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Teaching Electrical Engineering to non-EE Majors in a Flipped or Blended Classroom

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Teaching Electrical Engineering to non-EE majors in a flipped, or blended classroom

Abstract

We report the experience of teaching a large service course in Electrical Engineering (EE) for non-EE majors in a flipped, or blended classroom format, for five consecutive semesters during 2014 and 2015 (total, ~650 students). In order to engage students in active learning outside the classroom we created a large number of online self-assessments; in the terms of Bloom's taxonomy, they belong to the lower levels of learning – remembering and understanding. During the lecture time, we engage students in activities focused on the higher levels of learning – applying, analyzing, and evaluating. Our main research tools include the official end-of-semester course evaluations, which included both standard (University-wide) questions and the questions specially designed for the assessment of our course. We also used the statistics of students' votes with clickers during the lectures. The results reveal positive attitude of students to the online self-assessments and to active learning during the lecture time. The students' feedback has guided some of the adjustments of our teaching/learning strategies and indicated the need for mini-lectures in the blended classroom.

Contents

Introduction

In the medieval universities, which were founded *before* the printing press was invented, *lecture* (literally, *reading*) was the only way to convey information to students who did not have access to the precious manuscripts. The lecturer had to read them aloud, and the students took notes. Today, books are available to all, thus **wasting lecture time for reading aloud is not needed.** This simple notion led to many contemporary attempts to invert/flip/blend the classroom so that

> *… events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa* [1]

The multitude of specific recipes for how to flip a class reflects the diversity of education: even a brief search through ASEE publications with the keyword '*flipped*' yields more than a thousand papers describing various *flipped* courses. Not surprisingly, a recent survey admits that

> *There is a lack of consensus on what exactly the flipped classroom is.* [1]

Flipping a course requires at least 3 actions, which can be seen as disruptive innovations:

(1) Decide which "*events that have traditionally taken place inside the classroom"* will be moved outside the classroom, and explain to students how they benefit from this move
(2) Create the new teaching events *outside* the classroom to ensure that the student learning would not suffer as a result of the move (1), and
(3) Create the new teaching events *inside* the classroom to foster student participation in active learning and to utilize the scheduled lecture time more effectively.

Such innovations put additional loads on the shoulders of both the students and the instructors, causing natural resistance on both sides [2, 3, 4]. The learners' resistance was well articulated by one of our students who wrote:

> "*I am paying to be taught by a professor, not to read a book and teach myself."*

For a successful *flipping*, the instructors should create new types of teaching events outside and within the classroom [4], adapt to their new role in the classroom, and convince the students of the value of these innovations. For each particular course, these innovative actions (1 – 3 above) require careful planning, investment of resources, and courageous instructors and administrators.

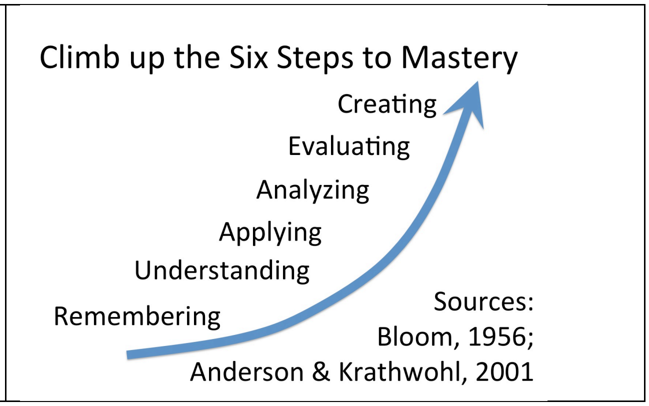
The presenting author of this report has been teaching a large service course in Electrical Engineering (EE) for non-EE majors for many years; his decision to *flip* it in 2014 was inspired by a lecture by Eric Mazur on peer instruction [Mazur], which included a vivid demonstration of active learning in class. In order to free up the lecture time for active learning, the class had to be flipped, or *blended*. To achieve this goal, all actions (1 – 3 above) had to be taken.

Our research questions and our challenges in flipping this course are intertwined. We had to create the strategies and the tools for student learning within and outside of class – and to investigate whether our creations were effective; we used the student feedback to make necessary adjustments, in particular, to decide whether the lectures could/should be eliminated.

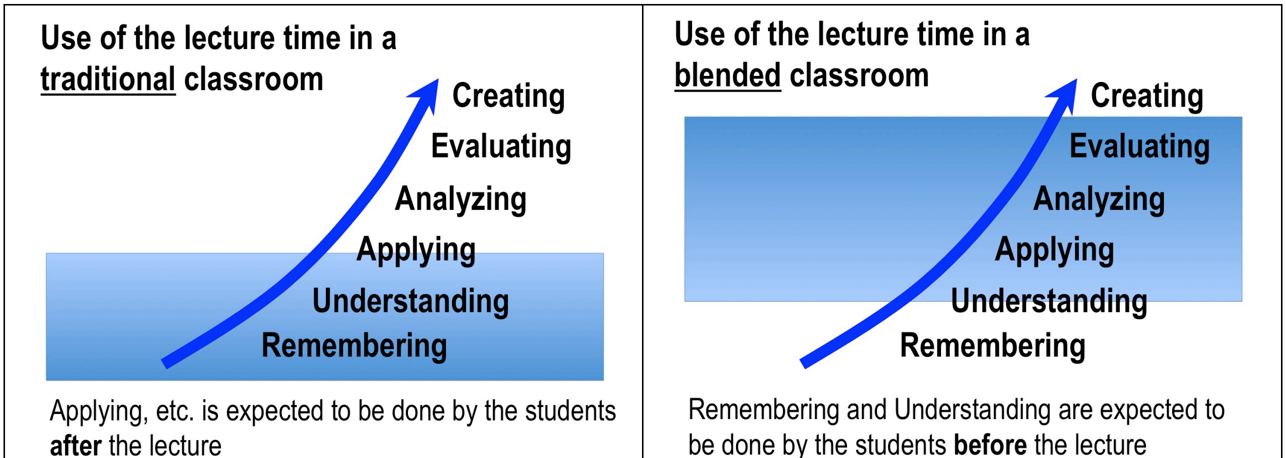
The theoretical foundation

Our strategies are based on Bloom's taxonomy of the steps to mastery [5], outlined in Figure 1.

Figure 1.
Bloom's taxonomy suggests that learning includes several steps or levels, the lower of which should be covered before the upper ones can be effectively addressed.



Bloom's taxonomy may provide guidance for successful *flipping* the course: it implies that *some of the lower-level activities* can be moved out of the classroom: see Figure 2.



The instructor is doing the "easy" work and leaves the "hard" work for students.	The students are doing the "easy" work, and the instructor does the "hard" work.

Figure 2.
Bloom's taxonomy may provide guidance for the creation of blended classroom.

We use Bloom's taxonomy as a guideline for distributing problems of various levels to be solved (a) in lecture time, (b) online, (c) in HW, and (d) on the exams. Noteworthy, the highest Bloom's level of learning – creating – is not highlighted in Figure 2; it is reached in application-focused HW problems and in Lab experiments.

Additional guidelines for the organization of coursework are: the concept of *flow* introduced by Csikszentmihalyi [6, 7], and the theory of self-determination by Deci and Ryan [8], which we discuss in more detail below.

How we make students learn before the lecture

The main challenge in teaching a service course for non-majors is the students' low motivation to take the course outside of their major fields of interest. Figure 3 summarizes the data collected via official University-wide end-of-semester evaluations.

Figure 3.
The data from the official end-of-term course evaluations reveal low student interest/motivation to take the required course.

