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You have nothing to lose: Worry-free flipping for PSE

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Abstract

Even though the COVID-19 pandemic forced all PSE instructors to move their teaching completely online, this has largely not changed most teaching practice, which has retained face-to-face lecturing as the main activity during contact between lecturers and students. This paper presents the case for shifting teaching to active learning by students, most effectively accomplished using the flipped classroom. With the advantages of adopting the flipping approach clear, one is left with two issues to resolve, both of which are the focus of the contributions of this paper: (a) how to effectively produce the necessary supporting materials (recorded lectures, online quizzes, and class activities), and (b) how to continuously foster engagement by the students. These contributions are supported by examples from the authors’ extensive experience of successful applications of active learning approaches relying on the flipped classroom in process design and process control courses.

Keywords: PSE education, active learning, flipped class

1. Introduction

All topics taught under the PSE umbrella benefit from more time-on-task made available for students to learn by class discussion, experimentation, and cooperative solution of open-ended problems – basically by “getting their hands dirty” – as a key component of their own learning process. Courses taught using the conventional teacher-centered, lecture-based approach have less time available for these crucial activities, and thus may achieve lower levels of learning outcomes.

The flipped format moves the lecture material online, to be completed by students as homework. Thus, the main justification to move to flipped format is the desire to increase the proportion of the student-staff contact time in which students are actively learning, rather than just listening to lectures (Crouch and Mazur, 2001; Felder and Brent, 2015). This makes better use of the shared time between teacher and students, which has a huge impact on students’ engagement, as does aiming to maximize the degree to which students are participating actively with the teacher and with each other, rather than passively listening to lectures. There are many existing studies that provide quantitative evidence that active learning improves course outcomes (e.g., Freeman et al, 2014, Velegol et al, 2015; Lewin and Barzilai, 2021). In an extended study involving secondary and post-secondary education, van Allen et al. (2019) found that the flipped classroom has a small effect of learning outcomes, but uncertain effect of student satisfaction, noting that the results depend strongly on how flipping is implemented.

Since the COVID-19 pandemic forced all teaching to move completely online, one would have thought that this would have motivated the transition to active methods in teaching. In fact, teaching pedagogy has largely not been affected by the potential of
technology, with much online teaching still teacher-centered, relying on synchronous lectures delivered over Zoom. Lewin et al. (2022) ran a survey that received 82 responses, mostly from veteran lecturers on PSE topics, which found that the main obstacles to change are the following: time taken away from research activities (65%), lack of available institutional funding (46%), and student dissatisfaction with new forms of teaching (32%). Teachers are clearly discouraged both by the significant investment of time and effort required to prepare quality online materials (prerecorded lectures and online exercises), and by the initial resistance of some students to active learning. Not surprisingly, there is reduced outcomes performances from the non-participants/non-engagers; Quantifiable lower outcomes are attained by students who engage less with the online materials and with class activity (Lewin, 2022).

The paper next discusses the link between active learning and learning outcomes. Next, in Section 3, the components of the proposed flipped class approach are presented, as well as details of what is required from the point of view of the lecturers and the benefits for students, with a focus on guidelines for practice that works. Next, working experience is shared regarding evidence for the contribution of the proposed teaching methodology to learning outcomes (exam results), followed by conclusions.

2. The Link Between Active Learning and Learning Outcomes

PSE topics are challenging to teach and to master since they all address the three top tiers in Bloom’s Taxonomy (Bloom, 1956): analysis, synthesis, and evaluation. Ideally, a combination of examinations and group project assignments are the vehicles for teaching and assessing students’ knowledge and competencies in all PSE topics. The utilization of project outcomes for assessing individual assessment requires careful checking to ensure all team members are truly contributing. For example, most process design courses also include a competitive design project component, calling for a demonstration of team-effort in addition to individual mastery. While both team and individual capabilities are important, examinations provide a reliable measure of the crucial mastery of individual students (Turton et al., 2013). Bloom (1968) postulated that the degree to which students achieve mastery depends on four conditions:

1. **Clear definition of what constitutes mastery.** It is the responsibility of the course instructor to clearly state the learning objectives in a manner that defines precisely what students need to achieve to demonstrate mastery.

