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Reducing Costs While Maintaining Learning Outcomes using Blended, Flipped, and Mastery Pedagogy to Teach Introduction to Environmental Engineering

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Abstract

As part of a cost-savings initiative, an existing course of 'introduction to environmental engineering' offered using a 'traditional' format of didactic class meetings supplemented with hands-on laboratory sessions, was changed significantly. The 'modified' format uses 'blended', 'flipped', and 'mastery' approaches to teach "2601: Fundamentals of Environmental Engineering" to approximately 60 sophomores pursuing baccalaureate degrees in environmental, civil, or architectural engineering, each semester. This paper presents a summary of the results from eight course offerings over a period of four years to more than 450 total students. Assessments included student grades; open-ended invitations for anonymous feedback at the end of each semester; anonymous, online surveys at a mid-point and at the end of each semester; the results of a common quiz administered in the first week of a follow-up course on water and wastewater treatment; and in-depth, qualitative feedback from a selection of high-performing students collected during face-to-face interviews during a follow-up course of independent, undergraduate research. In brief, a portion of didactic class meetings was replaced with pre-recorded, online digital lectures providing students with an opportunity for asynchronous, self-paced learning. The remaining twelve, 'required' face-to-face, inductive learning sessions promoted improved learning in the cognitive domain and introduced learning in the affective domain. A flipped-classroom coupled with a modified approach to mastery-learning 'required' students to review instructional content before meeting face-to-face including: a) reading the textbook; b) watching pre-recorded, online digital lectures; c) mastering online quizzes; and d) submitting written homework. All students who completed all 'required' assignments before the published deadline were assigned a grade of 'C', for the course. Students who completed additional 'optional' assignments had the potential to earn a grade of 'B' or 'A', for the course. The take home messages for this paper include: (1) a substantial initial investment of time may be needed to create course content using blended, flipped, and mastery pedagogy; (2) group and individual written work, oral presentations, and essays can be used side-by-side with quizzes, a midterm exam, and a final exam to create an 'all-you-care-to-eat buffet approach' to earn grades; (3) implementing a 'one miss' policy for 'required' assignments helps to lower student anxiety over grades; (4) costs were reduced and student learning was maintained through blended, flipped, and mastery pedagogy; (5) many students enjoy the new approach because they appreciate clear expectations and a flexible course format; (6) some students strongly resist the modified format; and (7) a willingness to persevere despite trial-and-error is necessary as students adapt to the new approach.

Introduction

Blended-learning, combing the dual requirement of learning from both online, digital media as well as in a face-to-face format, shows promise for cost savings while simultaneously maintaining student satisfaction[1, 2, 3, 4]. The flipped-classroom, where students are introduced to new concepts through reviewing instructional content before meeting face-to-face with the instructor, shows promise for improving student learning outcomes in particular when face-to-face instruction adopts inductive learning strategies[5, 6, 7]. Finally, mastery learning, where a student must demonstrate a minimum level of competence before advancing to the next concept, shows promise for accommodating diverse learning styles and pacing as students 'skim, grok, and master' concepts[8, 9].

The typical 'introduction to environmental engineering' course often is called upon to accomplish multiple objectives in a single offering, including: 1) serving as a 'point of entry' for students pursuing a baccalaureate course of study in a program of 'environmental engineering'; 2) serving as a 'survey' for students in another field of engineering (i.e., civil engineering, architectural engineering, chemical engineering, etc.); 3) serving as an 'interdisciplinary interface' for students in fields of science, health, or various aspects of sustainability (i.e., environmental science, environmental health, or 'sustainability science, technology, policy, communication, etc.'); or 4) serving as an 'opportunity for engagement' or an 'opportunity for recruitment' for students early in their baccalaureate course of study (i.e., 'freshman engineering'). A number of authors have reported case studies on the effectiveness of redesign of 'introduction to environmental engineering' in an attempt to accomplish these among other objectives[10, 11, 12, 13, 14, 15, 16, 17].

This paper reports the results of a case study wherein an existing course entitled, "2601: Fundamentals of Environmental Engineering," was redesigned incorporating blended, flipped, and mastery learning approaches to accomplish the dual objectives of serving as a 'point of entry' for students studying environmental engineering plus serving as a 'survey' for students studying civil engineering or students studying architectural engineering. The 'traditional' format for the course relied upon didactic class meetings delivered by a faculty instructor supplemented with hands-on laboratory sessions led by graduate teaching assistants (GTAs). Two, identical sections of class meetings were offered each semester to an enrollment of no more than 30 students, each. Three identical sections of laboratory were offered each semester to an enrollment of no more than 20 students, each. A total of 60 students could complete the course each semester, and 120 students could complete the course each academic year. If student demand exceeded these caps, an additional course was offered during the summertime. A faculty instructor delivered each section of class meeting. New concepts were introduced in the class meeting. Subsequently, reading assignments and homework from the required textbook were supplemented with hands-on learning in the laboratory led by a GTA. Grades were assigned based upon performance on homework, lab reports, a midterm exam, and a final exam.