Non-major students have do not desire to take this required course

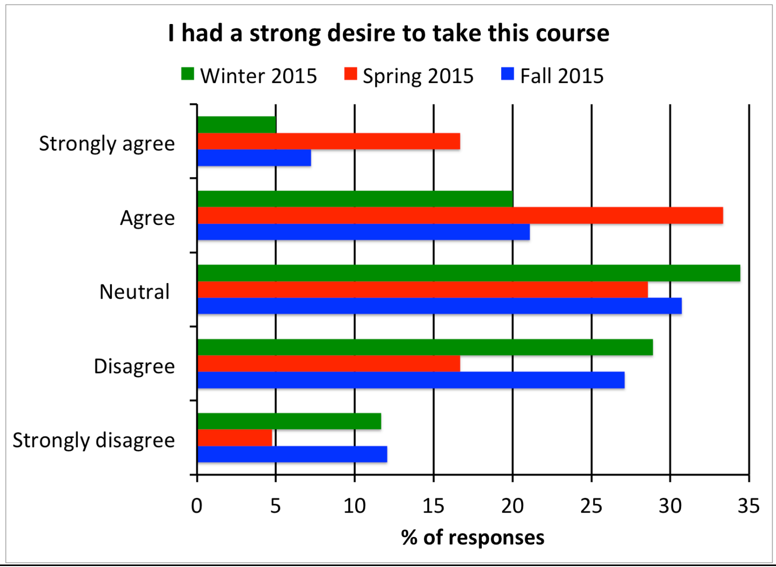


Figure 3 shows that the percentage of students who agreed or strongly agreed with the statement "I had a strong desire to take this course" was only 25% in the Winter 2015 (January – April; 180 responses out of 193 enrolled) and 28% in the Fall 2015 (September – December; 166 responses out of 198 enrolled). This percentage unexpectedly reached 50% in the Spring half-term 2015 (May – June; 42 responses out of 43 enrolled). One possible explanation of this difference is that the students deliberately planned to take this course in the Spring *half-term* when they would be less distracted by learning in other courses and by other responsibilities.

The analysis of students' responses to end-of-term course evaluations is our main research tool for this report; unless otherwise noted, all Figures present these official data.

The lack of initial interest in the course affects the students' attitude to learning and creates resistance to extra efforts such as reading before the lecture. We already quoted the feedback statement of one of the students who wrote:

> *"I am paying to be taught by a professor, not to read a book and teach myself."*

To overcome this negative trend, the instructors should provide incentives for students to learn in the *flipped* format. Non-EE engineering majors are motivated to learn EE if they see the value of this learning for their future studies and work in other engineering fields.

It is a two-way street. If the instructors maximize the use of lecture time for applications, their analysis and evaluation (see Figure 2), they need to ensure that every student is already prepared for this higher-level learning by remembering and understanding the concepts, basic laws, etc. This is the main driving force for moving the lower-level learning outside the classroom. Moreover, our student population is diverse (see details in *The demographics of the course* below); while some students need practice on the basics, other students find it unbearably boring. Being moved out of the scheduled class time, this practice becomes beneficial to all and raises the 'common denominator' of pre-existing knowledge of the material.

To make students learn before lecture, we created many quizzes in multiple-choice format for online self-assessment, assigned a week ahead, with the deadline 1 hour before the lecture begins. The main features of online self-assessments are:

1) Each quiz is focused on the material of the assigned reading (this provides a **specific goal** for students).
2) The level of difficulty of the questions in the quiz matches the level of difficulty of the examples fully solved in the assigned readings (thus **the challenges match the skills**).
3) The time for submitting the answer to each quiz is not limited, except for the deadline, and every student is given 3 tries without penalty (therefore **the student is in control**).
4) After the student enters the answer, the server promptly provides feedback, which includes the correct answer (**immediate feedback**).

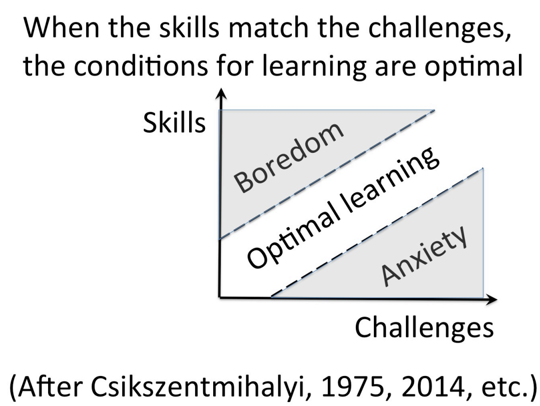
These features match the pre-requisites for creation of the *flow* experience "between boredom and anxiety" (sketched in Figure 4), which helps people do their best in learning and in many other activities, as found by Csikszentmihalyi [6, 7]. These pre-requisites include:

(i) Specific goals
(ii) The level of challenge matching the skills
(iii) The feeling of being in control, and
(iv) Immediate feedback.

Figure 4.
According to Csikszentmihalyi [6, 7], the appropriate level of challenge helps students remain motivated in their efforts.

If students feel that the challenge is reasonable, they will likely hold a positive expectation of success that will increase their tendency to persevere and work hard for the goal [5].

To achieve the *flow* experience in learning, the assignments should cause neither boredom nor anxiety



The logistics of our online quizzes:

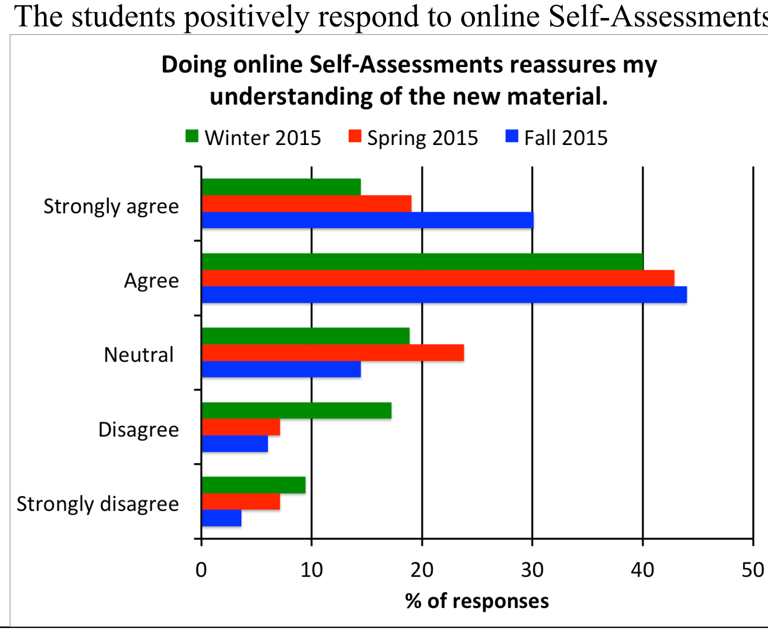
1) Each quiz is based on a bank of questions uploaded on the official University server, which also keeps track of enrollment, earned scores, etc. When a student logs on the server to do a particular quiz, the server takes a random draw from this question bank; for another try the server takes another random draw from the same bank.
2) Each student is given 3 tries to answer questions in every quiz, earning the same number of points for the correct answer regardless of whether the 1^{st} or the 3^{rd} attempt was successful (this provides ample opportunity to correct mistakes and reinforce learning).
3) For every set of quizzes, the student earns points for participation as well as the points for correctness of the answer.
4) One hour before the lecture (the deadline for completion of quizzes) the instructor can see on the University server all students' scores, thereby, assess their learning and decide which parts of the material need reinforcement in the forthcoming lecture.
5) The points earned for online quizzes self-assessments account for a significant part of the total score for the course (the exact number varied from 23% to 33% in different semesters). This grading scheme emphasizes the value of regular work on the course material (all exams combined account for only for 25% of the total score for the course).

