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Improving effectiveness of teaching large introductory physics courses with modern information technology

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Abstract

We facilitated active involvement in learning of all students addressing also their individual backgrounds by carrying out diagnostic tests, offering a variety of web based resources and class activities. Elements of the flipped class and multimedia means were introduced by providing video recording of lectures and getting feedback through question-answer sessions and by administering mini quizzes. The significant cultural, educational and ethnical diversity of the class required also to address individual qualities and preferences of the students by providing a wide range of educational materials. In the future, it is important to develop quantitative statistical characteristics which can serve as metrics for the efficiency of different course components. The roles of different course components were analyzed, in particular the final grade and the completion success of homework assignments and answers on clicker questions were correlated. The emphasis was placed on comprehension of the basic mathematics concepts needed for the course that was assessed at the beginning, and the problem solving skills were tested at the intermediate exams.

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1. Introduction

The preparation of specialists able to lead the development of scientific and technological innovation as well as to teach related disciplines goes through all stages of students' education. A particular role belongs to physics

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education, which teaches such skills as critical thinking, ability to find the right approaches to solving problems and then by expressing problems with equations finally reach quantitative answers. The teaching of such classes sets challenges in implementing the most progressive methods of education and efficient instructional materials that introduce active training and achieve a successful and long lasting effect of student learning.

The goal of this effort was to develop active learning methods in a core curriculum physics class setting. We have introduced features of the flipped classroom approach that draws on such concepts as active learning, engagement of students, and employment of Internet resources, such as TAMU MediaMatrix for streaming video recordings of lectures and polling software. The availability of recording technology and the ubiquity of web-based dissemination tools make the inverted class style both timely and effective, giving in addition the benefit of evaluating and assessing student activities.

This core curriculum course covers a broad range of topics in Mechanics, Thermodynamics, Sound Waves, Oscillations and Fluid Properties with typically ~700 students per semester (mostly first-year engineers). Students are divided into lecture classes of ~125 and further subdivided into recitations of about ~25. Weekly homework problems are assigned with Mastering Physics (Pearson e-text) which encourages critical thinking using the learned material. The main two goals pursued in teaching this course are to ensure for each student: (1) the understanding of the basic laws and concepts of physics in the above mentioned areas and developing skills of applying learned concepts to solving related problems, and (2) the ability to apply knowledge of mathematics to practically relevant problems in science and engineering.

The applied teaching techniques were intended to help students in mastering basic physics skills, including: (1) understanding of terms, notions and facts as well as learning concepts and theories, (2) developing problem-solving and mathematical skills, (3) the ability to apply principles and generalizations already learned to new problems and situations, (4) fostering the ability to think creatively, (5) learning to concentrate on major factors and to disregard insignificant ones; understanding the concept of accuracy of measurements and importance of correct estimates, (6) in laboratory work and research, to develop the ability to draw reasonable inferences from observations, to synthesize and integrate information and ideas, improve skills in using materials, tools, and/or technology relevant to the subject. (7) becoming adept at turning the physical quantities into symbolic variables, translating the problem into equations, and finding both a closed-form solution and a numerical answer; the ability to identify relevant laws and formulas appropriate to solve a given task, formulate and solve engineering problems.

The direct experience of teaching such a class and literature reports (Snetinova & Koupilova, 2012; Ogunleye, 2009) reveal evidence that there are several main problems in achieving successful outcome for all students of the class: (1) students come to study physics with very different backgrounds, and therefore diagnostics and identification of the points of weakness of each individual student early in the course are of utmost importance; (2) the concepts are well learned when they are used and actively applied in problem solving, however attempts to memorize formulas instead of applying analysis and critical thinking often prevail (Kima & Pak, 2002); (3) rather often scientific discoveries made in the 18th and 19th centuries (which make the basis for this course) remain disconnected from the realities of the modern science and technology, and therefore the task is to relate the concepts of the course with the contemporary physics and the state-of-the-art engineering applications and discuss these modern developments in the classroom.