The 'modified' format for the course includes: 1) a single section of class meeting; with 2) an enrollment cap of 60 students; and 3) taught by a single faculty instructor. No changes have been made to the laboratory format, which is led by GTAs. A cost savings of one instructional full time equivalent (FTE) was realized through the collapse of two, identical sections of class meeting. To achieve blended-learning, portions of didactic class meeting were pre-recorded and are offered via an online, digital format for asynchronous viewing. Student satisfaction has been assessed through anonymous surveys at a mid-point and at the end of each semester. To achieve a flipped-classroom, new concepts are introduced initially in the pre-recorded lectures and in the hands-on laboratory. Subsequently, 'required' face-to-face, inductive learning sessions utilized peer-peer sharing and small team persuasive arguments about case studies to promote improved learning in the cognitive domain and to introduce learning in the affective domain. Impacts on student learning have been evaluated using a common quiz administered in the first week of a follow-up course on water and wastewater treatment. A modified version of mastery learning was used to assign grades. All students complete 'required' exercises – including homework, online quizzes, and lab reports – before the relevant face-to-face sessions occurs. Students completing all 'required' exercises earn a grade of 'C' for the course. Students may complete 'optional' exercises – including homework, online quizzes, lab reports, in-class quizzes, a midterm exam, and a final exam – to earn a grade of 'B' or 'A' for the course. Student response has been assessed through open-ended surveys at the end of each semester. In-depth, qualitative feedback from a selection of high-performing students has been collected from face-to-face interviews completed during a follow-up course of independent, undergraduate research. This paper includes: a map of changes from the 'traditional' to the 'modified' format as well as an analysis of assessments performed during eight course offerings, offered over a period of four years, to more than 450 total students.

Methods

University Requirements for 'Fundamentals of Environmental Engineering.' According to the registrar, this course includes 2.0 semester credit hours of lecture and 1.0 semester credit hours of laboratory. The course description sates, "Course discusses fundamental chemical, physical, and biological principles in environmental engineering and science. Topics include environmental phenomena, aquatic pollution and control, solid waste management, air pollution and control, water and wastewater treatment systems, sustainability and life cycle analyses." For an existing, ABET-accredited baccalaureate degree in environmental engineering, this course provides an opportunity for assessment of the ability to design and conduct experiments, analyze, and interpret data; the understanding of professional and ethical responsibility; the ability to communicate effectively; and knowledge of contemporary issues. It also provides an opportunity to assess knowledge of chemistry and a biological science; and to analyze and interpret data in more than one major environmental engineering focus area. For an existing, ABET-accredited baccalaureate degree in civil engineering, this course provides an opportunity for assessment of knowledge of contemporary issues; and to apply knowledge of (one of) four technical areas appropriate to civil engineering. It also provides an opportunity to assess knowledge of chemistry. No materials from this course are used for assessment for an existing, ABET-accredited baccalaureate degree in architectural engineering.

Enrollment characteristics. This course is required of all undergraduate students in the Department of Civil, Architectural, and Environmental Engineering, and this course is typically completed during the sophomore year. Typical enrollment per semester is approximately 60 students, and typical annual enrollment is approximately 120 students. Of these students, approximately 25% are studying environmental engineering, 35% are studying architectural engineering, and 60% are studying civil engineering. Approximately 20% of the total student population is dual-enrolled in two of the degree programs (i.e., architectural plus civil engineering). Approximately 35% of the total student population is female. Approximately 20% of the student population is the first-generation in their family to attend college.

'Traditional' course format. An 'introduction to environmental engineering' course worth three semester credit hours was offered in each semester as two, identical parallel sections that each included, either: 1) a 50 minute class meeting at 8am on Monday and Wednesday; or 2) a 50 minute class meeting at 11am on Monday and Wednesday. Students were also required to enroll in a 125-minute laboratory at 1pm on either Monday, Tuesday, or Wednesday afternoons. The textbook, Principles of Environmental Engineering and Science by Davis and Masten[18], has been used for more than a decade, and the laboratory assignments were all created in-house. Each offering of the course ran for the full fifteen weeks of each semester, and a comprehensive final exam was administered during the sixteenth week. The 'traditional' course format required four instructional full time equivalents (FTEs) for lecture and six GTAs for laboratory, every academic year. The results on anonymous, summative course evaluations administered by the campus-wide Committee on Effective Teaching (CET) varied greatly from section to section, which is not unusual for many sophomore-level 'introductory engineering' courses.

