# CONCEPTUAL PHYSICS

## LARGE-SCALE RESEARCH ON CROATIAN HIGH SCHOOL STUDENTS' CONCEPTUAL UNDERSTANDING IN MECHANICS

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### 1 INTRODUCTION: WHY MECHANICS?

Mechanics is a fundamental discipline in physics and also a necessary prerequisite for the understanding of other areas of physics. Even more, mechanics introduces students in the method of the whole discipline of physics. Students' understanding of mechanics concepts is very important for the development of their further understanding of physics. However, mechanics is also a part of physics in which many students' alternative conceptions have been identified. The main non – Newtonian trend in students' thinking is characterized by the "motion implies force" idea (including impetus ideas), linking of constant force to constant velocity, a strong disbelief in Newton's third law and misunderstanding of gravity [1].

The main goal of this research was to estimate the average level of conceptual understanding of mechanics in the population of Croatian students at the end of gymnasium (a type of high school which prepares students for universities).

### 2 THE FORCE CONCEPT INVENTORY

The Force Concept Inventory [2] is a well known and widely used conceptual test in mechanics. It was constructed on the basis of the findings of physics education research on students' alternative ideas in mechanics and is used to diagnose the prevalence of those ideas in different groups of students. This resulted in a wide use of the test, first in the USA (e. g. [4]), and then also in many other countries (e.g. [5]) throughout the world. The FCI is a multiple choice test of 30 questions that investigates students' understanding of the Newtonian force concept without any use of mathematics. The FCI has had a large impact on the change of attitude towards physics teaching of many physics teachers throughout the world, since it demonstrated very clearly that students hold pre-Newtonian ideas about force and motion both before and after instruction on Newtonian mechanics. The advantage of the test is that it can be easily administered to large samples of students, thus making its results even more shocking and significant. Over time the FCI has acquired a status of a standardized instrument for measurement of students'

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minimum conceptual understanding of mechanics. High FCI score is considered a strong, although not perfect, indicator of Newtonian thinking in students, since Newtonian physics requires more than just the ability to recognize one Newtonian among four non-Newtonian answers. However, low FCI score undoubtedly indicates poor conceptual understanding of mechanics. The FCI authors have suggested that the score of 60% can be considered a threshold for the development of Newtonian thinking [2]. Below that threshold students' understanding of Newtonian concepts is insufficient for effective problem solving and such students have difficulties following physics courses at university level [3]. It is suggested that students with FCI scores above 80% can be considered Newtonians [2].

## 3 PHYSICS TEACHING IN CROATIA

The school system in Croatia consists of 8 years of elementary school followed by 4 years of high school. After high school students can continue their education at different universities and colleges. There are several types of high schools in Croatia, but in this study we have focused on one type called gymnasium. Gymnasium graduates typically continue their education at university level, whereas most of the graduates from other types of high schools don't. Gymnasiums can be of the general education type or they can specialize either in foreign or classical languages or in natural sciences and mathematics.

Physics is taught from the 7$^{th}$ grade of elementary school (age 13 – 14 years) until the 4$^{th}$ year of gymnasium (age 18 – 19 years) as a separate and compulsory school subject. In the 7$^{th}$ and 8$^{th}$ grade of elementary school students have two 45-minutes physics lessons per week. In gymnasium the number of physics lessons per week depends on the type of gymnasium. In the general education type gymnasiums (GE) and those which specialize in foreign or classical languages (FL/CL) students have two 45-minutes physics lessons per week throughout four years of gymnasium. In gymnasiums which specialize in natural sciences and mathematics (NSM) students have three 45-minutes physics lessons per week throughout four years of gymnasium.

For some years Physics Education Group from Physics Department, Faculty of Science in Zagreb has been conducting the FCI pretesting of the first year students and noticed that many students scored below the Newtonian threshold of 60%. This indicated that many of the students entering general physics courses still used pre-Newtonian ideas in mechanics despite six years of physics instruction at school.