Note that the students log on the server via the password-protected course management system such as Canvas, which is linked to the University Registrar's Office and has access to the class roster and gradebook. We rely on security of this system and on the students' integrity under the Engineering Honor Code, and do not take special measures to verify whether the online quizzes were completed by the correct person.

Although we have not proven whether our students reached the state of *flow* while doing online quizzes (which might deserve a special study), their attitudes to learning online are definitely positive: see Figures 5 and 6.

Figure 5.
The data from the official end-of-term course evaluations confirm the positive attitude of students to online quizzes as a learning tool.

The students positively respond to online Self-Assessments



In the terms of Bloom's taxonomy, the online quizzes correspond to the lower levels – remembering, understanding, and (partly) applying. Thus the online self-assessments can replace those parts of the homework, which were focused at these lower levels, to the relief of the students.

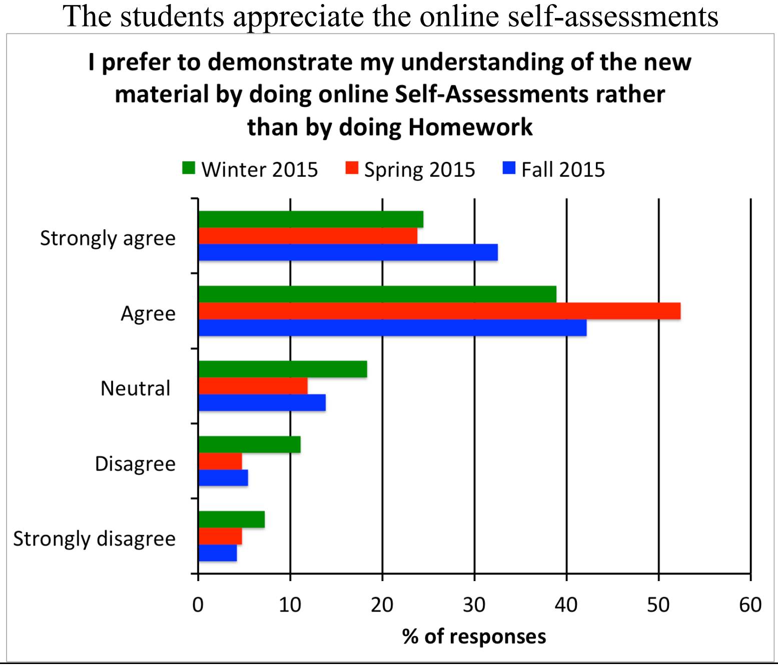
Table 1. Comparison of homework with online self-assessments

Learning by doing Homework	Learning via online Self-Assessments
The student may be unsure whether he/she understands how to approach the assigned problem, but receives no reassurance until the paper is graded (a week later).	The student receives immediate feedback, which demonstrates how to approach the problem and thereby provides reassurance/guidance.
If the solution was incorrect/incomplete, there is no second chance to resubmit.	If solution is incorrect/incomplete, the student has 2 more chances to resubmit.
By the time when the homework paper is graded, the student is not thinking about this topic anymore; the opportunity for learning is lost.	The feedback from the server arrives immediately, while the problem is still fresh in the student's memory; the opportunity for learning is abundant.

Students appreciate this distinction between doing HW on paper and self-assessments online: Figure 6 shows the data from the official end-of-term evaluations.

Figure 6.
The data from the official end-of-term course evaluations confirm the positive attitude of students to online quizzes as partial replacement for homework.

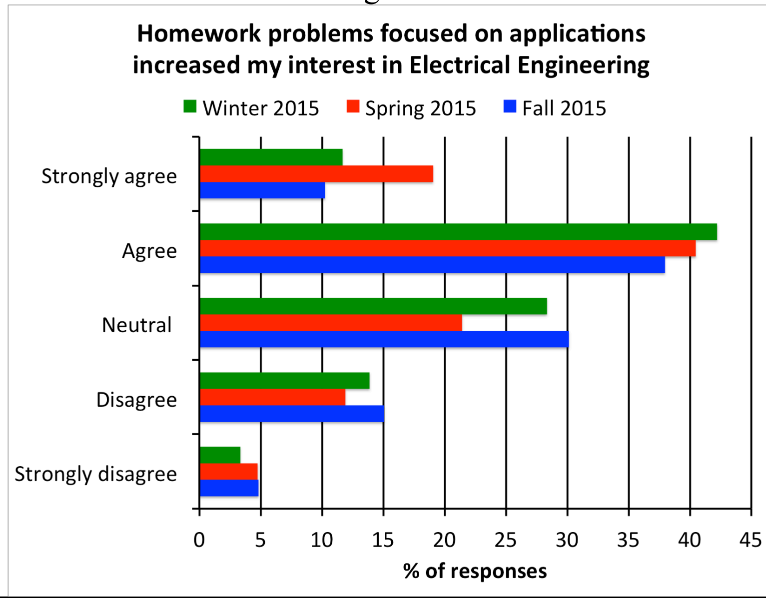
The students appreciate the online self-assessments



After the completion of online self-assessments, the students are prepared for the higher-level learning activities, including solving problems in lectures and doing homework on paper. By completing online self-assessments, students have already demonstrated their learning at the lower steps to mastery; thereby the homework to be done on paper gets shorter, focused on applications, comparison, analysis, and case studies.

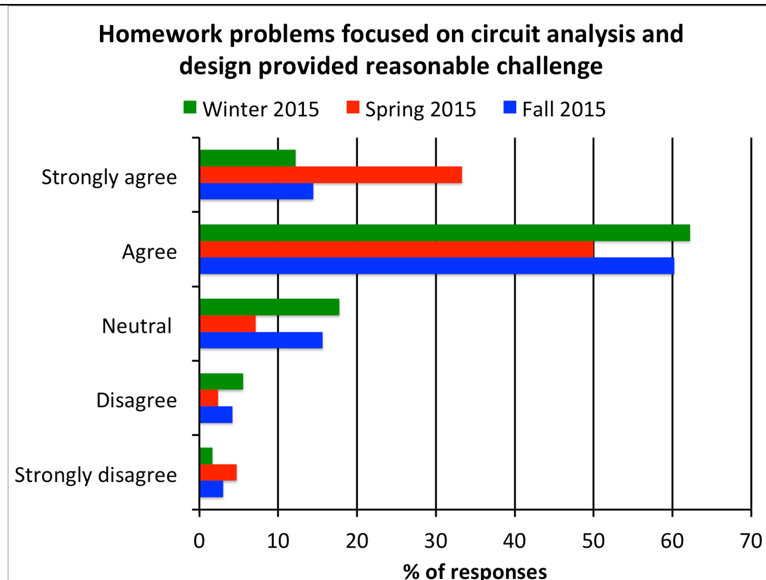
Figure 7.
The data from the official end-of-term course evaluations reveal the growth of students' interest in EE due to homework focused on applications.

Online self-assessments allow the instructors to shorten the homework on paper and focus it on topics, which are more interesting for students



As expected, students appreciate these higher-level problems (Figure 7) even when they present reasonable challenge (Figure 8).

Figure 8.
The data from the official end-of-term course evaluations reveal the positive attitude of students to higher-level homework problems focused on circuit analysis and design.

