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Iterative Improvement in Flipped Classroom Teaching of Lower Division Engineering Courses

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Abstract: Lower division engineering courses are important yet hard to teach as many students find these highly abstracted material hard to comprehend. Recent studies have suggested that flipped classroom teaching has potential to improve the teaching and learning of lower division engineering courses. While some educators are optimistic about the potential impact that flipped classroom teaching might provide, there are still many challenges to overcome during implementation. One of the major challenges faced by course developers, especially first-time developers, is to manage the heavy workload needed to design an effective practice that is suitable for their unique student body. This paper presents an iterative framework to help ease the adoption and continuous improvement of flipped classroom teaching, so that students' learning experience can be optimized over time. The framework is composed of two phases – the initial design phase and the iterative tuning phase. In the initial design phase, a strategy that allows an instructor to quickly convert the existing course materials used for other lecturing methods into those suitable for flipped classroom teaching is introduced. This process involves designing a course structure according to its objectives, rearranging course content, and patching additional resources. Then, the iterative tuning for improvement will be explained, with a focus on identifying and addressing the most critical areas for improvement. Since the course instructor only focuses on resolving the most critical issues every semester, the workload becomes manageable. The flipped classroom teaching of a lower division mechanical engineering course "ME 2040 – Circuit Analysis for Mechanical Engineers" is used as example to explain details about the utilization of the proposed course development and implementation process. Towards the end, the effectiveness of the development process in improving students' learning outcomes is discussed.

I. Introduction

Lower division engineering courses are critically important for preparing students with the necessary fundamental knowledge and skills for later technologically advanced courses. Many students find these "core" engineering courses in their middle two years of undergraduate education remarkably challenging, because the highly abstracted contents are hard to comprehend. Moreover, these course content seem to have little connection to "real" engineering[1]. Many of these courses are also known as gateway courses, bottleneck courses, and courses with high failure rate. These well-recognized challenges have been inspiring many educators to explore effective ways in teaching. In recent years, as technological developments keep driving down the cost for duplication of learning materials (e.g., shared videos online), flipped classroom teaching has been emerging as a new teaching strategy in improving students' learning outcomes[2]. Different from the traditional lecture teaching style, where students are often placed in a passive role of retaining isolated facts, flipped classroom teaching aims to foster student-centered active learning. There has been many positive experiences and practices published in the literature. The positive effect of flipped classrooms on student attitudes and performance compared to a passive lecture model has been reported by multiple studies[3–7]. It has also been reported that both students' learning achievement and satisfaction may be enhanced by using flipped classroom teaching[8,9]. Flipped classrooms have also been shown to be effective in science education[10,11] and in K-12 education[12,13].

Since flipped classroom teaching is generally divided into two parts – pre-class self-learning and in-class active learning, the theoretical rationale that justify flipped classroom teaching are also mainly from these aspects. That pre-class self-learning can potentially be more effective is supported by the learning styles theories – that individuals have unique learning styles and improved learning outcomes originate from matching learning experiences with particular learning styles[2]. Moreover, introducing flipped classroom teaching in the lower division core engineering courses can help undergraduate students improve their self-learning ability, which is a critical skill for engineers. The other rationale for flipped classroom teaching is based on active learning in the classroom. In flipped classroom teaching, since the basic knowledge are delivered outside classes, the recaptured class time will be used for more student centered active learning[14–17]. Active learning is broadly defined as "any instructional method that engages students in the learning process"[18], and can reduce failure rates and increase student performance based on Piaget and Vygotsky's learning theory[19]. There are many effective active learning techniques including peer assisted learning[20,21], cooperative learning[22,23], and problem based learning[24–26].