'Modified' course format. As part of a cost-savings initiative funded by the Provost's Office and supported by a cross-campus, course-sharing initiative, the "2601: Fundamentals of Environmental Engineering," course was substantially modified. The two, identical parallel sections of didactic class meetings were collapsed into a single section of inductive learning sessions, and the course was moved from two classrooms (one at 8am and one at 11am), and is now offered in a single, larger classroom at 8am. To further reduce the demands on classroom space, only twelve 'required' face-to-face, inductive learning sessions are included each semester. The remainder of the 'optional' class meetings is provided through a mixture of face-to-face recitation as well as online, synchronous question-and-answer between the instructor and the students. Asynchronous, blended-learning is employed to deliver the material that previously had been delivered in didactic class meetings. The course content is arranged into eleven modules, and each module includes at least one-hour of pre-recorded lecture delivered using online, digital media. The overall outcome of this approach includes: 1) reduced instructional FTEs; 2) reduced classroom space needs; and 3) increased needs for support for technology-enhanced learning.

The delivery approach of blended-learning was coupled with the pedagogical approach of a flipped-classroom 'requiring' students to complete reading comprehension, review of pre-recorded lectures, and homework, asynchronously, prior to face-to-face class time. The flipped-classroom pedagogy was adopted to allow inductive learning to take place during the limited, 'required' face-to-face class time. The objectives of this approach included: 1) improved learning in the cognitive domain as 'required' face-to-face, inductive learning sessions were used to clarify misconceptions and challenge assumptions in the cognitive domain; and 2) improved learning in the affective domain through peer-peer sharing and small team persuasive arguments about case studies with the faculty member serving as a guide-on-the-side. By requiring students to complete basic cognitive learning before class time, the limited number of face-to-face, inductive sessions could be focused on higher order cognition and affective domain learning.

As part of this experimental course redesign, a unique modification of mastery grading was used to assess student performance on 'required' and 'optional' exercises. Mastery grading allows an instructor to identify materials that 'must be learned', and to separate these materials from those that 'can be learned'. For 'must learn' materials, students repeat assignments until they demonstrate a predetermined level of mastery before a published deadline. For 'can learn' materials, students have a limited number of opportunities to complete an exercise for partialcredit before a published deadline. Within this redesigned course, mastery of 'required' materials earn students a grade of 'C' for the course, while performance on 'optional' assignments earns credit towards a grade of 'B' or 'A' for the course. The objectives of this approach included accommodating diverse learning styles and pacing as students approached this course as a 'point of entry' for studying environmental engineering or as a 'survey' to support studies in civil engineering or architectural engineering. If planned with care, the effective mapping of the course learning objectives to the content of the Body of Knowledge (BoK), coupled with the modified mastery grading approach developed for this course, allows an instructor to confirm that all students in the course have demonstrated proficiency at a mastery level.

Comparisons among course offerings. In the Spring of 2011, the instructor offered the course to a single section to approximately 60 students using an 8am class meeting time employing a didactic delivery of content. Thus, Spring 2011 provided a 'baseline' for the 'traditional' format. During the summer of 2011, the course was modified. In the Autumn of 2011, the instructor offered the course to a single section of approximately 60 students using an 8am lecture employing the 'modified' format employing blended, flipped, and mastery approaches. Thus, a comparison of Spring 2011 and Autumn 2011 allows a direct, head-to-head comparison of the 'traditional' format versus the 'modified' format. In response to negative student feedback regarding the 'zero miss' policy for 'required' assignments, in the Spring of 2012, the instructor changed the grading scheme to include a 'one miss' policy. The 'one miss' policy was permanently incorporated into the 'modified' format. Thus, a comparison of Spring 2012 and Autumn 2011 allows a direct, head-to-head comparison of 'no miss' versus 'one miss' mastery grading. In the Autumn of 2012, the instructor split the lecture into two sections, and offered the 'modified' format to approximately 30 students at 8am and approximately 30 students at 11am. Thus, a comparison of Spring 2011 and Autumn 2012 allows a direct, head-to-head comparison of the impact of class meeting time. In the Spring of 2013, the instructor repeated the course exactly as delivered in Spring 2012 (i.e., 'modified' format to a single section of approximately 60 students using an 8am lecture). Thus, a comparison of the results from Spring 2012 and Spring 2013 provides a means of evaluating the reproducibility of the assessment instruments and the variability among responses from class to class. In the Autumn of 2013, the instructor conducted an assessment of student satisfaction after four weeks of class and compared those results to the summative evaluation conducted in the final week of the semester. Thus, a comparison of the results of student satisfaction from week 4 and week 15 for Autumn 2013 provide a means of evaluating attitude shift among students during the semester. A comparison of the results of assessments from Spring 2012, Spring 2013, and Autumn 2013 provide further means of evaluating the reproducibility of the assessment instruments and the variability among responses from class to class.