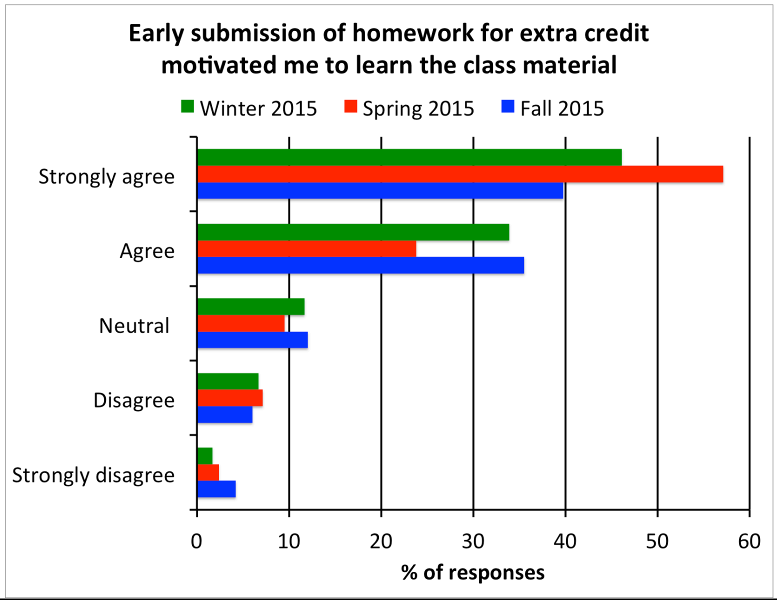


Note that, in the terms of Bloom's taxonomy, design belongs to the upper step – creation.

Another strong motivator to learning, which had been introduced in this class when it was still taught in the traditional lecture format, is the policy for dual submission of homework [9]. Every HW set is assigned on Wednesday, due on the following Wednesday. The Monday lecture reviews the HW topics; the Discussions on Tuesday provide further review. Every student who submits HW on Tuesday morning *before* the Discussions begin, earns extra credit: a flawless 100-point problem brings 115 points. Figure 9 shows that this dual submission policy motivates students to learn.

Figure 9.
The data from the official end-of-term course evaluations show that early submission of homework motivates students to learn.

The dual submission of HW motivates students to learn

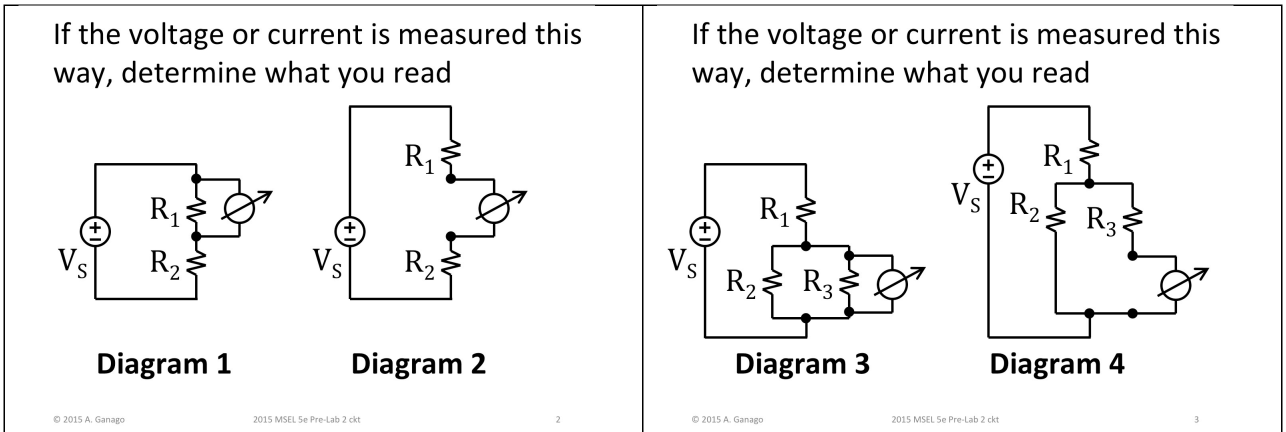


Noteworthy, this is a *dual* submission policy: suppose that a student who submitted HW before the discussion then finds out his/her error: there is no loss, because every student can submit the same HW on Wednesday and indicate on the cover page which of the two versions to grade. Thus the student does not risk to lose points by submitting HW early. By the end of the semester these extra credit points add up to at least 3.3%, which is almost definitely raising the total score to the higher letter grade (the course uses a straight scale with 4% bins). Students appreciate this raise: the number of papers submitted early grows later in the semester.

Examples of online self-assessments

The main challenge in creation the online self-assessments is that each quiz should be linked to a "bank" which includes many similar questions at the same level of difficulty. For this section, we chose two examples, which show how it is done in our course. We prefer qualitative and simple quantitative questions, which require clear understanding of concepts but do not take much time to complete.

Online self-assessments prepare students both for doing upper-level homework and for the labs. Figure 10 shows an example of questions, which may serve both purposes.



On each circuit diagram, the circle crossed with an arrow belongs to a multimeter, which can act either as an ideal ammeter or as an ideal voltmeter.

The numerical values of the source voltage and each resistance are given in every question.

Prepare to decide whether the statements like the following are true:

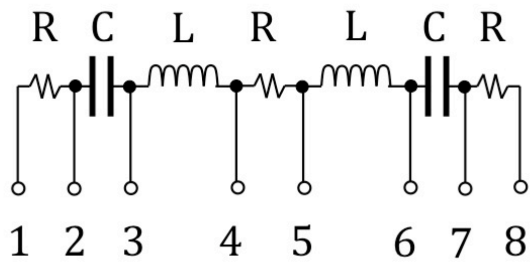
1) This is the correct way to measure the voltage across resistor R2
2) If the multimeter acts as an ideal ammeter, it reads 3 A
3) If the multimeter acts as an ideal voltmeter, it reads 7 V.

Figure 10.
This set of circuit diagrams accompanies the question bank for online Pre-Lab 2.

Despite their apparent simplicity, the correct solution of questions exemplified in Figure 10 requires understanding of several concepts (what is the difference between an ideal ammeter and an ideal voltmeter, etc.) as well as problem-solving strategies and skills (voltage division, current division, equivalent resistance, etc.). By completing this self-assessment, the students demonstrate their understanding and mastery, which can later tested in solving lecture practice problems and HW to be done on paper; used for test preparation and on real exams, etc.

Figure 11 presents another set of problems, which can be used as pre-requisite for the lab, in which the students solder a similar circuit and measure its performance. The completion of this self-assessment demonstrates understanding of the theory and the ability to apply it to various circuits. Such problems can also be used for lecture practice, exam practice and real exams, etc.

Consider the following connections of the input/output signals, and the common ground to this circuit: determine the type of filter:



Problem #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Connection of the signals to the terminals numbered on the circuit diagram													
Input signal	1	3	3	5	6	8	8	7	4	8	1	5	5	8
Output signal	2	2	4	4	7	7	6	5	6	7	3	3	7	6
Common ground	3	1	5	3	8	6	5	4	7	5	4	2	8	5

For each problem, provide the standard set of choices:

A. Low-Pass filter
B. High-Pass filter
C. Band-Pass filter
D. Band-Reject filter
E. None of the above.

(The order of choices may be swapped in order to avoid repetitions; choice E can be eliminated.)

Figure 11.
Many questions for self-assessment can be based on one circuit diagram.

With the self-assessments, email messages with conceptual questions disappeared: students work on the material themselves and sometimes need more tries to complete the quizzes, which the instructors gladly provide. Here are typical requests received by email:

> *I am still working on understanding this problem by reading the book. May I please have another attempt …*
>
> *I am requesting extra attempts for [quiz number]. I am having trouble figuring it out and would like to try again, thanks.*
>
> *I have run out of attempts for this question and I'm going over the content again this week to review.*

This is active learning outside of classroom.

Necessary adjustments

The creation of self-assessments has affected the course in many respects, because by completion of online quizzes the students demonstrate their learning of the material, thus additional demonstration of this learning may become unnecessary. Therefore, we reduced the weekly load from 5 or 7 problems to 2 HW problems to be done on paper; reduced the midterm exams from 15 problems to 7 or 8, and the final exam from 22 problems to 11 or 12 (all exam problems are in multiple-choice format).

