INCREASED STUDENT PERFORMANCE ON PHYSICS CONCEPT INVENTORY TEST AFTER STUDENT-CENTRED APPROACH IN UNIVERSITIES OF LATVIA

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Abstract

Education research has repeatedly shown that active learning in physics is pedagogically more efficient than traditional lecture courses. Widespread application of the active learning is slowed down by the lack of data on the performance of the active learning in widely varying circumstances of different educational systems. We measured the level of understanding of basic physics concepts using Force Concept inventory for students who enrol at different universities in Latvia in calculus-based and non-calculus-based groups and compared the student performance to the pre-test results elsewhere in the world. We measured the growth of concept inventory test results and studied the dependence of the growth on the teaching approach used by university lecturers. About 450 undergraduate students from 12 groups of science and engineering courses taught by 8 lecturers were involved in the study at three universities in Latvia. The Force Concept Inventory multiple-choice test was translated to Latvian and used for pre-/post-tests. The pre-test results showed that the maximum of the distribution of correct answers for non-calculus groups is around 20%, which is the value obtained by the random guessing of test answers, whereas the pre-test results of calculus-based groups was about 50% of correct answers. The test score after taking post-test confirmed that the growth of students' tests results is closely related to the teaching approach chosen by lecturer, showing that in order to provide physics graduates with a good conceptual understanding of physics, student centred teaching approach was crucial. The use of concept inventories in undergraduate physics education to measure the progress of learning appears to be particularly important in the current situation with a small number of students in physics and a critically small number of future physics teachers, when efficiency of teaching is of crucial importance.
Keywords: *STEM education quality, conceptual understanding, student-centred approach*

Introduction

In Latvia students are enrolled at universities after completing secondary education and after participating in Centralized Examinations organized by the State. There is no mandatory final exam in physics and students can enrol in the science and engineering faculties in Latvia without a physics exam grade. It is possible to be accepted at university only by the result of a mathematics final exam. Some Upper-secondary school graduates, who see their future in physics or engineering, choose the State

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Centralized Exam in Physics. Since at the undergraduate level of physics, students may enrol at universities without physics exam, the teaching staff at universities must reckon with unpredictably varying initial knowledge and understanding of physics for different students at the beginning of physics courses. Lecturer's claim that the understanding of physics after upper secondary is generally low, but it is only a subjective point of view, usually communicated without further justification or quantitative measurement. The teaching of physics courses also benefits from measurement allowing to quantitatively characterize the growth of student's understanding of physics and growth of skills to apply physics laws, depending on the learning approach used in a course.

In order to measure the understanding of student's basic concepts of physics at the beginning of undergraduate physics courses and to determine the growth of understanding, Force Concept Inventory (further FCI) was used at several universities of Latvia during this research in 2018–2021.

Research Questions:

- How high is the level of understanding of the basic physics concepts of students who enrol in calculus-based and non-calculus-based groups, as objectively assessed by concept inventory and how does this level compare against FCI pre-test results elsewhere in the world?
- How high is the growth in concept inventory test results for students depending on teaching approach used by university lecturers?

FCI was developed and first applied by Hestenes, Wells and Swackhamer (1992, March). The evidence of their study was essential: "the knowledge gained under conventional instruction is essentially independent of the teacher" (Savinainen, 2002). A revised version of the FCI was developed and placed on the web in 1995 (Halloun et al., 1995) and later appeared in Mazur's book (Mazur, 1997). A detailed analysis of FCI results with large statistics, including six thousand students in the study, was performed by Hake (1998).

The growth of student understanding of basic physics concepts is measured as FCI gain. Gain described in studies ranges from about 20%, which is just a fifth of the student's potential achievement, up to about 70%. For example, Georgia States Universities, US, recent study using FCI test included more than 5,000 students showed the average gain that range from 47.4% up to 71.3% (Caballero, Greco, Murray, Bujak & Marr, 2012). Similar results are seen in two other studies: at the University of Toronto first year Physics course (Lasry, Watkins, Mazur & Ibrahim, 2013) reports gain values of 34.03–45.02%; in the Physics and Astronomy New Faculty Workshop (Lee, Manju, Dancy, Henderson & Christensen, 2018) the average gain between 40–60% was observed.