2. **Systematic, well-organized instruction focused on student needs.** Our approach is based on pre-prepared, clear presentations of the course materials in which online lectures are composed of short video segments interspersed with practice activities, to enable students to actively control their initial acquisition of the basic materials. Then in the class meetings and active tutorials, students practice on more complex and advanced example exercises, first in cooperation with the course staff, and then on their own and with their peers. This sequence of actions leads to weekly cycles of systematic learning.

3. **Assistance for students when and where they experience difficulties.** The active tutorials are the ideal vehicle to aid students when they need it most: the first time when they attempt to solve example problems for themselves. This increases the likelihood that mastery will be achieved in less time.

4. **Provision of sufficient time for students to achieve mastery.** This implies the need to increase the time allotted to active tutorials at the expense of time expended in teacher-centered lectures and demonstrations. This is the reason for the shift
to switch lectures to online homework activities, which is the basis of the flipped classroom.

Bloom (1968) reports the modes of learning that improve outcomes, with the most significant obtained by personal tutoring, which increases the degree of mastery as exhibited by exam grades up to two standard deviations higher than for students taught by a conventional lecture-based approach. Amongst other factors indicated by Bloom (1984) as having significant positive effects on achieving learning mastery, are positive reinforcement and praise from the instructors, student classroom participation and time on task. Bloom reports that all these factors improve results by approximately one standard deviation higher than achieved by conventional lecture-based instruction.

The main justification to move to flipped format was the desire to increase the proportion of the student-staff contact time in which students are actively learning rather than just listening to lectures. This format makes better use of shared time between teacher and students to significantly impact students’ engagement, as does aiming to maximize the degree to which students are participating actively with the teacher and with each other, rather than passively listening to lectures.

3. Flipped-class Enabled Active Learning

This section describes the three phases of the flipped approach, the demands on teachers who choose to adopt it in their courses, and the benefits to their students.

3.1. The recommended flipped approach

Three PSE topics, process design, process control and plant design, have been taught annually at the Technion using a three-phase flipped approach, the first of which since 2015, and all three online since the COVID-19 pandemic struck. In this approach a weekly cycle consists of three steps:

(a) Asynchronous assignments in which pre-recorded video lessons are completed in advance of the week's activity by students as homework. Moodle lessons [https://moodle.org](https://moodle.org) are used as a framework for these, with each lesson being composed of a series of questions in which short video segments of lecture material are embedded.

(b) Synchronous class meetings, using Zoom or in F2F/hybrid sessions, in which students interact with the lecturer and with each other. Typically, these involve review of concepts from the online lesson, discussions generated by quiz questions, and open-ended problem solving.

(c) Synchronous active tutorials, using Zoom, in which students solve example problems for themselves. These usually begin with a brief review by the teaching assistant followed by problem solving by students working separately or in groups, utilizing breakout rooms. Our experience is that active tutorials run in Zoom breakout rooms are more effective than tutorials in regular F2F settings.

3.2. Requirements from the lecturer

The flipped format implemented imposes significant effort on the part of the lecturer:

(a) Online materials, namely, the prerecorded lectures involving 5-15 minute video segments and associated quiz questions need to be prepared, most effectively using a video editor such as Camtasia® [https://www.techsmith.com](https://www.techsmith.com). Each course typically requires of the order of 100 of each, which constitutes a huge investment. However, this effort is only invested once: the author prepared the materials for the process design course in 2015, for the process control course in 2017, and for the plant design course in 2020. No additional preparatory materials have been required for either course since then.
(b) The lecture time freed by moving lectures to online homework tasks for students to do on their own needs to be occupied by suitable activities. The main difficulty for many teachers, especially those who are used to just lecturing, is the required change in their mind-set, which shifts the contact time between lecturer and student from being teacher-centered to being student-centered. This means that class materials should be designed to support open-ended problem solving performed by the lecturer but stressing class participation, the use of pop-quizzes to generate class discussion on their solutions, and any other activity that will enhance students’ understanding. The development of these activities will take time to get right, and will likely evolve over time, as teachers become more accustomed to this mode of instruction.

(c) The active tutorials could be as simple as just having students solve what used to be homework exercises working in teams in recitation time, or more involved and specially designed exercises. The main objective is to ensure that the students are doing most of the work for themselves.