The center of gravity of the new grading scheme was shifted to the regular weekly learning, away from desperate cramming for the exams. The 100% for the entire course are accumulated from four major activities: online self-assessments (22% plus some extra credit), homework (22% plus extra credit for early submission), lab experiments (24%), and exams (25% for two midterms and the final combined). Smaller amounts of points are earned for the participation (voting with clickers during lectures, responding to surveys, etc.).

At the same time, we found that the self-assessments themselves needed adjustments. When we flipped the course in the Spring 2014, we included a detailed solution to every online problem. We assumed that, by doing so, we provided the resource, for which engineering students always ask – examples of fully solved problems, which the students would use in the broader context of learning the course material. However, the end-of-term evaluations revealed the sad truth: students used those detailed solutions *as a replacement* for learning in the broader context: see the data in Figure 12, for Winter 2015.

Students read the sample solutions online, not the book

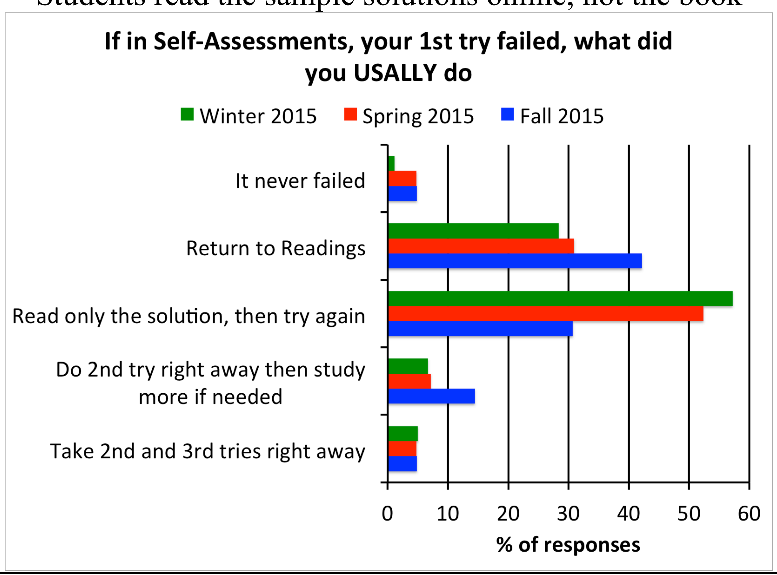
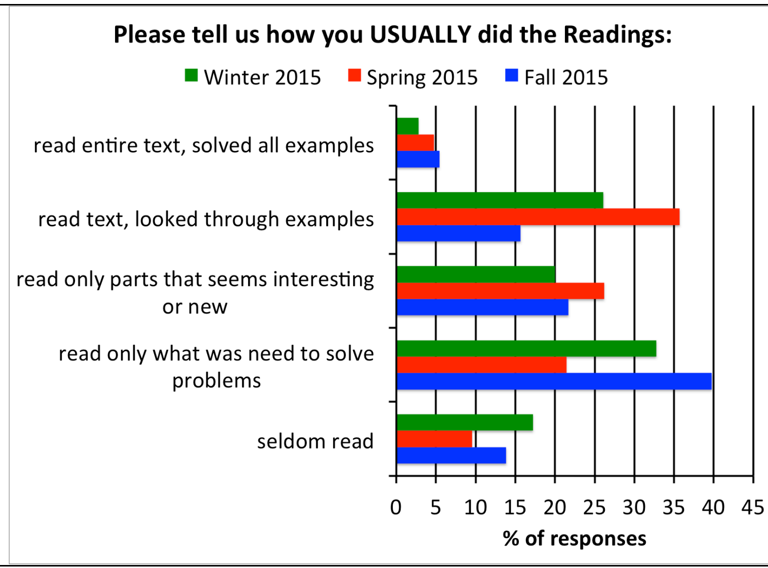


Figure 12.
The data from the official end-of-term course evaluations (Winter 2015) reveal that many students limited their learning to reading the solution to the particular problem in the online quiz. Therefore, our original educational goal to encourage student learning in the broader context of the course material was not achieved. For Fall 2015, we removed the complete solutions from the feedback.

Guided by this feedback, we revised our question banks for Fall 2015 by removing the complete solutions from online feedback and keeping only the answers with brief comments. The data in Figure 12 for Fall 2015 show that more students returned to readings, as we intended them to do.

However, Figure 13 for Fall 2015 shows a significant increase of reading *only what was needed* to solve the problems.

Figure 13.
The data from the official end-of-term course evaluations reveal the tendency of students to read only what was needed to solve the particular problems.



Thus we conclude: Every required piece of reading should directly lead to a quiz (otherwise, why require it to be read?).

Another adjustment was suggested by students' comments on teaching and learning in the blended classroom format. Our initial plan to entirely replace lecturing with active learning was not favored by students who insisted on at least partial teaching in the lecture style, for example:

> "*I would really like to have some sort of a short lecture at the beginning of class to go over the reading material before starting practice problems.*"

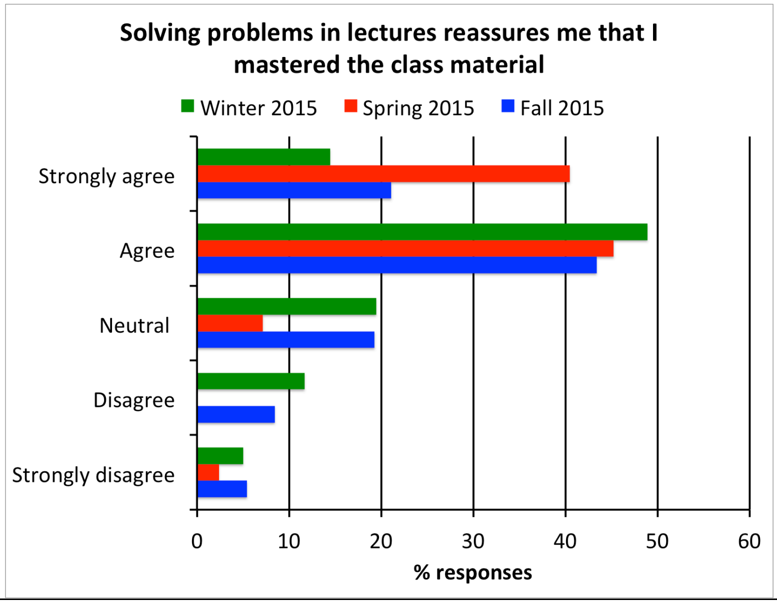
> *"It would be very beneficial if professor went over more concepts in class. The idea of reading the book to learn all of the concepts is no good."*

> *"Currently, we take self assessments and do homeworks, and THEN talk about those topics in lecture. That makes all the assignments very difficult, and it makes lecture feel like a waste of time. If we could cover the topics in lecture first, and THEN have assignments and homeworks on those topics, both aspects of the class would be much more useful as a learning tool."*

This feedback, from the official midterm evaluation collected in Winter 2015, made us revise the use of the lecture time. Presently, in every Wednesday lecture, when new HW is assigned, the instructor delivers a mini-lecture to preview the new concepts, demonstrates the problem-solving strategies and skills necessary for doing this HW, and encourages students to solve in class simple problems on the new material. Thus *lecturing* does not disappear completely but finds its new place in the big picture of active learning in class prior to doing the HW (see Figure 16 for a typical example of four consecutive votes with clickers).