So far, the FCI has been administered to countless thousands of students at many universities worldwide. The FCI has not lost its relevance and has been re-examined and as the research by Von Korff et al. (2016) suggests, interactive engagement teaching techniques are significantly more likely to produce high student learning gains than traditional lecturing approach.

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Research Methodology

Background

The study was initiated at University of Latvia. It relies on FCI test as a measurement tool. FCI test consists of two parts: pre-test and post-test composed of multichoice questions and is given at the beginning and end of the course. The measurement is performed by calculating the absolute and relative difference of the results (Hestenes et al., 1992; Lasry et al., 2013). In order to use it at universities of Latvia the FCI test was translated into Latvian and was given to students by several physics' lecturers during the period 2016-2018. During this period experience with the use of the test was gained and language translation inaccuracies were eliminated.

In the first year of the study, FCI pre-test and FCI post-test were carried out at University of Latvia only for one first year undergraduate calculus-based physics course in 2018, and the results were reported at the BalticSTE'19 conference by Cinite and Barinovs (2019, June). After that, the research was continued for students at several universities until autumn 2020, when due to remote training it was decided to not use the FCI test remotely. At this time, the test was administered, and data was analysed for 12 undergraduate student groups at three universities in Latvia involving approximately 450 students in total.

Participants

Students of undergraduate physics courses of three universities: University of Latvia, Riga Technical University and Ventspils University of Applied Science, were involved in this research during the time period 2018–2020. The research includes 445 student's pre-test results.

Not all students performed a post-test, and there were a number of reasons: firstly, for all groups studies started in person, but three out of twelve groups were forced to continue the studies remotely soon after the course started due to the Covid-19 restrictions; and several students did not complete the post-test due to other reasons. The post-test could not be performed if the physical presence of students were not possible during post-test. 344 FCI post-test results were obtained, but only 342 students participated both in pre- and post-test and their results were used to calculate the relative and absolute test score gain in nine groups.

About a quarter of students or 111 students were in calculus-based groups. Participants were approximately 18–20 years old, slightly more than half or 58% of all students were male and 42% female. The classes were taught by 8 lecturers at different levels of the academic ranking: three associate professors, three docents and two lecturers. Three of the lecturers have a doctor (Dr.) degree and other five have a masters (Mg.) degree.

Procedure

The FCI test has been used in a research by the University of Latvia since 2018. Two years before the start of this research, the FCI test was translated into Latvian

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and approbated to several groups of students and checked by university teaching staff to prevent translation errors. The original FCI procedure was retained in all research groups: the pre-test was given to students in the first lecture, before starting the course, the post-test was given out at the end of the relevant topic of the mechanics or at the end of a course of mechanics. Both parts of the test were carried out by students in-person, in-classroom, in writing. When it was possible, the course lecturer did not know the test questions in order to prevent the lecturer from preparing the students to correctly answer the specific answers of the post-test.

As in our previous study (Cinite & Barinovs, 2019) teaching effectiveness is characterized by relative learning gain, $\langle g \rangle$, which is defined as the relative change of test results with respect to the maximal possible test result increase from pre-test to post-test

$$\langle g \rangle = \frac{\langle Post \rangle - \langle Pre \rangle}{100 - \langle Pre \rangle},$$

where $\langle Post \rangle$ is group average post-test result and $\langle Pre \rangle$ is group average pre-test result. The relative gain is used since it less depends on the initial knowledge on students and allows to compare groups with different pre-test results. Our calculated gain can be compared to the 0 to 34% average gain $\langle g \rangle$ that has been observed for traditional teaching approach and classes with low student engagement (Hestenes et al., 1992; Lasry et al., 2013).