Assessments. Student satisfaction was assessed through anonymous surveys at a mid-point and at the end of each semester. Anonymous, summative course evaluations were administered by the campus-wide CET using an online tool, and the instructor used Survey Monkey to administer anonymous, mid-point surveys. Impacts on student learning were evaluated using a common quiz administered in the first week of a follow-up course on water and wastewater treatment. The response of students to changes in the course format was assessed through open-ended surveys at the end of each semester. In-depth, qualitative feedback from a selection of high-performing students was collected during face-to-face interviews completed during a follow-up course of independent, undergraduate research. As part of 'required' activities during the semester, student demographics were collected using online Myers-Briggs testing as well as a Learning Styles Inventory. Student performance on 'required' exercises was assessed using online and hand-graded exercises. Student performance on 'optional' assignments including: three quizzes, one midterm exam, one final exam, as well as written homework and written laboratory reports were also determined (with the assistance of GTAs in the case of laboratory reports).

Results and Discussion

In the spring of 2011, the instructor inherited a previous, 'introduction to environmental engineering' course including prior syllabi, notes about common laboratory exercises, and an assortment of existing laboratory materials. The textbook previously selected for the course was, Principles of Environmental Engineering and Science, 2nd edition, by Davis and Masten. During the first offering by the instructor in the Spring of 2011, no materials were changed. Didactic class meetings were used to deliver the course content to a single section of 82 students. A midterm exam and a final exam were used to assign the majority of the final grade. Three brief quizzes (corresponding to the drinking water, wastewater, and air pollution modules), typical homework assignments (i.e., 'complete the even number problems at the end of each chapter') and laboratory reports were also used in the determination of the final grade. The instructor required mandatory attendance at class meetings where new concepts were introduced. Subsequently, students were assigned to read relevant chapters in the textbook after concepts were introduced in class meetings. At the end of the semester, students were invited to complete an online, anonymous survey.

During the Summer of 2011, the course was substantially modified to include content delivery via asynchronous blended mode, the primary pedagogy was modified to adopt a flipped-classroom, and mastery learning was adopted as the means of assigning grades. The instructor reviewed the teaching materials previously created for the 'traditional' format, and selected a sub-set of materials to be included as part of pre-recorded, online digital lectures. The format for each 'required' online digital lecture included a single PowerPoint file complimented by four, separate, 15-min-long MP3 audio files. Sets of approximately 30 vocabulary terms, each, were selected from the 'required' reading for each of eleven course modules. Online, 'required' mastery quizzes for each 'required' lecture and mastery quizzes for the 'required' vocabulary terms were constructed using the digital Learning Management System (LMS, in this case, Blackboard). All of these materials to support the 'modified' format were uploaded into the LMS and alpha-tested to identify and eliminate errors in content, format, or performance. Subsequently, the instructor selected materials to be used in the inductive learning sessions. The development of the materials to support the 'modified' format required approximately 120 hours of the instructor's time (i.e., four-weeks of full time effort).

Table 1 includes a description of the course modules and face-to-face, inductive learning sessions with corresponding readings completed before the face-to-face sessions. As noted from Table 1, some chapters from the textbook are not explicitly covered as part of the 'modified'

Table 1. Course module number, module title, content for the 'required' face-to-face, inductive learning sessions, and associated textbook reading assigned for completion before the face-to-face, inductive learning session.

#	Module Title	Face-to-face Content	Textbook[a]
0	Course introduction	Review syllabus and introduce blended, flipped, and mastery learning	
0	Course introduction	Case study discussion: "Seven Principles for Good Practice in Undergraduate Education"[b]; and results of Learning Styles Inventory and Myers Briggs Type Indicator personality inventory	
1	Introduction to environmental engineering	Case study discussion of NSPE Code of Ethics	1
2	Risk perception, assessment, and management	Extended discussion of exposure calculation: Example 6-2 from text[a]	6
3	Chemistry and biology (review)	Q/A with emphasis on carbonate system	Skim 2, 3
4	Drinking water treatment	Case study discussion: "Walkerton (Ontario) – The Town Where Kids Died from E. coli"[a]	9-2, 10
5	Materials and energy balance	Q/A with emphasis on reactor hydraulics (batch, continuous, plug, completely mixed)	Skim 4
6	Wastewater treatment	Case study discussion: "Cuyahoga (Cleveland, Ohio) River Burning"[a]	11
7	Air pollution	Case study discussion: "The (Donora, PA) Fog"[a]	12
8	Solid waste management	Case study discussion: "Too Much Waste, Too Little Space"[a]	13
9	Hazardous waste management	Case study discussion: "Not a Good Time at the Beach (Times Beach, Missouri)"[a]	14
10	Emerging topics	Pecha Kucha presentations on the instructor's research in sustainable development	

[a] Corresponds to chapters in Principles of Environmental Engineering and Science by Davis and Masten
[b] Chickering, A.W., and Gamson, Z.F. (1987), *Seven Principles for Good Practice in Undergraduate Education*, originally appeared in March 1987 AAHE Bulletin

format, including: 5. Ecosystems; 7. Hydrology; 8. Sustainability; 15. Noise Pollution; and 16. Ionizing Radiation. The presentation of the instructor's research is used in place of the textbook material on sustainability, and the instructor has opted to invest a portion of the semester to focus in greater depth on Chapters 10 (Water Treatment), 11 (Wastewater Treatment), and 12 (Air Pollution).