Active learning during the lecture time

Besides mini-lectures, the necessity of which was just discussed, the scheduled lecture time is used for solving problems (usually, focused on the current HW or the forthcoming exam) and conceptual questions, as well as for demonstrations of how the real circuits work (which will be a topic of another paper). The style of problems for lecture practice combines qualitative and quantitative questions: for example, see Figures 10 and 11 above. Students promptly develop a positive attitude to this activity: see Figure 14.

Figure 14. The data from the official end-of-term course evaluations show the positive attitude of students to solving problems in lecture time.	Students positively respond to solving problems during the lecture time 

The lecture time, if we do *not* use it for *reading* from notes or PowerPoint slides, can be very effective for student learning and for developing interactions between the students and the instructor, and among the students (peer instruction). The role of the instructor is altered from the traditional *reader* to a coach who helps the students master the winning strategies through repeated practice and interactions with classmates, in several steps [9, 10, 11, 12]:

Step One
The instructor provides new material to the students. This can be done in the following ways:

(a) Brief explanation in lecture
(b) Assigned readings
(c) Online SA (which were due before this lecture)
(d) Doing homework (which is due soon).

Step Two
But have the students learned anything? **The instructor can obtain feedback *in real time*** (without waiting for the HW scores or test results) only in case (c) above, because the scores for online SA get automatically posted on Gradebook and can be reviewed before the lecture.

However, even these scores do not necessarily reveal or ensure the student learning and understanding of the material (see the Comment below).

Comment: Since students read only what's needed to answer particular quizzes (Figure 13), they may overlook the fundamentals necessary for real understanding of the material. For instance, *after* successfully completing the quiz on calculations of the gain in Op Amp circuits, only 35% of students could answer simple questions on the Golden Rules during lecture.

Step Three
The instructor gives the students a simple problem in the multiple-choice format to solve in class. The problem is focused on the new material, and can be solved in a minute or two.

Step Four
The students solve this problem and vote with clickers. The instructor promptly receives feedback on their performance and has to choose the next action. According to Eric Mazur (book, personal communication):

- ✓ If < 20% students voted for the correct answer, a mini-lecture is required because the class as a whole has not understood the new concept.
- ✓ If the correct answer collected between 20 and 80% of the class votes, the instructor encourages students to talk with their neighbors: see Step Five below.
- ✓ If > 80% students voted for the correct answer, the class as a whole has perfectly understood the new concept; the instructor congratulates the class, *briefly explains why this answer is indeed correct,* and proceeds to the next topic.

Step Five
The students discuss their solution with the neighbors: every student is encouraged to convince the neighbors that his/her answer is correct. This is the most exciting – and the noisiest! – part of the lecture time. Usually, the students take a minute or two to talk with their neighbors; then the noise subsides, **and the instructor asks the students to vote again.** Most often, the percentage of correct answers increases, even if the correct answer was not the most popular in the first vote. Eric Mazur explains (personal communication): if two students both had wrong – but different – answers, they might see each other's errors thus they both start looking for the correct answer and may reach it: for instance, see Figure15 below. However, it may also happen that the percentage of correct answers *drops* after the discussion with neighbors (we have all experienced agreeing with charismatic speakers who were not saying the right things).

Step Six
The instructor announces which answer is correct, the percentage of correct votes, etc., **comments on the effectiveness of discussions with neighbors, briefly explains why the chosen answer is indeed correct**, and why the other answers are wrong. The explanation is necessary: if the instructor simply says that answer A was the most popular and correct choice, students might still be unsure how to solve the problem and why.

Figure 15 shows typical results of two consecutive votes for the correct answer to the same problem. Between the votes, students spent ~2 minutes discussing their solutions with neighbors.

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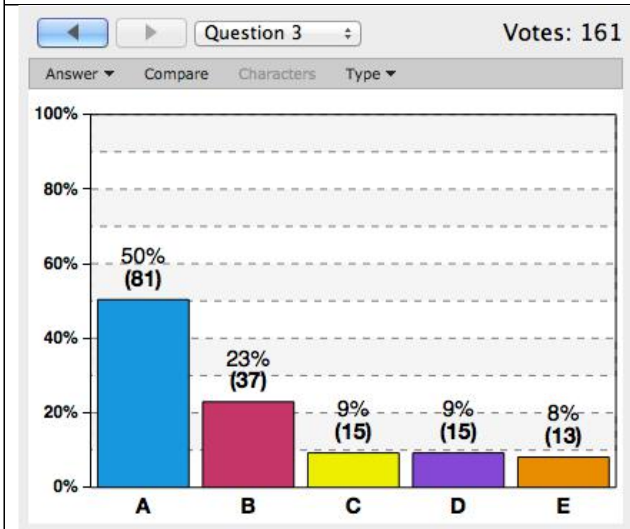
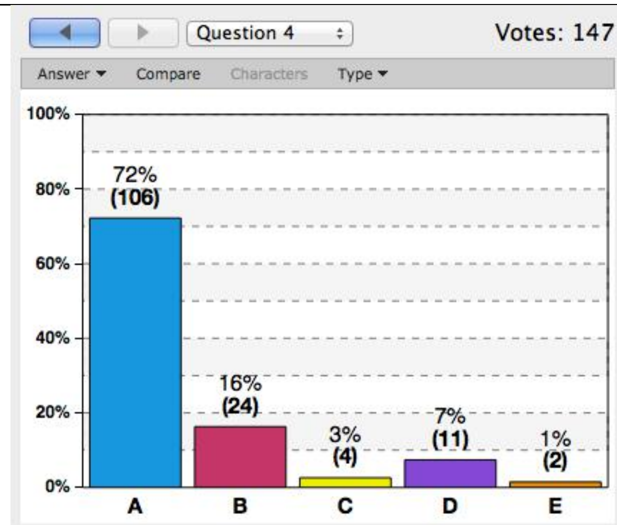
<tr><td>The first vote</td><td>The second vote</td></tr>
<tr><td>
</td><td>
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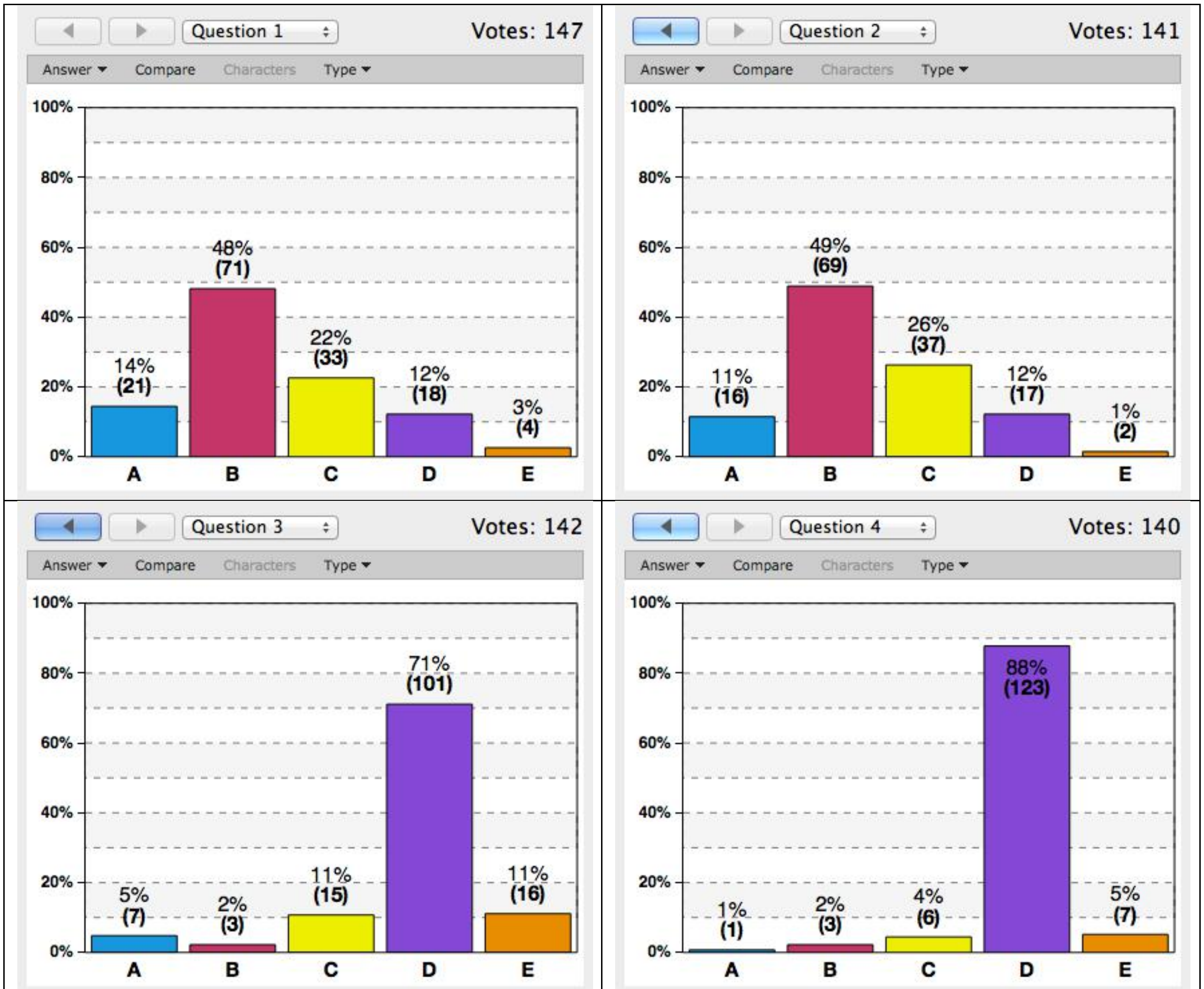
<tr><td>Students voted after they solved the problem individually.</td><td>After the first vote, students convinced their neighbors that their answer was correct.</td></tr>
<tr><td colspan="2">The percentage of correct answers increased from 50 to 72: the number of correct votes increased from 81 to 106 after the students discussed their solutions with neighbors in classroom.</td></tr>
<tr><td colspan="2">Figure 15.
Typical results of two consecutive votes on the answer to the same problem, before (left panel) and after (right panel) students discussed their solutions with neighbors. The correct answer is A.</td></tr>
</table>

