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IMPACT OF INTERACTIVE TEACHING METHODS ON HETEROGENEITY

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We describe an investigation of the heterogeneity in conceptual understanding of first-year engineering students by using the force concept inventory (FCI) as a diagnostic tool. The average FCI pre- and posttest results depend significantly on the type of school graduation. Even interactive teaching methods that have proven to be more effective in learning outcome cannot dissolve this heterogeneity within the first year of university study.

Keywords: active learning methods, Force Concept Inventory, heterogeneity, learning outcomes

INTRODUCTION

Lecturers of introductory physics courses at universities face the fact that the groups of students are considerably heterogeneous with respect to their pre-knowledge. In Germany this heterogeneity has been increasing over the last decades due to new admission rules to higher education. In this context, we measured heterogeneity in terms of conceptual understanding of Newtonian mechanics using the force concept inventory test (FCI) [1] as a diagnostic tool. We investigated to what extend this heterogeneity can be overcome by using interactive teaching methods.

The effectiveness of teaching methods in physics education is widely measured by the force concept inventory test (FCI) [1]. The 1998-survey study of Hake et al. reports that by usage of interactive engagement methods in the US the average learning gain is approximately doubled compared to traditional formats [2].

Within an implementation project fostering active learning methods at German universities of applied sciences in STEM-education [3], we shifted our didactic approach from conventional lectures to interactive engagement methods, which we adapted to the German education system. Our teaching methods [4] are mainly based on just in time teaching (JITT) [5] and peer instruction (PI) [6]. In order to assess the outcome of this shift we used the FCI. Together with the test we asked the students for information on their previous physics education at school, including school type.

TEST METHOD

The Force Concept Inventory

The force concept inventory test (FCI) was designed to assess students' conceptual understanding of Newtonian mechanics [1]. It is considered to be the most reliable and well established concept test for introductory physics and it is widely used to evaluate physics courses (see [2]). The test consists of 30 multiple choice questions to be answered in 30 min yielding a maximum of 30 points. Statistically 6 points can be achieved by mere guessing.

We use the FCI test as a pre-test within the first two weeks of introductory physics courses and as a post-test at the end of the corresponding course three or seven months after the pre-test depending on the duration of the physics course (one or two semester).

After the test the students get to know the number of points they achieved, but they will never see the questions except during the test. The students are informed that the results are used for diagnostics only and have no influence on the final exams.

On the answer sheet students are asked to give information about the type of school they attended previously and the number of hours of physics instruction per week at school. Further an identification number is given so that results of pre- and post-test can be correlated. We calculate an individual gain for each student by calculating the ratio of the achieved increase of points and the maximum achievable increase:

$$gain\ g = \frac{p_{post} - p_{pre}}{30 - p_{pre}} \qquad (1)$$

with p_{pre} : number of points achieved in the pre-test

p_{post} : number of points achieved in the post-test

Be aware that this gain definition refers to the individual points achieved by a single student whereas the gain defined by Hake [2] is based on mean values achieved by a class.

Student Groups

In the five academic years from 2013/14 to 2017/18 a total of 39 classes of first-year students from all nine different engineering programs at the Technical University of Applied Sciences Rosenheim, Germany were investigated. These groups were taught by nine different lecturers, with four of them using interactive engagement methods. We collected pre-test data of 2783 students in 39 classes and post-test data of 1433 students in 37 classes allowing us to calculate individual gains for these 1433 students.

The varying number of students for pre- and post-test is partly due to students who left the class and partly due to students who did not turn up for the post-test. This is a usual behaviour since attendance is not mandatory. An analysis of the students who participated at the pre-test only and did not perform the post-test shows that there is no bias with respect to school type or test result. The reported results are therefore representative.