2. Demography of students

This study describes teaching results in one class. The demographic data of the students are listed as two charts. There were total of 110 students in the class of which 49 responded to the survey. The average age was 19.7(2) years. The gender was almost equally divided (53.1% females, 46.9% males). In ethnicity, enrolment was highest for Caucasian (67.3%), then Asian (18.4%) and Hispanic (12.2%). The majority had their education in the USA (95.9%) followed by Asia and Europe. Their majors divided into many bio- and agri-sciences and engineering specialties.

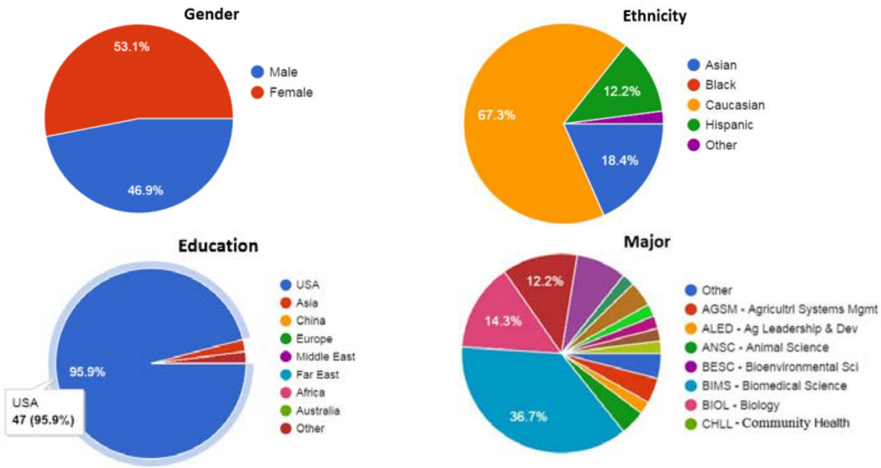

Figure 1. Demography of students (out of 49 responses).

3. The approaches (used, in progress and to be implemented)

3.1. The approaches used

First, all students were asked to take a compulsory mathematics diagnostics test. The material of the course required a mastery of the following mathematical concepts (Toback et al., 2005): 1) simple algebraic expressions in one variable; 2) systems of equations in two variables; 3) quadratic equations and identities; 4) geometry and trigonometry (vectors are taught in the first class hours); 5) fractions, numbers, exponents, powers of 10; 6) word problems and proportionalities. The requirement was to pass with 100% on all sections of the diagnostics test during the first week of class with an unlimited number of attempts.

Second, the elements of the flipped classroom setting were used. A flipped class is similar to a workshop with students trying to apply their beforehand-learned knowledge as part of their preparation for the class to put forward and answer questions and solve problems (Herreid & Schiller, 2013). An important component of this learning process is the students' interaction with one another. The role of the instructor as a facilitator/mediator is to select the questions and ideas that can be most instructive and enlightening and direct the students' quest for the correct answers, encouraging a collaborative effort. Flipped classroom is a valuable addition to the traditional lecture-homework format, since it shifts the priority from merely covering the material to active student attempts to master it. Before the class, students were provided recorded material and slides of the upcoming lecture and were advised to read the respective chapter in the textbook. At the beginning of the lecture a mini quiz was offered with clicker responses that immediately showed prevailing multiple choice answers, and thus allowed the instructor to assess preparation of the class and the level of comprehension of the material.

Short tutorial video lectures let students move at their own pace, rewind to review portions, and skip through sections they already understood, meaning students come to class able to use the software and prepared to do creative projects with their peers. Free interactive software enables students to discuss, apply, and get feedback from what they hear in the lecture. In a traditional lecture, students often try to capture what is being said at the instant the speaker says it. They cannot pause to reflect upon what is being said, and they may miss significant points, because they are trying to transcribe the instructor's words. By contrast, the use of video and other pre-recorded media puts lectures under the control of the students: they can watch, rewind, and fast-forward as needed. This ability may be of particular value to students with disabilities or to those for whom English (used in this course) is not their first language. Devoting class time to discussion and application of concepts gives instructors a better chance to catch misconceptions and erroneous thinking, especially those that are widely spread in the class. It also provides a possibility to relate the course materials to examples from the forefront scientific research and technical applications.