Figure 15 exemplifies the favorable situation, in which 50% of students solved the problem correctly without any help from the instructor or the classmates. Consulting with their neighbors, many students participated in active learning during the scheduled class time (the best way to understand is via explaining to someone; the best way to learn is to ask questions). Noteworthy, the instructor did not provide any information to students between the two votes (in particular, did not show the results of the first vote).

The role of the instructor in active learning is to address the immediate needs of the students. In particular, Figure 15 shows that more than 30% of 161 students in the classroom did not vote for the correct answer even after consulting with neighbors; even more might remain uncertain why the most popular answer was correct. Thus, to make this teaching/learning event successful, the instructor must explain how the problem should be approached, what strategy leads to the correct answer, and why other suggested answers (in the multiple-choice format) are wrong. Lacking clear explanations, the students remain unhappy and wish for the traditional lecture, in which the instructor shows the whole solution step by step, albeit without active learning.

Figure 16 exemplifies a different situation, in which the instructor's intervention became necessary in the form of a mini-lecture: it presents the results of four consecutive votes on the same problem, with the mini-lecture given after the second vote. The votes in Figure 16 belong to a problem given in a Wednesday lecture, focused on the new material for the forthcoming HW, after a brief preview of the concepts. See the legend of Figure 16 for further information.



After a brief explanation of a new topic in lecture, the students were given a problem on this topic. Their first vote (upper left panel) shows the results of individual solutions; their second vote (upper right panel) was taken after they discussed their solutions with the neighbors in classroom. The correct answer was D. Apparently, the students did not understand how to solve the problem and could not convince their classmates that their solution was correct. After the instructor announced that **the correct answer was chosen by 12% of the voters,** oh, how they listened! The instructor gave a mini-lecture on the problem-solving strategy (not disclosing *which* answer was correct) and challenged the students to solve the same problem again. The lower left panel shows the results of their individual solutions; the lower right panel shows their final vote, which was taken after the students discussed their work with their neighbors (trying to convince the neighbor that their answer was correct). **Within ~20 minutes of class time the number of students who solved the problem correctly increased from < 20 to > 100** (compare the results of their individual solutions in the upper left and lower left panels). **The votes for the correct answer grew from 12% to 88%.**

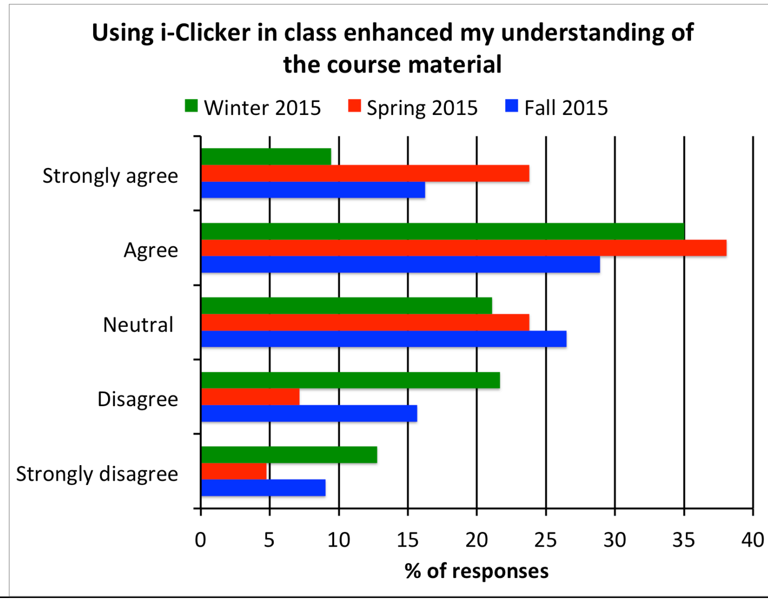
Figure 16.
A complete sequence of four votes for the correct answer to the same problem.

Figure 16 shows the effectiveness of a mini-lecture combined with problem solving and peer instruction and exemplifies active learning in class.

Figures 17 and 18 demonstrate the positive attitudes of students to active learning in lecture time.

Figure 17.
The data from the official end-of-term course evaluations show the positive attitude of students to using clickers in lecture time.

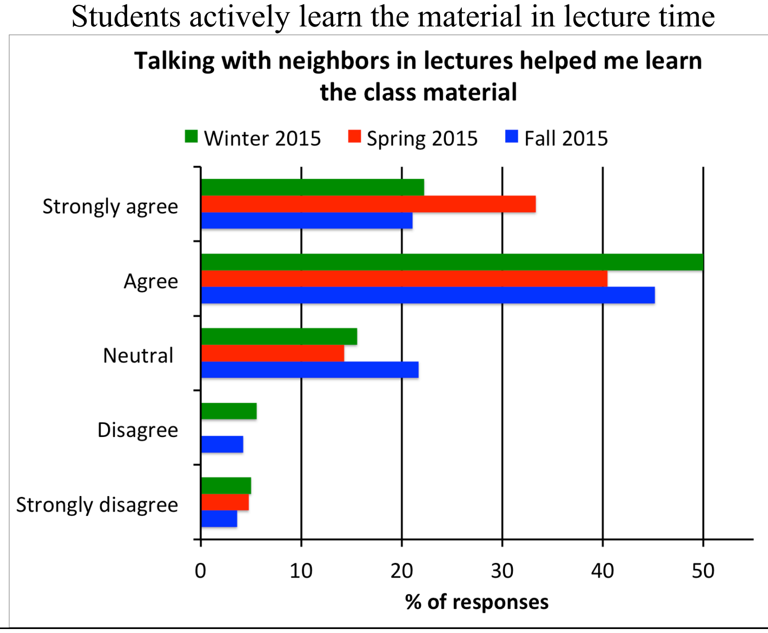
Students positively respond to active learning in lecture time



Talking with neighbors about the problem, which the students just solved individually seems the most interesting part of the lecture for the students and the instructor alike.