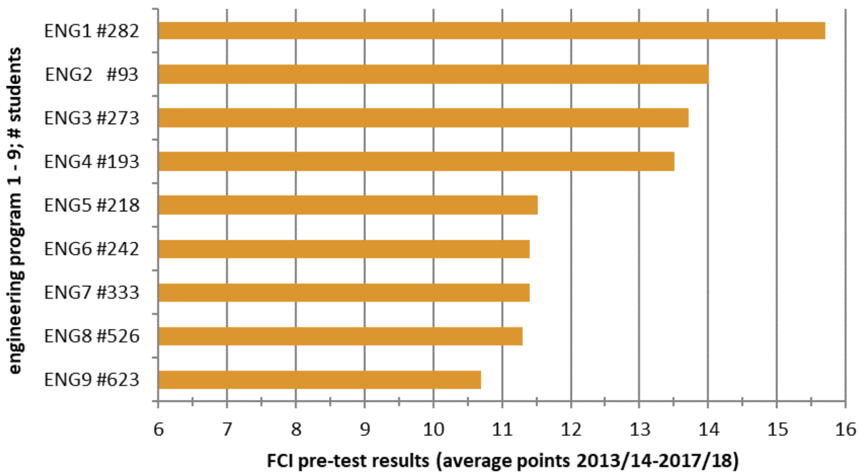

Fig. 1. Average points achieved in the FCI pre-test for students in nine different engineering programs (five academic years, 2783 students in programs like mechanical engineering, electrical engineering or industrial engineering). Numbers give the amount of students within each group.

The distribution of test results varies systematically between bachelor programs even for the pre-test (see fig. 1). Obviously there is a self-selection when choosing the study program. As we directly want to find out whether the heterogeneity in pre-knowledge decreases after one year of study, we selected the largest student group (industrial engineering, same lecturer and teaching method) and compare only the students who took part in both, pre- and post-test.

HETEROGENEITY OF PREVIOUS KNOWLEDGE

The pre-test reveals information on the level of students' conceptual understanding of Newtonian mechanics. In figure 2 we show data for the industrial engineering program (342 students). This restriction is done in order to get rid of systematic differences between the study programs.

The German school types qualifying for tertiary education at universities of applied sciences (*Fachhochschulen*) are mainly *Gymnasium*, *Fachoberschule (FOS)* or *Berufsoberschule (BOS)*. The latter two are based on a *Realschule* – degree and are partly specialized. For our purpose we distinguish between the specialization aiming for a technical bachelor program (*FOS/BOS technical*) an all other programs (*FOS/BOS other*) which are specialized for e.g. economics or social studies. For more information on the German education programs see [8].

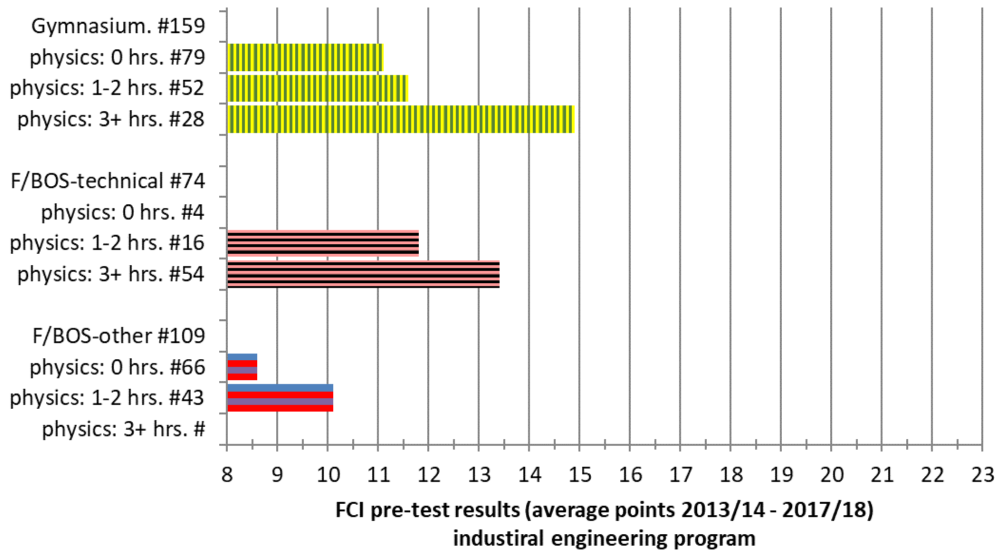

Fig. 2. Average points achieved in the FCI pre-test for different groups of students (five academic years, 342 students studying industrial engineering) clustered by school type and weekly hours of physics instruction at school. Numbers give the amount of students within each group.

