in results in some problems e.g. Problem 8-11. This gap is well noticeable both for regular and honors students, the discrepancy is probably due to the different curriculum in the different countries. (Figure 1.a and b)

It is clear from Figure 1. that regardless of the curriculum and the country, there are difficult topics (e.g. Problem 5 and 12). More about this subject can be read in the next paragraph.

Table 2. The results of the Mechanical Baseline Test written at ELTE, Hungary in 2016 just after the admission (pre-test) and at the beginning of the second semester, after finishing the introductory physics course (post-test). The table shows the percentage of students who chose the correct answer.

Students tested by MBT	Pre-test	Post-test	Introductory courses
ELTE, Physics BSc Regular	0.52	0.58	Lecture: 4, Practise: 2 or 4, 25-30 students/group
ELTE, Physics Teachers	0.58	0.79	Lecture: 4, Practise: 2 or 4, 15-20 students/group
ELTE, Earth Sciences BSc	0.37	0.41	Lecture: 3, Practise: 1 35 students/group

The MBT was used as a post-test to investigate the effectiveness of the introductory physics courses and to see if changes in curriculum or instruction methods are needed. Students were tested at least one week after the exam, so the repeated test is supposed to measure not the factual knowledge, but the conceptual understanding of the students, as most of the student use short term memory for taking exams. Since we did not expect much change in the results of the honors students as they had already almost reached the master level, the test was not rewritten by them. The results in table 2 show that in case of small practice groups the development in conceptual understanding is more pronounced. However, more students should be tested, since about 10-20 % of the students drop out during the first semester from the university

3. Difficult topics in mechanics

MBT reveals that problems 5, 7 and 12 are difficult even for advanced students, in spite of that these problems belong to the core of the basic mechanics. It was found that these problems can be identified as difficult concepts regardless of countries and curriculums. Therefore new teaching methods should be searched, which are adequate to overcome the deficiencies in these topic all over the word [5]. Let us see these problems in detail!

3.1. Problem 5

Problem 5 is addressed to reveal the deficiencies in the qualitative understanding of acceleration. The task is to choose the correct direction of the acceleration of a sliding block on a frictionless ramp in position II. (Figure 2.)

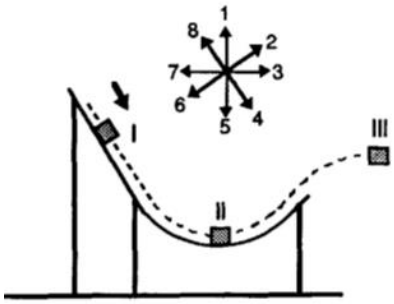

Figure 2. The graph in Problem 5 in the MBT [4].

It is worth mentioning that this was the hardest problem amongst the questions. Figure 1 shows that the percentage of the correct answers was low regardless of the nationality of students. It is reported in [7], that even professors struggled with solving this problem. According to the interviews made with students at ELTE the root of the typical wrong answer (that the acceleration is zero) is that students does not clearly differentiate the concept of velocity from that of the acceleration. The reason for that probably lies in the introduction of these concepts. Both the velocity and the acceleration are first defined in case of unidirectional linear motion, where the velocity and the acceleration vectors are parallel.

3.2. Problem 7

In this problem a block of mass is pulled by a string with a force *F* at angle above the horizontal. The students should determine the relations among the given different forces acting on the block, if it moves with constant velocity. The problem is phrased so that only the concept of Newton's second law should be needed, meanwhile, it also gives the information that whether or not students have grasped the concept of normal force and friction, since the understanding of the magnitudes of forces on the graph is essential for the simplest friction model.

The typical wrong answer includes the assumption that F equals to K. Many papers are about the difficulties in teaching friction (e.g. [8]), where one of the challenges is to make the students understand that the normal force is not the gravitational force or the adequate component of the gravitational force if the object is on a ramp.

For solving strategy using vector components in an adequate coordinate system is suggested along with changing the introduction of the friction force with the following arrangement. Let us put the object into the jaws of a vice. Here the normal force is horizontal thus it can be easily recognized that in this case the normal force is independent of the gravitational force.

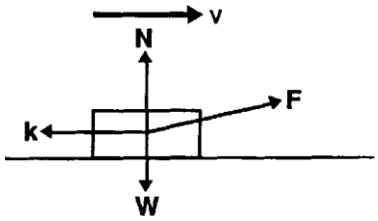

Figure 3. The graph in Problem 7 in the MBT [4].

3.3. Problem 12

In problem 12 somebody is swinging. The students have to determine the tension in the rope at point Y. This is one of the few problems in the MBT when a formula is needed to solve the problem.

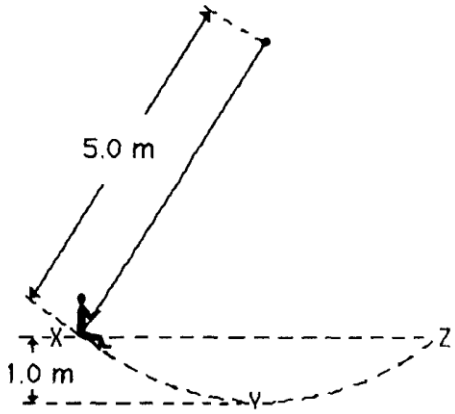

Figure 4. The graph in Problem 12 in the MBT [4].

According to the surveys, this was the second hardest problem both in the USA and Hungary. (Figure 1.) Especially in case of regular students. The reason for that is that the circular motion was found hard to teach worldwide. Firstly, the coordinate system is changing from point to point. In addition, Newton's second law should be used not the usual way. In most of the problems Newton's second law is used to determine the magnitude and the direction of the acceleration knowing the forces acting on the object. But in case of circular motion the direction of the acceleration is known and one should conclude from it to the direction/magnitude of other forces (e.g. static friction force). On top of that, the deep understanding of the concept of the acceleration is indispensable and as it was shown that the acceleration is a very difficult concept.

4. Conclusions

- Using Mechanics Baseline Test as a pre-test enables to identify the average conceptual level of students confirming the existence of student with low physics knowledge.
- MBT helps to identify difficult concepts in introductory mechanics. We found that the identified difficult concepts exist regardless of teaching methods, age or countries.
- Conventional methods do not produce good results at the test, but individual work can improve the conceptual knowledge of the students.

We would like to work out a new approach of teaching based on individual work. Due to misbelieves, typical mistakes and the reasons underlying should be identified with interviews. We think that with adequate homework and experiments the conceptual understanding of student with a given deficiency can be strengthened.

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