While flipped classroom teaching seems very promising in improving students' learning of the lower division core engineering courses, instructors also face many challenges in adopting this teaching strategy since flipped classroom teaching is not a single fixed model that can be simply duplicated. Flipped classroom teaching just provides a structure or inverted idea for instructors to redesign a course, where the detailed design of every components can be very different. For example, the pre-class content can be interactive online tutorials, video lectures, textbook reading, and so on. Moreover, it requires more time for the instructors to redesign the course as a flipped classroom[27]. To develop a flipped classroom course, the instructors need to develop both inside and outside classroom activities. What makes it more time consuming is the flexibility in developing these materials, which requires a large amount of time for searching materials from multiple sources, organizing them, and improving them. In addition, instructors normally need to be mentally prepared for unexpected complaints from students who are not used to the new teaching and learning styles. Students might resist changing to flipped classroom teaching because passive learning in a lecture is easier and less intimidating compare to being actively involved in a class[28]. Students, who need assistance in regulating or properly scheduling their time to prepare for flipped classroom teaching, might have a hard time to keep up with the progress of the course. If not designed well, these students might have difficulty comprehending the course material resulting in negative opinions on flipped classroom teaching[29,30].

To address some concerns and help ease the transition in adopting flipped classroom teaching, this paper proposes a framework to help instructors develop flipped courses through an iterative manner. The rest of the paper will be organized as follows. In section II, fundamentals of flipped classroom teaching will be introduced including its structure, key components, advantages and disadvantages. With the fundamental expectations of a flipped course in mind, section III explains the proposed iterative framework for developing flipped classroom courses. An example of flipping a lower division engineering course, ME 2040 - Circuit Analysis for Mechanical Engineers, is used to explain the utilization of the proposed framework in Section IV. Finally, results and discussion are given in section V.

II. Fundamentals of Flipped Classroom Teaching

While there has not been an official definition of flipped classroom teaching, it is commonly expected to have the following two components: 1) individual learning outside the classroom (also known as pre-class self-learning), and 2) active learning activities inside the classroom [2]. Both components emphasize student centered learning, which has become the primary theoretical foundation used for justifying flipped classroom teaching [2]. Aside from these two components, Abeysekera and Dawson's added a third component as "student accountability for in-class activities through pre- or post-class activities" [31]. While this component is crucial for the success of flipped classroom teaching, it can also be viewed as a derived component based on the successful implementation of the first two components.

From a course developer's perspective, the first two components can be used to explain the structural difference between a flipped classroom teaching and traditional lecturing. Flipped classroom requires instructors to structure a course into pre-class and in-class activities. Pre-class activities generally include book reading, video watching, note taking, pre-class quizzes, and so on. Aiming to optimize strategies for providing pre-class content instruction, Jensen et al. tested three methods of pre-class content learning — interactive online tutorials, video lectures, and textbook style readings, while holding the content and the in-class application activities constant. This study found that video lectures offer a small advantage to overall student learning over interactive tutorials or textbook-style readings[32]. If possible, it is probably best to provide students with multiple ways to prepare for class, and let them pick those that suit them. Compared to pre-class actives, in-class activities are much more flexible. Some common individual activities include polling (e.g., iClickers), gaming (e.g., Kahoot), concept maps, individual problem solving, one-minute paper/reflection, and so on. Some examples of group activities are think-pair-share, group problem solving, in-class projects, opinion line-up, sticky-note clustering, fishbowl, cumulative brainstorming, crowdsourcing, etc.. More details of in-class active learning activities can be found in[33].

In addition to the basic components and structures, knowing the advantages and challenges of flipped classroom teaching is also helpful for instructors to maximize the positive effects and reduce the negative effects on students' learning. This topic has been comprehensively reviewed in[34]. The advantages of flipped classroom teaching are mainly in improved students' learning performance[35], satisfaction[36], engagement[37], and flexibility of learning[38]. The top challenges are time consuming and heavy workload for instructors [39,40], limited student preparation before class[41], and quality of videos[42].