## 4 METHODS

We chose to focus on students in the final year of gymnasium, since they make the majority of students who enter universities. The population of students in the final year of gymnasium had 12366 students in 2006/07. Most of them (84.5%) were in the GE and FL/CL gymnasiums, and only 15.5% were in the NSM gymnasiums. The sample of students in the study included 1676 students, or 13.6% of the population. In the sample there were 429 students (25.6%) from the NSM and 1247

students (74.4%) from the GE and FL/CL gymnasiums. The sample represented proportionally different regions of the country as well as different types of schools. The number of participating schools was 54 which make 36% of all gymnasia in the country.

Students were tested in the period from October 2006 until February 2007, without any special preparation for the test. The latest improved version of the FCI available at http://modeling.la.asu.edu/R&E/Research.html was used. The test was translated in Croatian.

The testing was anonymous, but each student was assigned a code so that they would be able to later identify their test scores. Students had to mark their answers on a special answer sheet. The allocated time for taking the test was 45 minutes. Participating schools were later informed about students' test scores and were asked to pass that information on to their students.

## 5 RESULTS AND DISCUSSION

Results are displayed in Figs. 1, 2 and 3. Distributions of students' test scores are shown with the accompanying statistical information (arithmetic mean, median, standard deviation $\sigma$ and standard error of the mean $\sigma/N^{1/2}$ for each distribution). The distribution of scores for the whole sample is shown in Fig. 1. The results for students from the GE and FL/CL gymnasiums are shown together on one graph (Fig. 2) and the results of students from the NSM gymnasiums are shown separately (Fig. 3).

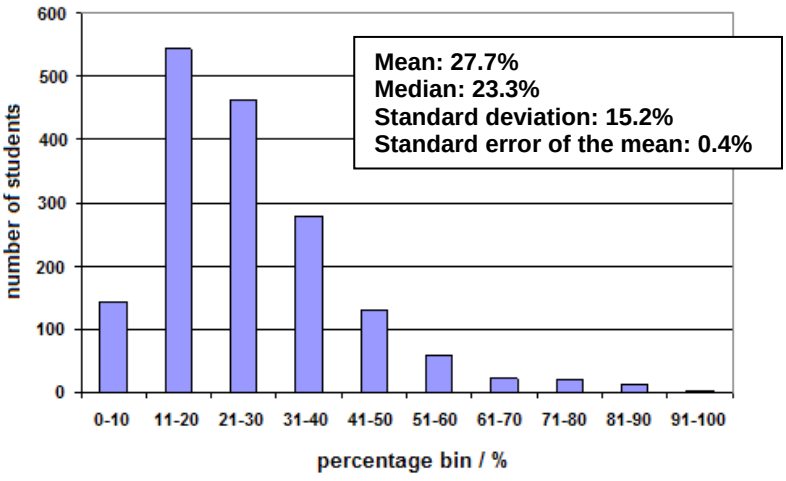


**Figure 1** Distribution of test scores for the whole sample.

Figs. 1, 2 and 3 suggest that Croatian students in the final year of gymnasium are still mostly pre-Newtonians, as measured by the FCI standard. The average FCI score of the whole sample, as well as the scores of the two sample subgroups are

well below the threshold of 60%. We have found 4.7% of students in the sample with scores above 60% and 1.2% of students with scores above 80%.