For comparison of the FCI pre-test results for different secondary school types we have clustered the data with regard to school type as well as the number of weekly hours of physics instruction in the last two years at school. The mean FCI-results for each group are shown in figure 2. As mentioned above data are restricted to one study program only.

It can be seen that the mean values of the pre-test results for *Gymnasium* and *FOS/BOS technical* are comparable. Results for *FOS/BOS other* are considerably lower and close to results that can be achieved by mere guessing (i.e. 6 points). Within the school types the mean values increase with the number of instruction hours.

Results for the *Gymnasium* and *FOS/BOS technical* groups are in a similar range as the FCI-pre-test data from universities of applied sciences from 2003 [9]. In the 2003-study, *FOS/BOS* was not split into different fields (technical and other), but at that time almost all students from *FOS/BOS* who entered engineering study programs came from *FOS/BOS technical*.

The students from *FOS/BOS other* contribute strongly to the large heterogeneity of first-semester students.

EFFECTIVENESS OF ACTIVE LEARNING METHODS

In 2013 we began to implement just-in-time teaching [5] and peer instruction [6] in our introductory physics courses. Classes consist typically of 60 to 90 students. A reading assignment and a short online quiz is given weekly. The quiz consists of several questions addressing conceptual understanding as well as a few low level problem-solving tasks. In addition, students are asked to pose a question on the corresponding topic. Based on the answers to the quiz the lecturer decides "just in time" on which topics to focus within the lecture. In almost every or every second lecture we use peer instruction [6] to help students to develop an understanding of the physical concepts. In addition, we make use of the so called "Tutorials in introductory Physics" by McDermott et al [7] up to six times in a term.

We compare the learning outcome of these classes with results from classes held by different lecturers in traditional lecture format. The traditional teaching format is based on oral lecture combined with problem solving instruction, demo experiments and might contain some activating elements, for example discussions in small groups.

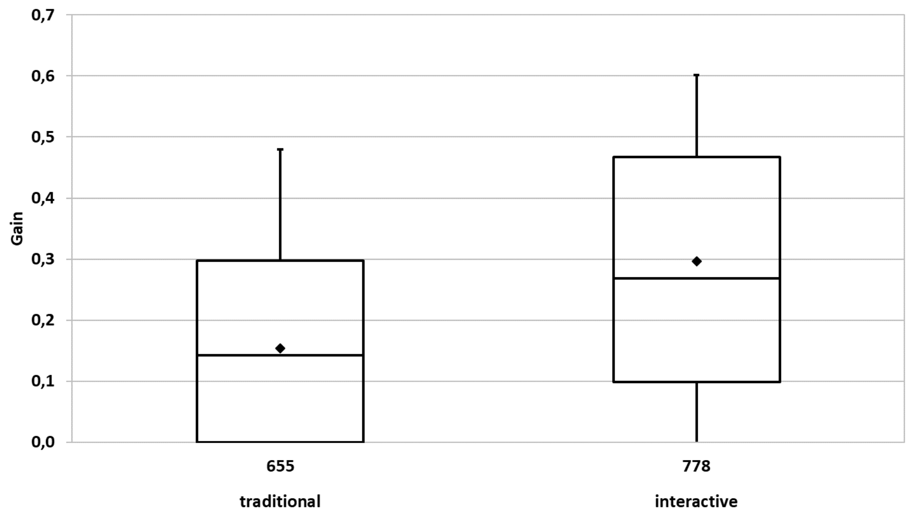

Fig. 3. Distribution of individual student gain in FCI test calculated according to eq. (1) for traditional lecture and interactive teaching methods over five academic years 2013/14 – 2017/18 (mean (♦) and quantiles (10%, 25%, 50%, 75%, 90%))

Within the five academic years 2013/14 to 2017/18 four lecturers have applied the interactive teaching methods on 19 introductory physics classes within six different engineering education programs. FCI post-test results from a total of 778 students out of these classes are available. The learning gain of these is compared with results from 655 students out of 18 introductory physics classes within six engineering education programs held by six different lecturers the traditional way. In figure 3 the distribution of the individual gain as calculated with eq. (1) is shown for these two groups. The mean of the gain for interactive teaching is with 0,30 significantly higher than the 0,15 achieved with traditional methods. This result confirms the findings summarized in [2].