III. Iterative Improvement Framework

A. Framework overview

As illustrated in Fig. 1, the overview of the iterative improvement framework is composed of two phases – initial design phase and iterative tuning phase. Herein, the course objectives are used as references or standards to evaluate the performance of the teaching practice. The initial flipped course is developed by reorganizing the existing course materials into before-class, in-class, and (optional) after-class activities, and further enriched by materials collected from other resources or designed by the instructor. Note that instructors can add post-lecture activities as well, but they need to be careful to ensure that the workload for students is reasonable. Then, it will enter the iterative tuning process. The tuning actions are determined by two factors, the difference between the objectives and outcomes and experience from the instructor. Here, the difference between the objectives and outcomes can be measured by instructor's observations, students' feedback, and others (e.g., observations by colleagues). Instructors can select the most critical and implementable actions to take in each iteration such that the workload in improving flipped classroom teaching is manageable.

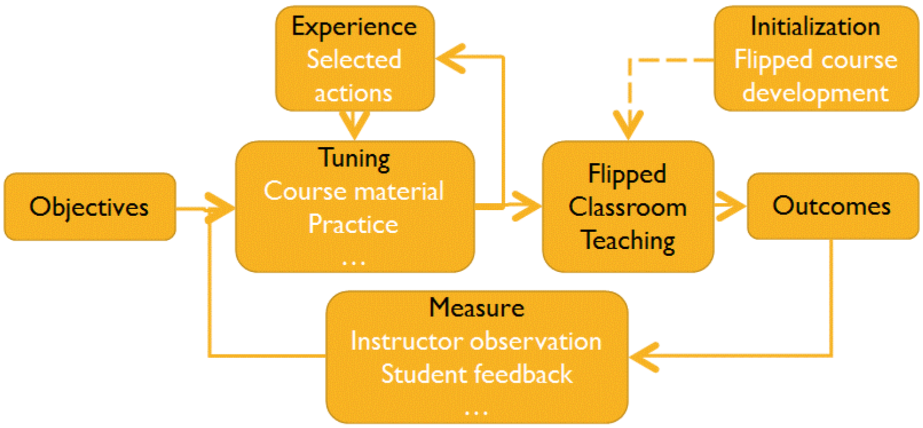

Fig. 1 Iterative framework to improve flipped classroom practice

B. *Initial design*

It is important to recognize that there is plenty of preparation work before offering a flipped classroom course. These preparations are in two sets, preparation for the course materials and adapting the instructor's role in the classroom. As indicated in Fig. 2, traditional lecturing uses in class time for knowledge delivery and after class time for practice, while flipped classroom uses pre-class time for students to learn fundamental knowledge and in class time for active learning. By comparing the two teaching strategies, a rough action plan on how to convert a regular course to a flipped course can be formed. From the course material preparation point of view, this rough action plan is composed of three parts: 1) convert the fundamental knowledge lecturing material to ones that students can use to learn before the class, 2) convert some of the conventional homework assignments to in-class activities, and 3) adopt active learning activities for students to learn advanced knowledge.