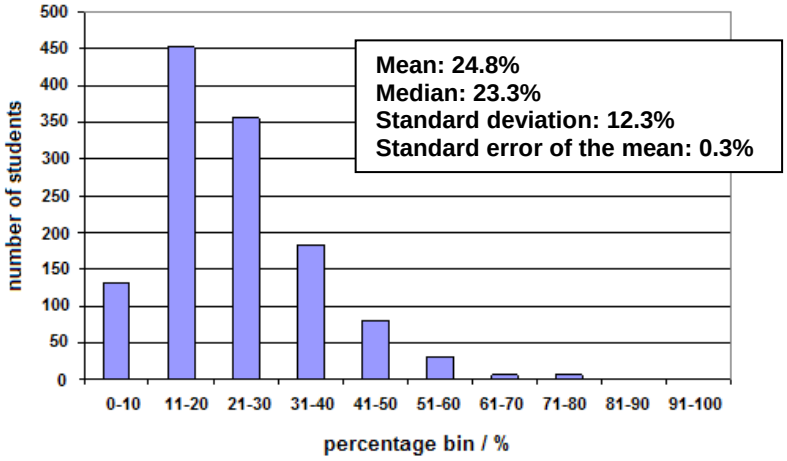


**Figure 2** Distributions of test scores for the GE and FL/CL gymnasiums.

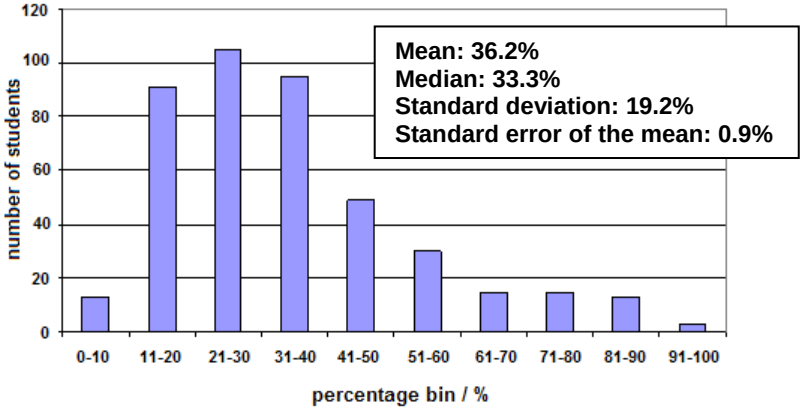


**Figure 3** Distribution of test scores for the NSM gymnasiums.

As expected, the results of the students in the NSM gymnasiums are better than in the GE and FL/CL gymnasiums. Students who score above 60% come almost exclusively from the NSM schools.

All gymnasium students learn mechanics in the first year of gymnasium (age 15-16 years) and the testing was done in the fourth year, with the gap of 3 years between the instruction and the FCI testing. Students did not know what the test was about and they have not been preparing for it in any way. The testing was anonymous and students were not given any grades for it, so it was possible that

their motivation was not very high. These factors have probably influenced the results and made them appear somewhat lower than they would have been otherwise. However, we have following reasons to believe that these factors have not played a very significant role in the research:

1) The gap between instruction in mechanics and testing is large, but during that time the students have been learning other physics topics which relied very much on Newtonian concepts. These concepts therefore should have been in use by students over the three years since they learned mechanics and should have even been refined through their application in other contexts.
2) If students had been randomly choosing answers there would have existed a recognizable pattern of approximately equally distributed distracter frequencies on any particular question. The analysis of the actual distracter frequencies revealed that it was not the case. Students' choice of answers was consistent with the expected frequencies of alternative conceptions in mechanics based on the findings of physics education research worldwide. Students also generally showed interest in the test and in their score on it.

## 6 CONCLUSION

The aim of this research was to estimate the level of conceptual understanding in mechanics in the population of Croatian students in the final year of gymnasium. The average measured FCI score of (27.7 ± 0.4) % is low, considering that these students have been learning physics for six years. Students in gymnasiums which specialize in natural sciences and mathematics have achieved a higher average score of (36.2 ± 0.9) %, but both scores are well below the FCI 60% threshold of Newtonian reasoning in mechanics. It can be concluded that the large part of the Croatian gymnasium students are still pre-Newtonians when they finish school and enter universities. This finding suggests that physics instruction in gymnasia is not very effective in developing conceptual understanding of mechanics in students. Physics instruction in Croatia is still largely of traditional lecturing type, which has been shown by physics education research to be rather ineffective in changing students' alternative conceptions and in developing conceptual understanding of physics [4]. Lecturing type of instruction should be replaced by more interactive teaching which will take into account students' prior knowledge and their intuitive ideas about physics. Another problem is the too extensive gymnasium physics curriculum which forces teachers to cover topics rather quickly. Developing conceptual understanding of physics is a difficult task which takes time. It would therefore be important that the number of topics in gymnasium physics curriculum is reduced to allow more time for the meaningful teaching of the remaining topics.

Similar problems are found in other countries as well (e.g. USA [4] or Germany, [5]). It appears that it is not easy to achieve high FCI scores, especially in general student population. Even though we have not attempted in our study to establish a link between the type of instruction and the FCI scores, we have come

across anecdotal evidence that where interactive teaching methods are used scores are higher than the average, but to confirm that link further research would be required.

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