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Figure 4 shows the FCI-results achieved at the end of the introductory physics course in the industrial engineering program grouped by school type. In comparison with the results of the pre-test at the beginning of the course (fig. 2) it can be seen that the mean value of each group increased by 4 to 6 points. The highest improvement (6 points) is in the *Gymnasium*-groups, the lowest (4 points) in the *FOS/BOS technical* groups. As the difference in increase is small between the groups, the overall heterogeneity does not significantly change within the first year of university study.

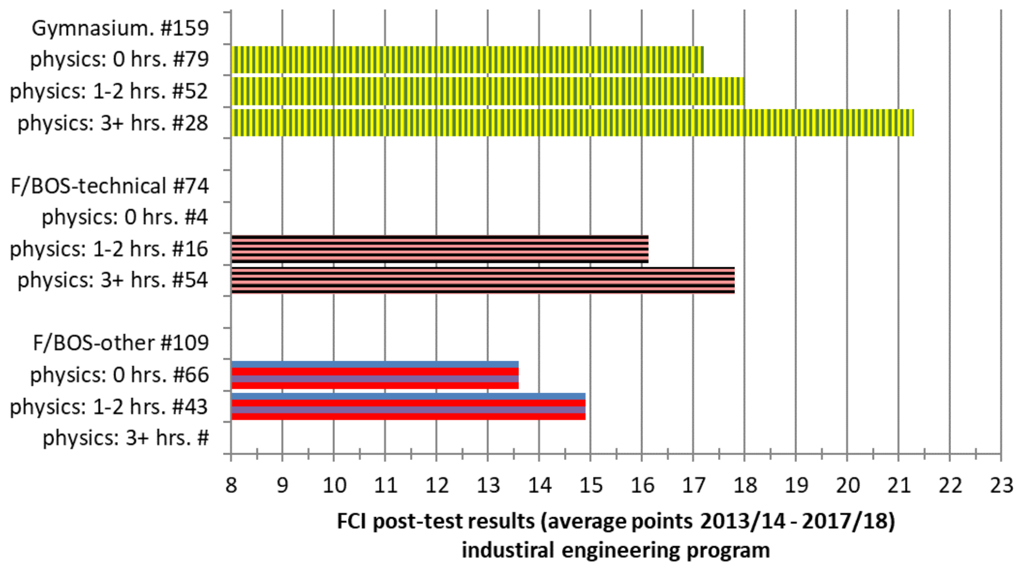

Fig. 4. Mean points achieved in the FCI post-test for different groups of students (five academic years, 342 students studying industrial engineering) clustered by school type and weekly hours of physics instruction at school. Numbers give the amount of students within each group.

CONCLUSIONS

The data presented here show that the previous knowledge in mechanics of students entering various engineering study programs depend strongly on the type of school graduation and the amount of physics that was taught at school. Especially those with a degree from *FOS/BOS other* have on average a significantly lower conceptual understanding of Newtonian mechanics and thereby increase the overall heterogeneity. The pre-test results vary a lot between different engineering study programs due to a self-selection of the students.

Interactive teaching methods that are proven to be more effective than traditional lectures significantly increase the level of conceptual understanding. Nevertheless, differences in mean values of the force concept inventory test achieved for the different school type groups remain after one year of study. The interactive teaching methods used obviously do not level out the learning outcomes of the different groups but ensure a higher increase in understanding for all levels compared to traditional lecturing. Both – students with lower and with higher previous knowledge in mechanics - benefit from interactive teaching methods, thus not leveling off heterogeneity.

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