Figure 18.
The data from the official end-of-term course evaluations show a highly positive attitude of students to peer instruction in lecture time.

Students actively learn the material in lecture time



The recorded results of the votes such as shown in Figures 15 and 16 do not tell the whole story. Unrecorded remains the *dynamics* of votes: during the first seconds, *nearly all* votes are cast for the correct answer but they come from a small fraction of the class population; after about a minute this fraction reaches ~25% of students in the classroom. Apparently, this fraction of the class is on top of the material. Then, after the instructor starts the countdown, the remaining votes come in from the rest of the class; usually, they are more or less correct but sometimes it seems as if these late votes were cast almost at random, just to get the point for participation.

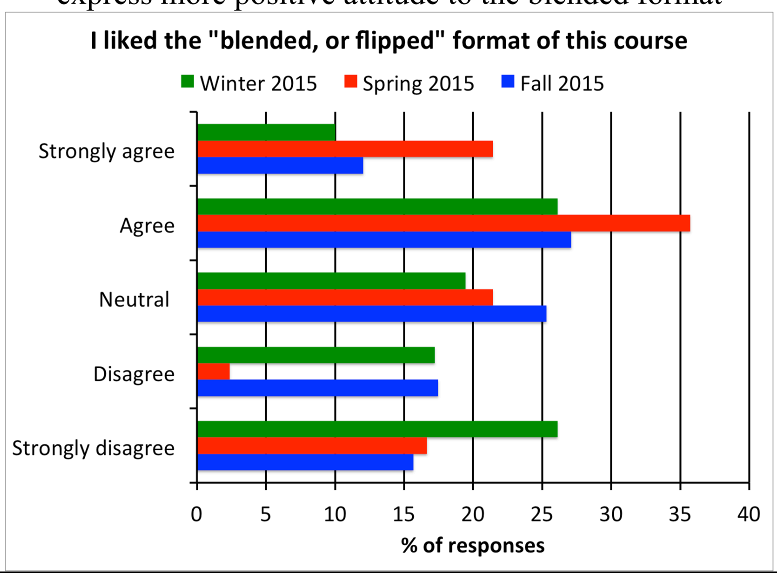
Discussion and conclusions

This fraction ~25% of correct votes in lecture time coincides (or correlates?) with the percentage of students with strong initial interest in the course material (Figure 3). A second look at Figures 6, 9, 13, 17 reveals more positive attitudes to various aspects of the course expressed by the students who took the course in the Spring 2015 half-term: recall that 50% of those students were initially interested in taking the course vs. 25 and 28% in the Winter and Fall semesters.

The same more positive attitude to the blended classroom format is clearly seen in Figure 19.

Figure 19.
The positive attitude of students to the blended format of the course correlates with their positive attitude to the class as a whole: cf. Figure 3 and compare the results of Spring 2015 with those of other semesters.

The students who took the course in the Spring 2015 express more positive attitude to the blended format



Overall, based on the analysis of the students' responses to the official end-of-term course evaluations over 3 semesters of 2015, we conclude that the students appreciate the main features of flipped, or blended, classroom, including the self-assessments (Figures 5 and 6), focusing HW on applications (Figures 7 and 8), solving problems in lecture time (Figure 14) and other forms of active learning in class (Figures 17 and 18), as well as the early submission of HW (Figure 9). Therefore, we obtain positive answers to our research questions on the choice of strategies and tools for flipping this class. At the same time, we conclude, in agreement with others [13, 14, 15] that lecturing as way of instruction has its own value in the process of active learning in the flipped classroom, and should not be eliminated.

Due to the many changes of the course explained above (shorter HW assignments and exams, restructured grading scheme, etc.), direct comparison of the course parameters before and after flipping does not seem reasonable. In particular, due to several attempts given for the self-assessments (and additional attempts granted per request of students), the scores for this part of learning 'saturate at the top' rather than 'spread on the curve': their averages exceed 90% of the maximal possible; the HW scores are also high. These high scores agree with our goal: since the course content is focused on the basic learning, every diligent student should be able to succeed.

Undoubtedly, many other instructors have created their sets of online quizzes for students. For instance, our approach is similar to that used by Leonard *et al.* [16] but it is distinct because we do not impose any requirements to excel in any of the quizzes.

It is well known that limited time is the major challenge for flipping a course, noted as the barrier by 70% of the surveyed faculty [4]. In our case, the main investment of time was required for the creation of online self-assessments and uploading the question banks, quizzes, etc., on the University server. The former was partly simplified by our prior experience in creation exam problems in multiple-choice format; for the latter we obtained the Departmental support (hourly pay to the students who uploaded the problems), which we greatly appreciate.

The demographics of the course

This course is among the largest used for flipping: according to the survey [4], only 8.6% out of 908 flipped courses enrolled > 100 students; others were much smaller. Figure 20 presents the demographics information (note that the color coding is distinct from previous Figures).

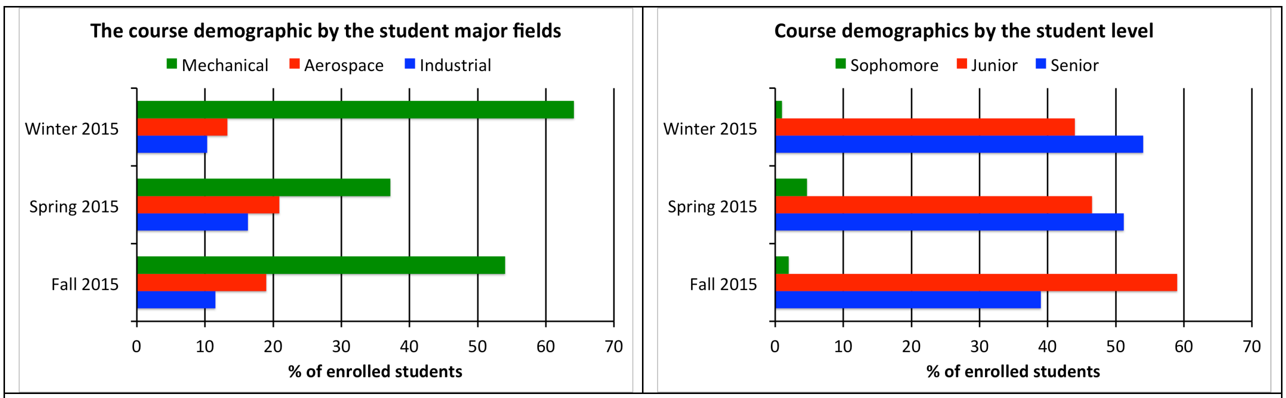


Figure 20.
The course demographics by the major (left panel) includes only 3 most populous specialties; Mechanical Engineering majors make more than 50% of enrolled students (with the exception of Spring 2015); in the Spring term we had a wider variety of majors, including Biochemical, Computer Science and Computer Engineering, Engineering Physics, Economics, etc. The demographics by the academic level (right column) shows that juniors and seniors comprise more than 90% of the enrolled students.

Acknowledgments

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