After studying instructional materials and viewing videos, forming in combination a learning module (Sadaghiani, 2012), students were given the opportunity to ask questions, express their opinions and suggestions regarding the material they studied. These responses helped the instructor to introduce necessary adjustments. What is vital and useful was preserved, and those parts of the instructional materials that were not meeting the expectations and needs of students were excluded. Students had time to ask and put forward their own hypotheses and try themselves to find the answers. This approach stimulated the development of inquisitive minds by using an inquiry as one of the powerful learning experiences, since inquiry is central to science learning. When engaging in inquiry, students are stimulated to describe objects and events, to ask questions, to construct explanations, to test those explanations against current scientific knowledge, and to communicate their ideas to others. They had to identify their assumptions, to use critical and logical thinking, and to consider alternative explanations. In this way, students actively developed their understanding of science by combining scientific knowledge with reasoning and thinking skills.

Third, a library of video recordings of lectures and problem-solving tutorials. A library of lecture video recordings was offered to students for viewing before each class. These recordings produced with Camtasia software were uploaded to the MediaMatrix teaching website of our university.

3.2. The approaches in progress

Forth, the development of an interactive site on the Internet with a physics forum for instructors and students. The existing website for the course presented the current course materials (syllabus, announcements, examples of previous exams, lecture notes and slides) and provided information to each individual student on his/her grades. For interaction with students also the Mastering Physics website (http://www.pearsonmylabandmastering.com) was used. These initial instructional materials will be complimented by a database of questions-answers from the class that we will initiate and maintain. We will also provide links to useful Internet sites with additional materials, such as Java applets; creating a virtual laboratory with possibilities to reproduce with models real situations presents another interesting direction. We also plan to record “teasers”, namely short videos pre-recorded by the instructor, which are highlighting recent relevant engineering and physics breakthroughs to stimulate students’ interest.

3.3. The approaches to be implemented

Fifth, for real time interactive teaching Google Forms will be used. This free online software is interactive in real time and allows for the many students to ask during the class questions simultaneously in written form, which can be viewed on the computer screen by the instructor, who can select the most critical and enlightening questions for discussion with the students. Google forms with questions provide also a feedback for interacting with the students who asked them, and the answers can be given to the whole class without disclosing which student asked the question (only the instructor knows this). Google forms permit also to test different modalities of the in-class and out-of-class interactions: Answers can be provided not only by the instructor, but for instance, to stimulate student-student learning, also the students themselves can provide answers receiving then credit. Quite memorable and rewarding can be finding a solution to a challenging question, especially if this question is put forward by the student himself or his peers (Herreid & Schiller, 2013).

Sixth, work of students in groups. It has been noticed that students learn a great deal from peers (Boud, 2001). So we will design a group project for each chapter, where students from the different engineering disciplines are grouped together to combine their knowledge with what has been taught in that chapter. A group consists of ~10 students and they complete one project and can choose which chapter to do. Collaborative projects encourage interactions among students, making it easier for them to learn from one another, exchange knowledge and support their peers. As an example, they can be asked to apply concepts of stress and strain, linear and volume expansion, static strain to designing the foundation of the tallest tower in the world (like the Burj Khalifa designed by Adrian Smith, TAMU university graduate, class of 1966). How many pillars of steel and concrete must be in the foundation? How long and wide it should be, so this building can be constructed on desert sand? What are the friction forces, which must be present, so it does not sink? To answer all these questions students with different backgrounds and knowledge will contribute their part, developing interpersonal communication skills, effective solving skills and the abilities to approach non-traditional problems and to relate different topics of the course and intrinsic motivation learning skills.

4. Outcomes

The final grade was composed of the following components: 3 exams 60%; Final (comprehensive) 20%; Lab 7%; Recitation 5%; Homework (Mastering Physics) 8%. To stimulate student progress the following rule was introduced: “if the grade on the Final Exam is higher than the lowest grade on one of the four exams during the semester, that lowest grade is replaced by its average with the Final in computing the course grade.”