The content included in the module on drinking water treatment is provided in Exhibits 1, 2, and 3 as examples of the type of content included in each of the eleven modules (please contact the instructor for additional material, if interested). The format for each module includes a 'For Your Information' (FYI) document that outlines the learning objectives as well as the instructions for completing both 'required' and 'optional' assignments. The full module, including the pre-recorded, online digital lectures and the 'required' online vocabulary and lecture quizzes are delivered to the students via the LMS. As provided in Exhibit 1, the learning objectives are constructed using an approach based upon Bloom's taxonomy for the cognitive domain. The stated learning objectives are 'lower order' with a focus on 'remembering' and 'understanding'. The 'required' exercises are designed to accomplish the learning objectives for each module. Students, who master the 'required' exercises, earn a grade of 'C' for the module. The learning-objectives are used subsequently to construct in-class quizzes and exams; therefore, students know which materials are going to be tested.

Exhibit 1. The drinking-water-module, learning-objectives.

> The objective of this module is to introduce students to water pollution and their sources, drinking water regulations, and the unit operations used for drinking water treatment. By the end of this module, students should:
> 1) describe pollutant classes including their origin and treatment;
> 2) recognize key vocabulary used in drinking water treatment; and
> 3) describe the major unit operations of a drinking water treatment plant. [End Exhibit]

Exhibit 2 provides the 'required' exercises for the drinking water module. The vocabulary terms included: point source; pesticide; EDC; MCL; nanoparticle; transient non-community drinking water system; SWTR; Schmutzdecke; and THMs. After reading the text and taking notes on the vocabulary terms, the students completed an online, multiple-choice quiz administered via the LMS. Students must earn a perfect score on the multiple-choice quiz to demonstrate mastery of the vocabulary. Students may attempt the quiz as many times as necessary to demonstrate mastery. It has been interesting to note the variety of approaches that students employ to complete the quiz. Some students use the strategy: 1) take the quiz once without reading the text; 2) then, read the text and take notes on the vocabulary terms; and 3) finally, demonstrate mastery on the quiz using two or three additional attempts to earn a perfect score. Other students use a trial-and-error strategy and attempt the quiz fifteen or more times – without reading the text – before earning a perfect score. While one may argue that the first strategy is perhaps 'better', it should be noted that the trial-and-error approach may be understood to be similar to the learning style of 'flash cards', which is also effective for recall.

Exhibit 2. The drinking-water-module, ‘required’-exercises.

Detailed instructions of REQUIRED exercises

1) download the file entitled, ‘vocabulary part one Chapter 9’; read Section 9-2 of the text making notes about the vocabulary terms; using your notes, achieve a 100% on the required online vocabulary quiz entitled, ‘M4 required vocab quiz part one chapter 9’
2) complete the required discussion board exercise entitled, ‘M4 required pollutant class’
    a. select ONE of the pollutant classes (i.e., nutrients, salts, arsenic, etc.) described in section 9-2 of the text (a total of 13 different pollutant classes are discussed)
    b. search the popular press (internet sources are acceptable and ENCOURAGED) for a news story where this pollutant is discussed as a concern.
    c. You need to make TWO separate posts which include the following:
    d. Post One: a brief summary of the article including:
        i. Article citation (publication name, article title, author, date of publication, page numbers, URL/web site, etc.); What is the pollutant of interest (i.e., nutrients, salts, arsenic, etc.); Who was impacted; How was the ‘who’ impacted; Where did this impact occur; Why did this impact occur
        ii. As a conclusion to your post, support or refute the statement, “I agree that pollutant XXX is a concern in the news story because…” Cite specific at least two specific examples from the story and reference any external citations employed in your summary (your statement should be less than 250 words including the two specific examples).
    e. Post Two: at least one professional and thought provoking criticism of someone else’s concluding statement (i.e., While I agree with your overall conclusion, I believe you could improve your argument by… etc.) (your statement should be less than 250 words and include two reasons/suggestions).
3) download the file entitled, ‘vocabulary part two Chapter 10’; read Chapter 10 of the text making notes about the vocabulary terms; using your notes, achieve a 100% on the required online vocabulary quiz entitled, ‘M4 required vocab quiz part two chapter 10’
4) follow the links to the, ‘required lecture’; listen and watch the required lecture (four sections, each approximately 15 minutes in length. Audio files are provided as MP3. PowerPoint files are also provided.); achieve a 100% on the required lecture quiz entitled, ‘M4 required lecture quiz’
5) complete the REQUIRED written homework and submit by the deadline
    a. In your own handwriting, redraw and label Figure 10-2, Figure 10-3, and Figure 10-4 from the text (artistic ability is not being graded, rather you may use boxes, arrows, and words to redraw and label each figure).
    b. In your own handwriting, recopy the six important softening reactions (starting on page 476 of the text).
    c. In your own words, rewrite the definitions for Type 1, Type 2, and Type 3 sedimentation (page 484 of the text). Give an example of a type of material that would settle according to each of these definitions (i.e., a spherical, glass marble in a bucket of water would settle according to Type 1 sedimentation).
    d. List and briefly define (in less than 250 words) the factors involved in the effectiveness of chlorine disinfection (page 492 of the text). [End Exhibit]