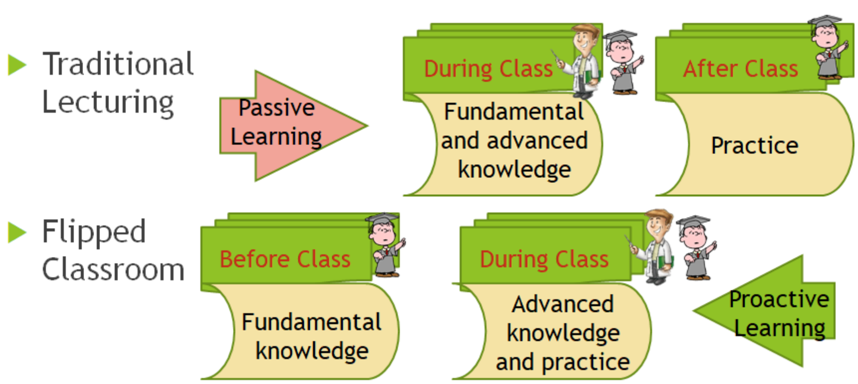

Fig. 2 Comparison of the traditional lecturing to flipped classroom teaching

Before making any changes, it is necessary to refine the course objectives to ensure they are specific and measurable, and written from the learner's perspective. A good list of course objectives should be a good guideline for instructors to assess students' learning and for students to guide their study. There have been numerous studies explaining how to design course objectives, as well as how to align teaching and assessing to course objectives[43,44]. Once the objectives are done, the next step is to build the structural framework of the course. As illustrated in Fig. 3, this structural framework is generally composed 4-7 course objectives, each course objective is met by 2-3 module objectives, and each module objective is met by 3-5 knowledge points. If these objectives are mapped to a textbook, the course objectives may correspond to book chapters, and module objectives generally correspond to book sections. In total, there can be around 15-30 module objectives for a course offered in a semester, depending on if each module is designed for a whole week or one class meeting time.

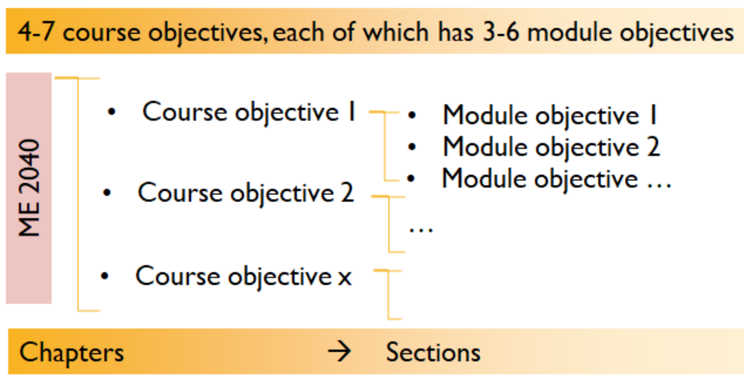

Fig. 3 Structural framework derived from learning objectives

The next step is to align the course material with the objectives. After the course developer's existing materials have been fully sorted, the missing components on this big map can be easily identified. It is a good time to start searching for resources that will fill in these gaps. It is not recommended for the flipped course developers to start with video developing without having a clear overall picture. After this course material reorganization, additional resource foraging, and patching, a flipped course should be casted in a rough shape.

C. Iterative tuning

As pointed out before, there are many variables one can tune to improve the flipped classroom teaching experience. For example, the instructor can continue improving the quality of videos by making them more interactive or continue designing an activity to make it more engaging. To avoid being overwhelmed by the workload, it is important for the instructor to identify the most critical ones to work on. The primary criteria to judge how critical the issue is should be based on how the corresponding reform will help improve students learning outcomes such that the objectives can be met. An example will be given in the next section to further explain this iterative tuning process.

IV. Practice in Flipping Circuit Analysis Course

A. Background Information

Flipped classroom design and teaching of the lower division major related circuit analysis course "ME 2040 – Circuit Analysis for Mechanical Engineers" is part of the project "Promoting Active Learning Strategies through the Flipped Classroom Model in STEM Gateway Courses", which is funded by the First in the World program of the U.S. Department of Education. This project aims to build student-centered solutions into gateway STEM courses, including pre-calculus, calculus, and physics, as well as several fundamental engineering and computer science courses. In fact, the exploration for effective teaching of ME 2040 has never stopped, multiple iterations of redesign have been performed. These modifications were mostly focused on adjustments of course objectives and contents such that it can better fit into the curriculum. Currently, ME 2040 is a 3-unit low-division required lecture course of Mechanical Engineering students, and requires students to receive a "C" or better grade to take other upper division courses that have it as a prerequisite. Some unique challenges faced by instructors in teaching this course are: 1) the course content is very abstracted and hard to visualize for many beginners, 2) it is a lecture course that heavily relies on calculation and analysis, which seems to have little application, and 3) many students who selected mechanical engineering major do not show strong interest in electronics in general.