The following two metrics were used to evaluate the students learning at the end of the semester. Figure1 displays the final overall grade points versus their solved homework assignments on Mastering Physics, and Fig 2 depicts the final overall grade points versus their clicker point score. These measures indicate that both the homework done out of class and the participation in class are important contributors to learning. On one hand the homework could be repeated with different numbers until a particular problem was solved and for the typical students this correlated also with the amount of time spent. On the other hand he clicker points tested pre-class preparation and knowledgeable class participation.

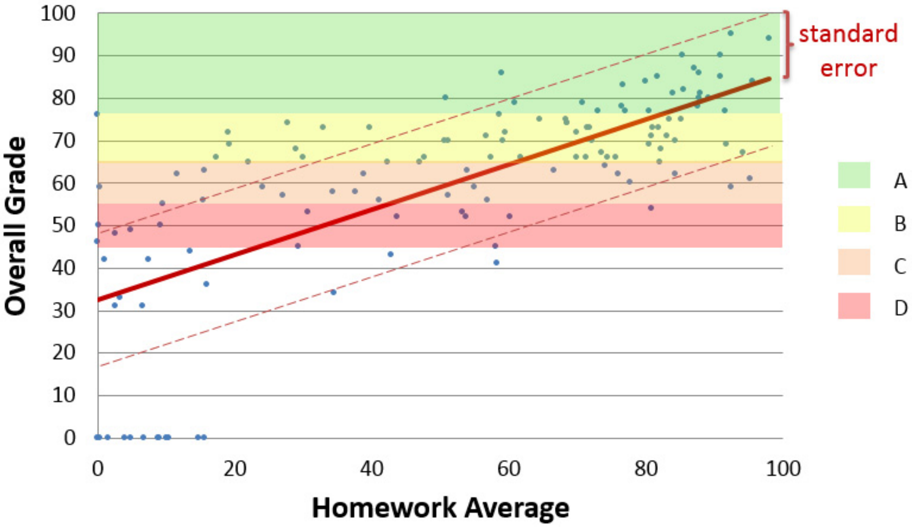

Figure 2. Final course grade vs. homework average. The ranges for A-D grades are shown by different colors.

At the end of the course an anonymous survey of students was conducted with questions targeting their evaluation of different components of the course. The students positively responded to a possibility to view the material in the form of video recordings of lectures; they also appreciated other components of the course, such as obligatory tutorials and testing in mathematics, homework with Mastering Physics and mini quizzes before the lectures.

A direct correlation can be seen between the time spent on graded Mastering Physics homework assignments and the final grade (Fig.4). However, this trend of higher grade with larger amount of time dedicated to homework breaks down for the portion of the dependence corresponding to the largest time spent. Apparently, these were the students who tried hard, but for different reasons still could not manage the top grade. Several points with zero final grade belong to students who dropped the class.

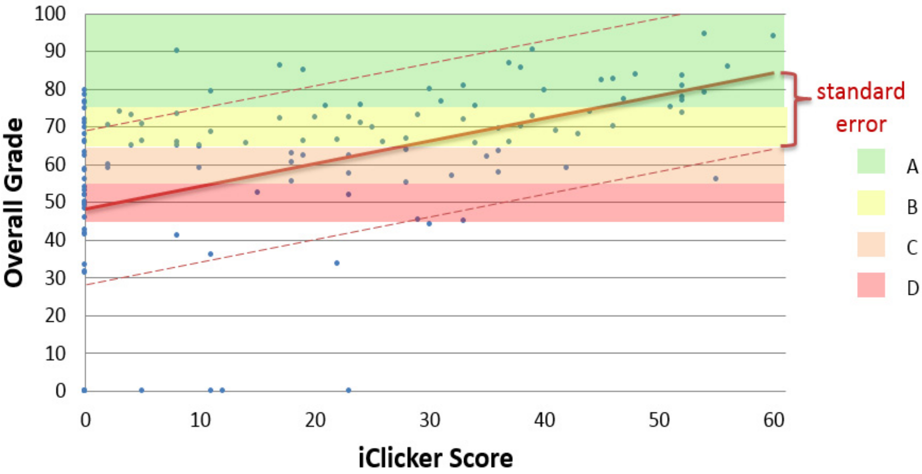

Figure 3. Qverall grade vs. i-clicker score. The ranges for A-D grades are shown by different colours.