Research Results

FCI Pre-test Results

Data for all 12 group pre-test results are collected in the Table 1. The group's average pre-test results are in the 18–54% interval of correct answers. Pre-test results for three calculus-based groups are relatively high, in the interval 49–54%; for nine non-calculus-based groups the number of correct answers is between 18% and 37%. The FCI post-test was administered only for nine groups, as three groups started to study remotely after the pre-test. The average relative gain and the average absolute gain of each group was determined for nine groups possessing post-test results.

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Table 1
FCI Test Results for Twelve Student Groups, 2018-2020

	N.	Semester	Group average FCI pre-test result	Group average FCI post-test result	Group average absolute gain	Group average relative gain	Learning approach S – student centred, L – lecture centred
			%	%	%	%	
calculus based groups	1	Fall 2018	54	65	11	27	L
	2	Fall 2019	49	81	32	65	S
	3	Fall 2020	51	*continued learning remotely*			
non calculus based groups	4	Fall 2018	37	49	12	23	L
	5	Spring 2019	22	48	26	33	S
	6	Fall 2019	23	54	31	40	S
	7	Fall 2019	25	60	35	47	S
	8	Fall 2019	26	43	17	25	L
	9	Fall 2019	23	61	37	51	S
	10	Spring 2020	26	*continued learning remotely*			
	11	Spring 2020	18	*continued learning remotely*			
	12	Fall 2020	22	48	26	34	S

FCI Gain Results

We separately analysed results for two groups: the results of groups where lecturers worked with a lecturer-centred approach and the results of groups where lecturers worked with a student-centred approach. In the student-centred classes 70–80% of time was spent on lectures and 20–30% of time was spent on peer instruction (Mazur, 1997). Lecturer-centred approach classes consisted of information presentation by lecturers followed by solving standard end-of-chapter exercises at different levels of difficulty. Several lecturers in student-centred classes were considerably less experienced than lecturers in lecturer centred classes.

In each of these groups, we analysed the results of calculus-based groups and the results of non-calculus-bases groups separately.

For a calculus-based group with a lecturer-centred learning approach, the group's relative gain is 27%, for a group with a student-centred learning approach average relative gain is 65% which is the highest result in this study. Similar difference of gain in student-centred classes being higher is for non-calculus-based groups. In these groups, a lecturer-centred approach for two groups has resulted in relative gain 23% and 25%, a student-centred learning approach for five groups has yielded 33–51% range for relative gain.

The results are shown in Figure 1, where the idea and visual style of the Figure is adapted from Hake's study (1998). The Figure 1, where different symbols: a blue triangle and a yellow diamond, highlights separately the groups in which the lecturers worked with different learning approaches.

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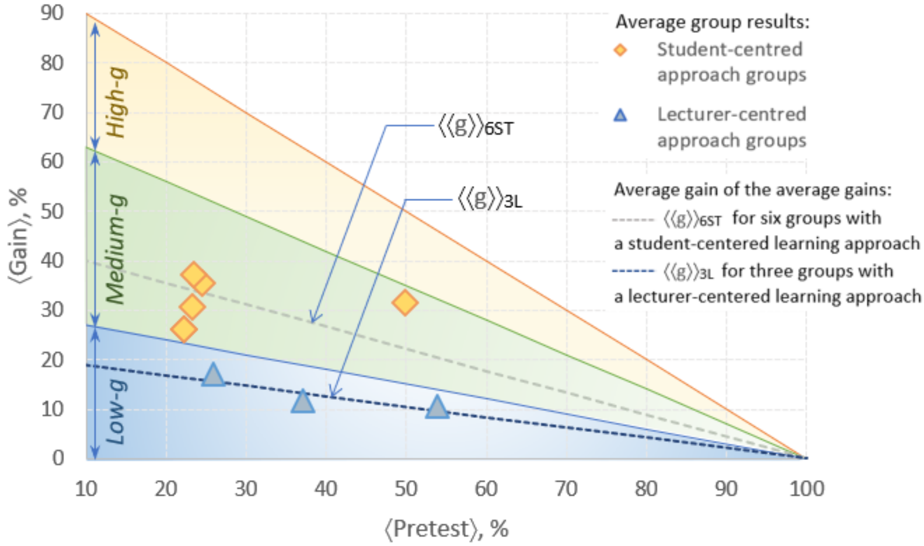
Figure 1
Pre-test Results versus Absolute Gain