The pre-recorded, online digital lecture for the drinking water module introduces the Safe Drinking Water Act; the differences among surface water and ground water treatment plants (i.e., SWTR versus lime softening); source water selection and protection comparing the water sources and treatment for New Orleans, LA versus New York City, NY; advanced treatment technology such as the Orange County water recycling program; and a review of drinking water unit operations including coagulation/flocculation, sedimentation, filtration, disinfection with chlorine and ozone, activated carbon, air stripping, membranes, and ion exchange. After listening to the pre-recorded, online digital lecture, the students complete an online quiz administered via the LMS. The quiz includes multiple choice, true/false, and matching. Students must earn a perfect score on the multiple-choice quiz to demonstrate mastery of the concepts introduced in the pre-recorded, online digital lecture.

The 'required' discussion board exercise allows an opportunity for peer-peer interaction as students conduct basic research on the internet, summarize their findings, and offer a persuasive argument for peer feedback. By including discussion board among the 'required' activities, the students learn to overcome fear of sharing with peers. In particular, it is noteworthy that the requirement to provide, "at least one professional and thought provoking criticism of someone else's concluding statement," often results in a 'back-and-forth' online discussion recruiting multiple students to share their opinions on the research and persuasive arguments of others. The description of 'required' activities provided in Exhibit 2 includes many of the 'typical' cognitive domain activities undertaken in the 'traditional' format of 'introduction to environmental engineering'. Students have approximately two weeks to complete the 'required' exercises for the drinking water module, which corresponds to the length of time used in a course following a 'traditional' format. One can note that the primary emphases among the 'required' exercises include the recognition of vocabulary terms as well as the rewriting of figures and equations from the text. These are matched to the learning-objectives as presented in Exhibit 1. By employing a flipped-classroom format, the students are completing cognitive domain activities before meeting in the face-to-face, inductive learning sessions. Failure to complete any portion of the 'required' exercises by the published deadline automatically results in a grade of 'F' for the entire course. By employing a high stakes, clearly defined requirement, the students are treated as adult learners, and the responsibility for earning a grade of 'C' is clearly placed within the responsibility of each student as encouraged by Chickering and Gamson[19].

The description of 'optional' exercises included in Exhibit 3 is consistent with the 'traditional' format for courses of 'introduction to environmental engineering'. In contrast to Exhibit 1, where the stated learning objectives for the module are 'lower order' with a focus on 'remembering' and 'understanding', the nature of the 'optional' exercises fit more appropriately with 'mid level' Bloom's taxonomy for the cognitive domain with a focus on 'apply' and 'analyze' (i.e., Chapter 10, Chapter Review question 17, "Compare slow sand filters, rapid sand filters, and dual-media filters with respect to operating procedures and relative loadings rates," and Chapter 10, Problem 10-24, "For a flow of 0.8 m3/sec, how many rapid sand filter boxes of dimensions 10 m x 10 m are needed for a loading rate of 110 m3day/m2?"). Whereas, the 'required' exercises are selected to evaluate the learning objectives for each module (i.e., Exhibit 1), the 'optional' exercises are designed to provide a means of evaluating students to assign a grade of 'B' or 'A'. Although different standards are often used at different institutions, it is not

Exhibit 3. The drinking-water-module, 'optional'-exercises.

Detailed instructions of OPTIONAL exercises:

1) complete the OPTIONAL written homework and submit by the deadline
    a. NOTE: optional online lectures (MP3 with PPT) are available to assist with learning additional material covered in the text
2) complete the optional discussion board exercise entitled, 'M4 optional TED Lifesaver bottle video discussion'
    a. watch the online video at: http://www.ted.com/talks/michael_pritchard_invents_a_water_filter
    b. You need to make TWO separate posts which include the following:
    c. Post One: (10 points total) a brief summary of the TED talk that includes:
        i. (1 point) what event triggered the creation of the Lifesaver bottle; (1 point) How long did it take to get water to the Superdome after Hurricane Katrina; (1 point) What was the limit of size for conventional hand-held filters before the creation of the Lifesaver bottle; (1 point) Who gave the presenter the rabbit droppings; (1 point) How much water can you filter with a single Lifesaver bottle
        ii. (5 points) One argument for the Lifesaver bottle is that you can ship these filters to the people in their homes thereby reducing the need to create centralized refuge camps or other dense collections of people where diseases are more rapidly/readily communicated. Do you agree with this premise of distributed water filters, and do you accept the argument that the Lifesaver bottle works best because it reduces congregations of people? Cite specific examples from the story and reference any external citations employed in your summary (your statement should be less than 250 words and include at least two citations supporting your stance)
    d. Post Two: (10 points total) at least one professional and thought provoking criticism of someone else's concluding statement (i.e., While I agree with your overall conclusion, I believe you could improve your argument by… etc.)
3) Instructions for submission of OPTIONAL written homework (handwrite all work; use 8.5x11 paper; label: name, date, assignment, and page numbers; box final answers):
    a. (12 points total; 4 points each) Chapter Review p. 507ff #'s 12, 17, and 21
    b. (15 points total; 3 points each) Problems p. 508ff #'s 10-4, 10-14, 10-22, 10-24, and 10-26
    c. (12 points total; 4 points each) Discussion questions p. 514ff #'s 10-4, 10-5, and 10-6
    d. (11 points total) Re-calculate example 10-5 on page 477 of the text assuming that the groundwater has the same composition as reported in Problem 10-4 on page 509 of the text (and assuming 2.3x10-5M CO2, pH of 7.6, and pump rate of 200 liters/second). Be sure to follow ALL steps as described in example 10-5. Handwrite your work. Show all calculations. [End Exhibit]

uncommon to identify a grade of ‘C’ with average or adequate performance, a grade of ‘B’ with goodness or solid accomplishments, and a grade of ‘A’ with outstanding distinction and excellence. Therefore, the learning objectives (i.e., Exhibit 1), and the ‘required’ exercises (i.e., Exhibit 2) are selected to correspond to a grade of ‘C’; whereas the high marks on the ‘optional’ exercises are selected to correspond to a grade of ‘B’ or ‘A’.

In the ‘modified’ format for the course employed in the Autumn of 2011, grades were calculated as follows:

- Every student was required to complete all ‘required’ exercises by the published due date.
- Students with any incomplete ‘required’ assignment received a grade of ‘F’ for the entire course.

This is a very high stakes approach to mastery learning. One benefit of this approach is that students clearly are treated as adult learners, and the deadlines are shared at the start of the semester with regular reminders provided electronically throughout the term. Expecting such a high degree of professionalism should help students to understand the value of the course content.

Completion of the ‘required’ exercises earned students a grade of ‘C’, which was calculated as 70 points (out of a total of 100 points for the semester). The ‘optional’ exercises were weighted to provide a total of an additional 30 points (out of a total of 100 points for the semester). A total of 50% (i.e., 15 of 30 points) of the ‘optional’ points could be earned through in-class quizzes, the midterm exam, and the comprehensive final exam. A total of 50% (i.e., 15 of 30 points) of the ‘optional’ points could be earned through discussion boards, handwritten homework, and laboratory reports. Distributing the points among different types of assignments and sharing the full schedule for all ‘optional’ assignments at the start of each semester allows students to plan an individual strategy to earn a custom grade (i.e., students who naturally perform well on exams could do ‘less’ homework; while students who naturally perform poorly on exams could do ‘more’ homework). In all cases, at the end of the semester a straight scale was used to assign letter grades (i.e., 70-79.4 was a ‘C’; 79.5-89.4 was a ‘B’; 89.5-100 was an ‘A’). Using this modified mastery approach, it was not possible for a student who completed all ‘required’ exercises to earn less than a grade of ‘C’ for the course. Furthermore, it was entirely possible for all students in the course to earn a grade of ‘A’ for the course.

Table 2 provides the percentage of students earning the distribution of letter grades. One can note that the grade distribution using the ‘traditional’ format in Spring 2011 was similar to the grade distribution using the ‘modified’ format in Autumn 2011. Thus, the change in format – including blended, flipped, and mastery learning - did not reduce learning as measured by grades.

In the Spring of 2012, the blended, flipped, mastery approach was utilized again. But based upon strong, negative feedback from students completing anonymous, open-ended surveys at the end of the Autumn 2011 semester (data not shown), the ‘no miss’ policy for all ‘required’ exercises was relaxed slightly and students were allowed ‘one miss’. Thus, every student was assigned a single, ‘free pass’ that could be used for any ‘required’ exercise. Table 2 suggests that the change to a ‘one miss policy’ corresponded to a reduction in the motivation of students to complete ‘optional’ exercises as reflected in a downward distribution of the percentage of

Table 2. Percentage-distribution of letter-grades among all students.