B. Course Redesign Practice

This flipped classroom course was initially revised from the previous course materials developed for hybrid teaching, which offers some of the convenience of online courses without completely losing face-to-face meetings[45]. Like traditional courses, a hybrid course normally also has two designated time slots per week. But, students and the instructor only meet once a week and the other time is used for students to learn the fundamental knowledge independently using online materials provided by the instructor.

As described in section III. B, the initial design was done by reorganizing the existing course material then adding extra material. The whole course has in total 7 course objectives, which are further broken down into 15 topics (i.e., weeks) with 34 module objectives. Note that explaining to students how to use these objectives to study is very helpful. An example in Fig. 4 shows the course materials and their organization on Canvas (a course management software). The topic is used to help students meet the module objectives 1 and 2 under course objective 4, as shown below.

Course Objective 4: Model, analyze and use operational amplifiers

Module Objectives:

1: Model the op-amp device

2: Analyze a variety of circuits that contain op-amps or their networks

3: Describe the applications of op-amps

4: Design op-amp circuits

As it can be seen, the course materials are divided into two parts – pre-class and in-class part. Note that the "Practice 8" link is used for students to submit their work mostly done during class and no extra assignment is design for after-class usage. Instructors can add post-lecture activities as well, but they need to be careful to ensure that the workload for students is reasonable to ensure the quality of pre-class preparation. Before class, students can prepare for this topic through reading, video watching or both, and then finish a quiz. The quiz is used to ensure students' preparation for the course. In-class materials contain summative lecture notes, examples to be used for instructor lead problem solving in the class, as well as additional problems for students to practice during class with a submission link – noted as "Practice 8". All the necessary course materials are online at least one week ahead of the class schedule. It worth noting that the videos were all collected from free online resources such as YouTube. There is plenty of room to improve the quality of these videos, but it is not critical in the initial flipped classroom course design phase.

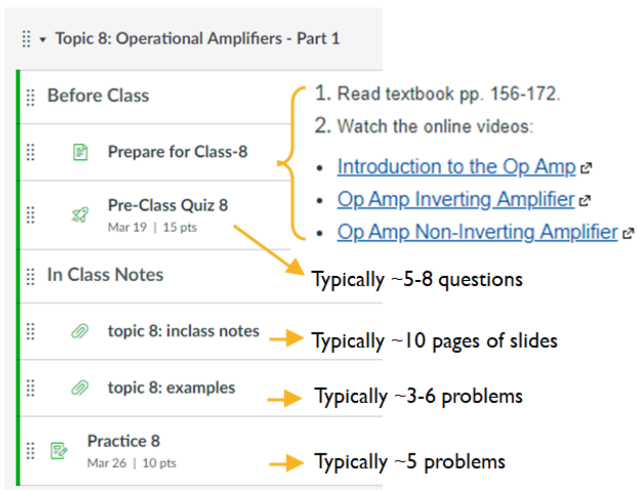

Fig. 4 Example of course material structure obtained from initial design

After this initial design phase, the course will be ready for the first implementation. From now on, the course design enters the iterative tuning phase. The goal for tuning is to minimize the discrepancy between the course objectives and student learning outcomes. The measures of the discrepancy are mainly based on the instructor's observation, students' feedback, and students' performance in quizzes and exams. Places for improvement are mainly from the following three groups, including the course materials, activities used both outside and inside the classroom, and active learning techniques.

Examples of these three categories that are used in ME 2040 are given as follows.

- Course materials provided to students: Pre-class course materials include 1) textbook reading, 2) online videos (each video last 5-10 minutes), and 3) pre-class quizzes (ensure students' preparation). In-class course materials include 1) summative lecture notes, 2) examples, and 3) extra problems for practice.
- Main activities used throughout the whole course: 1) pre-class quiz, 2) summative lecture, 3) instructor lead problem solving, 4) student lead problem solving, 5) group

problem solving, 6) homework problems in class, 7) homework checking, and 8) exam correction.