Three different colour bars in Figure 1 show the level of the relative gain achievement: 'Low-*g*' result of the groups , a 'Medium-*g*' result , a 'High-*g*' result .

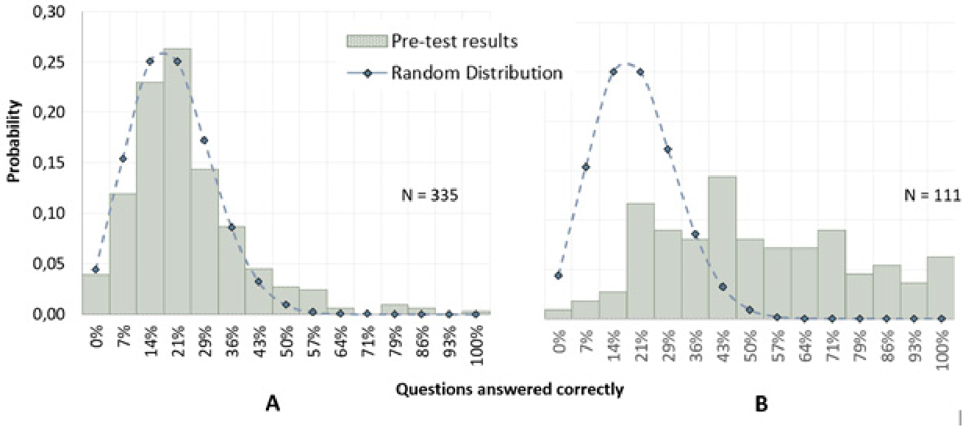
As shown in Figure 1, for those groups where lecturers worked with a student-centred approach, the results are found in the medium-gain area. Regardless of the pre-test results, students were able to achieve a relatively high gain. For lecturer-centred learning approach groups, regardless of the outcome of the pre-test, the gain is placed in a low-achievement area. Among these groups, there is also one calculus-based group with the highest pre-test score of 54%, but only 27% relative gain result.

Normal Distribution and Random Probability of Results

The maximum for probability distribution of correct answers in the pre-test for non-calculus groups is close to 20%, which is close to expected maximum for the random guessing of the test answers in a multiple-choice test with 5 answers for a question. In order to see what part of correct answers could be explained by a simple chance, we have compared the results of the pre- and post-tests with a distribution for random guessing one correct answer out of the five equally possible answers. As can be seen in Figure 2, the pre-test results of non-calculus-based groups with N = 335 students remarkably well coincide with the binomial distribution generated by random guessing and both distributions are almost indistinguishable. That suggests that students in non-calculus groups might not possess the knowledge of the basic concepts of physics prior to enrolment at university even if their score is above the average and their higher score might be by a pure chance. On the left side of Figure 2, the centre of distribution of correct answers for students in calculus-based groups is shifted to the right comparing to the probability distribution predicted by random guessing and points to some initial knowledge of students.