(d) It is important to continuously monitor the activity of each student, and follow-up on those students who are less active. This task is facilitated by a myriad of tools that are available in learning support systems.¹

3.3. Benefits to the students

Low-performing students typically do not significantly engage during the semester, leaving most of their effort for cramming just before final exams. This behavior is unlikely to achieve mastery of the taught materials. In each week of a course taught in flipped format, students need to prepare for class meeting and active tutorials by covering the pre-prepared materials ahead of time. They then benefit from participating effectively in the class meetings, by responding to the pop-quizzes, contributing to class discussion and brainstorming during the open-ended problem solving. Finally, they participate in active tutorials where they solve exercises for themselves, mentored by the course staff. This combination of activities increases the performance of the entire class, as will be described next.

4. Class Experience with the Teaching Method

As a teacher of process design for more than 20 years, I have taught using the full spectrum of possible approaches. This began with a traditional teacher-centered instruction, in which the course materials were transmitted via lectures and demonstration-recitations to my students, termed Phase I. The first transition was to active tutorials, where at least students were actively engaged in problem-solving for themselves, termed Phase II. The last major change, Phase III, was the move to the flipped classroom paradigm in 2015, which freed even more time for students to get to grips with the course material for themselves. I also teach process control and plant design, both of which are now also taught in the flipped format as previously described.

As described in Lewin and Barzilai (2021), the outcomes achieved by the students of the process design course have incrementally improved over the last 15 years, as illustrated in Figure 1, which shows a bubble plot showing disks whose diameters are in proportion to the fraction of the high-performing students in each year’s class, $p$, centered on coordinates, whose ordinate and abscissa are the average grades of the high- and low-
performing subsets of the class in each year, $\mu_1$ and $\mu_2$ respectively. These parameters are determined by fitting a bimodal distribution to actual exam grade distributions using the approach of Lewin (2021). Note that as $\mu_1 \geq \mu_2$ by definition, all disks have to be centered under the dashed line $\mu_1 = \mu_2$ indicated in Figure 1. The best performing classes would be those represented either by disks of any diameter in the top right of the plot (high average exam grades of both high- and low-performers, irrespective of their proportions), or lower on the right with large diameters (high average exam grade of high-performers, whose proportion dominates the population). Conversely, classes represented by disks on the left would be characterized by low average exam grades of the high-performers, and even lower average grades of the low-performers. As can be seen in Figure 1, in Phase I, the class disks, shown in black, are on the left. The transition to Phase II indicates a shift to the right, maintained after the transition to the flipped class in Phase III.

Figure 1. Bubble chart summarizing binomial distribution diagnosis (adapted from Lewin and Barzilai, 2021). The statistics for each year are centered on the $\mu_1 – \mu_2$ plane, with the disk diameter proportional to $p$. The disks are color-coded according to period: black – Phase I: 2005-2010 (before active tutorials), grey – Phase II: 2011-2013 (before flipping), white – Phase III: 2015-2020 (after flipping). The dashed line indicates $\mu_1 = \mu_2$.

Figure 2. (a) 2021 Process control course outcome distribution for the entire class and separate distributions for (b) the 20 students that attended active tutorials the least and (c) the 20 that attended the most, out of a total of 50 students examined. In the histograms, abscissae indicate numbers of students, plotted against exam grade bins.
What is the cause of the bimodal distribution present in all exam grade histograms? As discussed in Lewin (2021), these could be inherent heterogeneous capabilities of the students in the class, or the consequence of the degree of engagement in the course materials. Certainly, there is evidence for the link between engagement and final exam grades, as shown in the example data in Figure 2 in which the exam grade distribution in the final exam of the process control course in 2021 is shown in comparison with separate distributions – one for the 20 students that attended active tutorials the least, and other distribution for the 20 that attended the most. Note that whereas the average exam grade for the entire course was about 70.1%, the average grade of the 20 students that attended the most tutorials was 78.7%, while that for the 20 least attending students was 60.5% -- more than one standard deviation lower than that achieved by the most attending students.

5. Conclusions

This paper advocates a change in teaching practice of PSE – from teacher-centered to student-centered instruction. It is worthwhile to consider moving much of the teaching materials from the lecture room to an online setting and require students to cover these materials on their own in preparation for class and tutorial activities. The effort is worthwhile in the long run, as better-prepared students will learn more effectively with the instructors and TAs, especially if they are expected to take an active part in the problem-solving sessions in class. The paper has provided evidence of the outcome improvements that can be expected.

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