- Main active learning techniques employed in the classroom:1) think-pair-share (think, discuss with a partner, and share the answer), 2) peer instruction (pause during class and ask students to explain or show on the board), 3) group work (learn with classmates in groups), 4) role playing (e.g., students play an instructor's role to design an exam according to the learning objectives), 5) peer review (have TA and classmates help review the work), and so on.

To ensure that the tuning process will converge fast to yield an optimized solution while not dramatically increasing workload for instructors, it is always helpful to start the revision from the big picture before moving to details. The big picture concerns the overall operation of the course. A good question to survey the students might be "What are the top three things you like and three you dislike in this flipped classroom course?", or "Which topic did you find most difficult and easiest?" These questions help the instructor to find if the resource distribution on the contents or activities are proper. As it moves on, more detail-oriented surveys can be performed to find critical issues to address. Example survey questions can be "Rate the effectiveness of each of the following components/activity/active learning techniques in helping with your learning using a scale of 1-5." Other than student surveys, there are many other very important sources that can provide useful information to improve the course, such as the instructor's observation, peer classroom observation, course management software statistics, as well as quiz and exam performance.

By using this strategy, the top three issues identified in Fall 2017 for ME 2040 (the first time this course was offered as a flipped course) are 1) "heavy workload", which echoes the findings from many other publications in literature. It turns out that many students could not finish in-class practice problems and must do homework after class in addition to preparation for the next class; 2) student lead problem solving activity is hard to manage and were rated by students as not helpful in contributing to their learning; and 3) too many instructor-led solving examples, and students do not have time to practice themselves.

In Spring 2018, the following adjustments were made in ME 2040 based on the findings from Fall 2017, including 1) reduce the number of practice problems such that more students can finish before the class ends and less time will be needed outside of the classroom for practice; 2) student lead problem solving activity was dropped such that more time is reserved for students to practice in class; and 3) reduce the number of instructor-led solving examples and use the time for more active learning activities, such as think-pair-share, work together in groups, role play, peer review, and just in time teaching. It worth mentioning that in Spring 2018, both the large and small sessions were taught by the same instructor using the same materials. Typically, a small session has less than 35 students, and a large session has less than 75 students. Students' general response to active learning techniques are positive but different in the two sessions. For example, the students in both session rate role-play and peer review very high. But the students in large session do not like peer-instruction and just in time teach while students in small session have opposite opinions. In addition, based on students' exam performance and the instructor's monitoring students' time consumption statistics, two critical issues were identified: 1) students had poor performance in conceptual questions, 2) students spent much longer time on the pre-class quizzes than expected (on average, one hour or more were spent on several quizzes), and 3) attendance checking interrupted some in-class activities.

Based on the above findings, the following adjustments were made in ME 2040 in Fall 2018: 1) Since this is a large session, peer instruction and just in time teaching were dropped from the activities; 2) a lot of calculation problems in quizzes were replaced by conceptual questions; and 3) the instructor stop taking attendance to save 5 minutes for in-class activities to avoid disturbing these activities.

V. Results and Discussion

Students' exam grades are used as the main performance indicator to show effectiveness of using this strategy for instructors to develop flipped classroom courses. This course has been offered in flipped classroom teaching for three semesters, one large session in Fall 2017 (79 students), one large (75 students) and one small session (36 students) in Spring 2018, and one large session (63 students) in Fall 2018. The grades for Fall 2016, a hybrid offering with 54 students is provided for reference. While class size may affect the effectiveness of teaching and learning, this paper tries to explain the process for improvement, which suits both small and large session courses.