Figure 2

Histogram of the FCI Pre-test Results

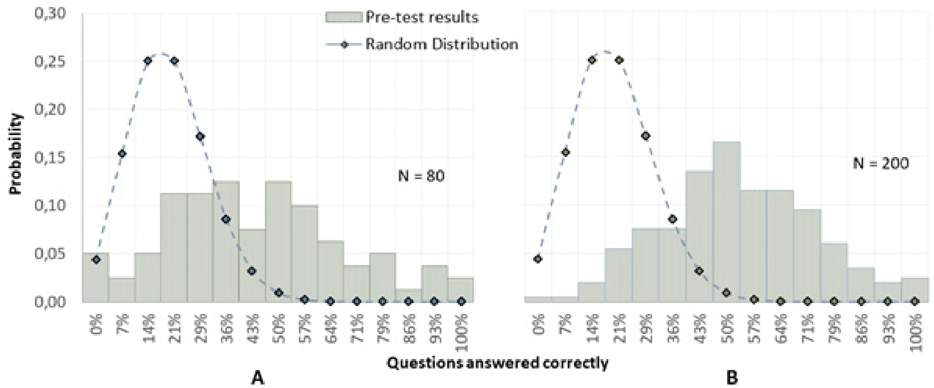


Note: A – non-calculus-based and B – calculus-based students; and dashed line of random probability distribution to answer correctly one of the five possible answers for each question.

In the post-test results for all groups the random probability distribution is placed to the left from distribution generated by students' answers, (see Figure 3) showing the growth of student knowledge in both groups.

Figure 3

Non-calculus Groups FCI Post-test Results



Note: A – Lecture centred groups and B – Student centred groups result.

Discussion

The results of this study show that the groups in which lecturers worked with a student-centred approach were able to achieve high relative Gain above 30% despite the low pre-test results for the students. This agrees with the original study of the FCI (Hestenes et al., 1992) that found high relative Gain above 34% achieved by lecturers working with a student-centred approach. Groups, where lecturers worked with a lecturer-centred approach, demonstrated low efficiency, irrespectively to the group's pre-test results. The gain results of this research demonstrate that in universities in Latvia relative gain falls in intervals of 25–65% similar to the studies elsewhere in the world.

The pre-test results for non-calculus-based groups showed that the maximum of the distribution of correct answers is around 20% which is the value obtained by the random guessing of one correct answer of five multichoice test answers. The pre-tests result of calculus-based groups was about 50%. The post-test result confirmed that the growth of students' tests results is closely related to the teaching approach.

In this study the gain as measured by FCI did not depend on lecturer's scientific degree or lecturer's status on an academic pedagogical or academic researcher level. This also has been observed in the study of Hestenes and Halloun (1995).

Conclusions and Implications

The results of the 4-year study on FCI pre-test for 12 undergraduate level student groups have been compiled from 445 students who learned physics in science and engineering courses of three universities in Latvia. To our knowledge, this is the first published FCI study in Latvia and the Baltic states.

FCI pre-test results show the level of students' understanding of the physics basic concepts at the beginning of the studies: the mean pre-test scores for the three calculus-based groups ranged from 49% to 54%, and for the nine non-calculus-based groups ranged from 18% to 37%. Relatively high pre-test scores for calculus-based groups may be explained by students' motivation to study physics, this and other variables should be included in a future research. The distribution of the pre-test results of the non-calculus-based groups is close to the random probability distribution when students correctly guess one of the five possible answers to a question.

The achievement of the student groups as characterized by the relative gain of pre-/post-test results correlates with the lecturer's teaching approach. Groups where training took place through a lecturer-centred approach reached the Relative Gain in the range of 23–27%; two of those groups were non-calculus-based, one calculus-based group.

The result of about 25% reached in lecture-centred learning groups shows that students had been able to reach just a quarter of possible gain on a basic mechanics comprehension test. Those groups also had relatively more students that showed a negative gain. This could indicate a student's confusion in understanding of the basic principles of physics and following guessing of correct answers in the post-test.

Groups where lecturers worked with a student-centred learning approach have shown larger growth in conceptual understanding with the relative gain above 34%. The highest result 65% was observed for the student-centred working calculus-based group.

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The main bulk of studies using FCI is done in United States. This research allowed to verify the FCI in the context of very different education system of Latvia. The research confirmed that in order to provide physics graduates with a good conceptual understanding of physics as measured by FCI, student centred approach is crucial.

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Declaration of Interest

Authors declare no competing interest.

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