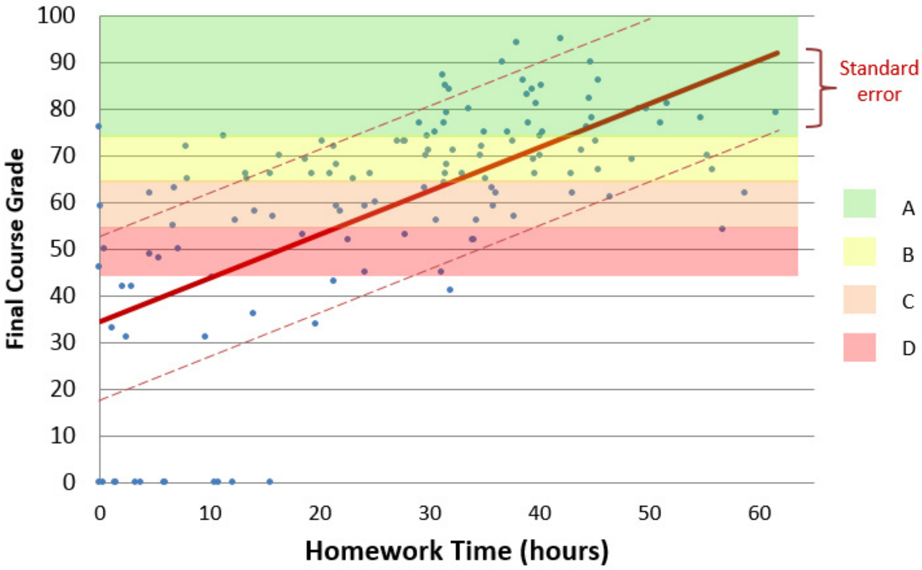

Figure. 4. Final course grade vs. time spent on home assignments.

The dependence of the time spent on each weekly homework assignment (Fig. 5) allows to make the following conclusions: (1) more time was spent in the beginning of the course (weeks 1,2) as well as on the weeks of the exams and just preceding them weeks (for the three administered exams these are weeks 5-6, 8-9 and 12-13 in the graph).

The average time spent by the students on graded tutorials (Fig. 6) indicates a spike in the beginning of the semester, when students had to familiarize themselves with the Mastering Physics system and a relatively uniform time spending throughout the rest of the semester. A relatively small average time that the students spent on each

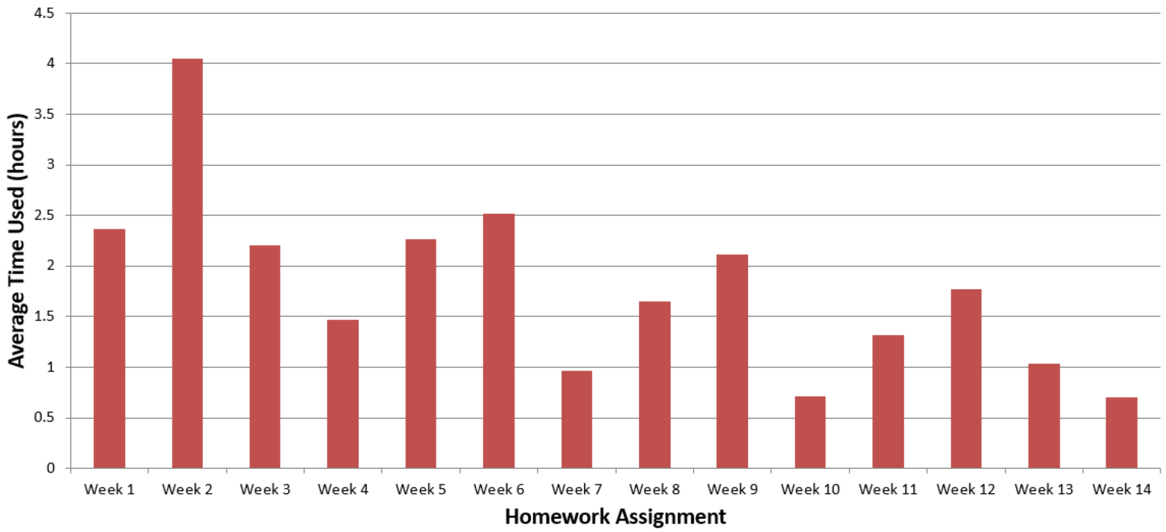

Figure. 5. Average time used by students for each weekly home assignment during the semester.