The mean and median grades of students' midterm and final exam grades are shown in Table 1. Students who missed the final exam were dropped from this statistic. The numbers of students who missed the final exams are 1, 9, 2, 0, 5 in Fall 2016, Fall 2017 large session, Fall 2017 small session, Spring 2018, and Fall 2018, respectively.

Table 1. Median and mean values of students' midterm and final exam grades

Semester		Fall 2016	Fall 2017	Spring 2018	Fall 2018
Midterm Exam	Median	45	60	65	79
	Mean	45.2	62.2	63.4	73.1
Final Exam	Median	30	32	54	46
	Mean	34.8	37.1	56.0	47.8

It can be seen that students' mid-term exam has been consistently improved from 60.0 in Fall 2017 to 65.0 in Spring 2018 and 79.4 in Fall 2018. From the final exam performance, it can be noticed that significant improvement was observed in Spring 2018 when adjustment was progressively made in utilization of active learning techniques. More details can be seen from the box plots in Fig. 5, where the central mark indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The lines extending parallel from the boxes are known as the "whiskers", which indicate variability outside the upper and lower quartiles. Outliers are plotted individually using the '+' symbol in-line with whiskers.

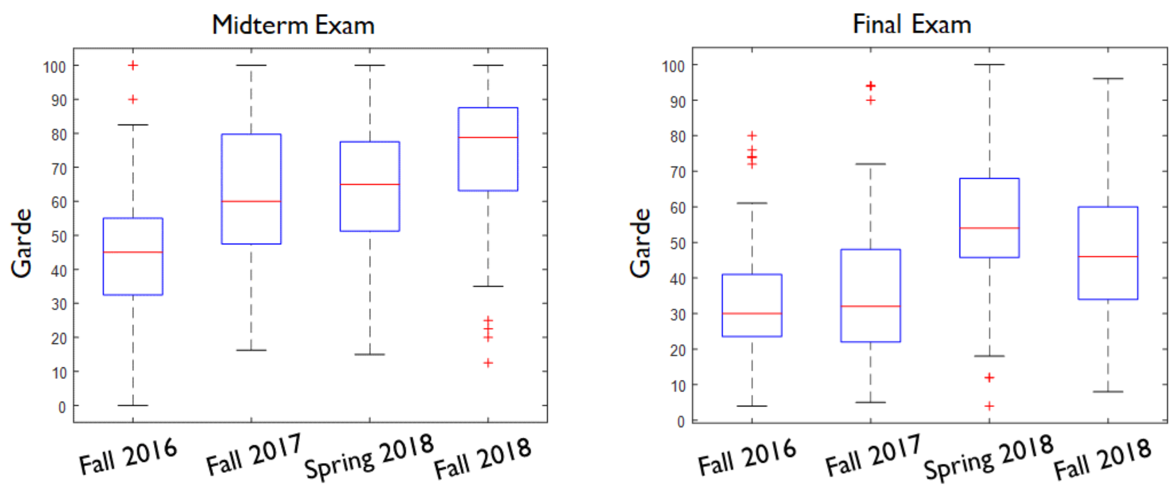

Fig. 5 Box plot of student grades

VI. Conclusion

This paper presents an iterative framework to help instructors ease the adoption and continuous improvement of flipped classroom teaching, so that students' learning experience can be optimized over time. In this framework, course objectives are used to guide the course design process. The initial version of the flipped course can be obtained by reorganizing the course materials for traditional teaching to fit this structural framework, and then supplemented with materials collected from other sources. In the iterative tuning process, various variables related to three categories – course materials, activities used for both outside and inside of the classroom, and active learning techniques, will be adjusted to improve students' learning outcomes to meet course objectives. To avoid being overwhelmed by the workload, the instructor can identify the most critical ones to work on, based on how the corresponding reform will help improve students learning outcomes such that the objectives can be met. The example of flipping a lower division engineering course, ME 2040, was used to further explain the utilization of the proposed framework to help with course improvement.

VII. Acknowledgement

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