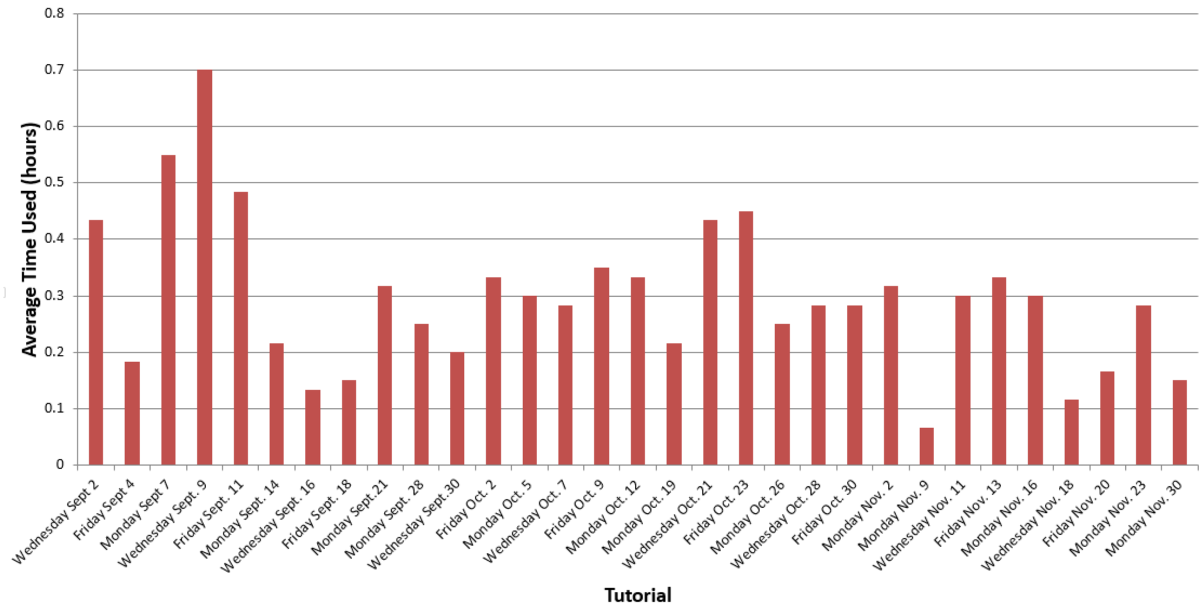

Figure. 6. Average time spent by students on graded tutorials during the semester.

Mastering Physics graded tutorial (about 20 min) shows that they did not experience significant conceptual or technical difficulties with their web-based homework.

5. Conclusions and future steps

In this work we aimed at improving effectiveness of teaching large introductory physics courses by implementing different approaches: using Internet Mastering Physics homework assignments, administering mini quizzes, providing pre-recorded videos of lecture presentations. With these approaches also some elements of the flipped class setting were introduced. The evaluation of outcomes was done in two ways qualitatively through an anonymous student survey and quantitatively by statistical measures. The significant cultural, educational and ethnical diversity of the class required also to address individual qualities and preferences of the students, and providing a wide range of educational materials helped in this respect. In the future it is important to develop quantitative statistical characteristics which can serve as metrics for the efficiency of different course components. In particular, the assessment of development of critical thinking throughout the course can be performed by giving the California Critical Thinking Skills Test (CCTST) at the beginning, at midterm, and at the end of the semester to demonstrate the students' progress in this dimension. The usage in the course of Mastering Physics for students' homework besides freeing time of the instructor provided a benefit of giving quantitative measures of student's efforts expressed in time spent on each of the assignments allowing to make conclusions on the distribution of their efforts throughout the semester.

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