Grade	Spring 11 ('traditional' format)	Autumn 11	Spring 12	Autumn 12 (8am)	Autumn 12 (11am)	Spring 13	Autumn 13
A	53	40	14	24	35	26	33
B	24	39	31	60	40	53	42
C	8	6	47	12	25	19	23
D	2	0	0	0	0	0	0
F	13	1	0	0	0	0	0
Drop	0	14	8	4	0	1	1

students earning various letter grades. In contrast, the satisfaction of students as assessed through an anonymous survey at the end of each semester showed a significant increase in satisfaction as reflected in an upward distribution of Likert-scale scoring as shown in Figure 1. In other words, although the distribution of grades 'dropped' when comparing Autumn 2011 to Spring 2012 in Table 2, the response of students to questions regarding overall satisfaction showed an 'increase' when comparing Autumn 2011 to Spring 2012 in Figure 1. Although the sample size is relatively small (i.e., fewer than 60 individual students), it is interesting to note that shift to a 'one miss' policy corresponded to an increase in student satisfaction. This observation suggests that student learning (as measured by grades) is strongly related to the expectations of the instructor (i.e., students perform better when high stakes are employed; yet evaluations of the instructor are poor because of student anxiety). With further study, one might be able to correlate student learning, student anxiety, and student satisfaction with the expectations of the instructor to demonstrate that increased student anxiety results in more learning (i.e., higher student grades) and less satisfaction (i.e., lower faculty evaluations).

Figure 1 provides the results from five representative survey questions regarding student satisfaction. Responses to the questions were collected using a Likert-Scale from 0 to 4 (from 0 poor/strongly disagree to 4 excellent/strongly agree). The five questions included:

a) Evaluate this course, independent of the instructor's effectiveness, in terms of its educational value to you.
b) Rate the instructor's concern for your understanding of the material.
c) Rate the instructor's ability to stimulate and motivate you.
d) Rate the overall teaching effectiveness of this instructor.
e) I would recommend this instructor to other students.

'Darker' responses correspond to 'greater' agreement with each statement.

A comparison of the results of the surveys of student satisfaction for Spring 2011 and Autumn 2011 show an increase in student dis-satisfaction – an increasing number of students responded negatively to all five questions. The trend in these results track well with the strong, negative feedback from students completing anonymous, open-ended surveys at the end of the Autumn 11 semester where the 'no miss' policy was highly cited as 'unfair' (data not shown). A comparison of the results of the surveys of student satisfaction for Autumn 2011 and Spring 2012 show an increase in student satisfaction with an increasing number of students responding positively to all

Figure 1. Results of anonymous survey questions electronically available to all students via an online tool.

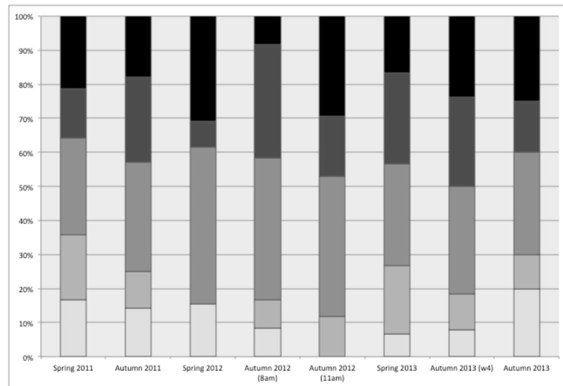
y-axis: Cumulative percentage of students' response to each statement (from 0 to 100%).

Strongly agree (black)
Neutral (50% grey scale)
Strongly disagree (white)

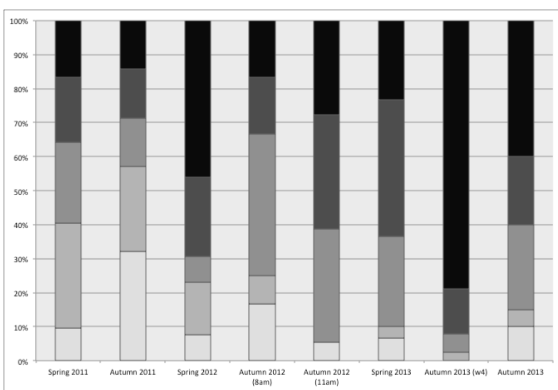
x-axis: Course offerings (from left to right).

Spring 2011, Autumn 2011, Spring 2012, Autumn 2012 (8am), Autumn 2012 (11am), Spring 2013, Autumn 2013 (week 4), and Autumn 2013.

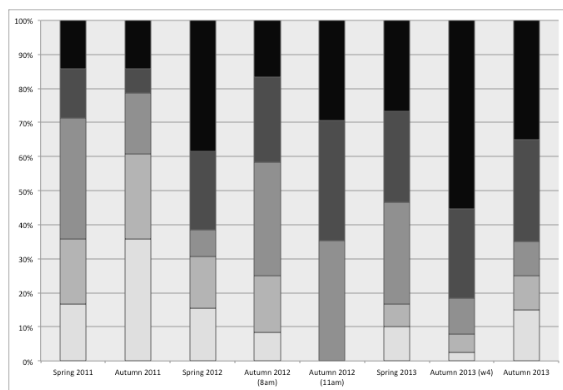
a. The course was valuable (independent of instructor's effectiveness).



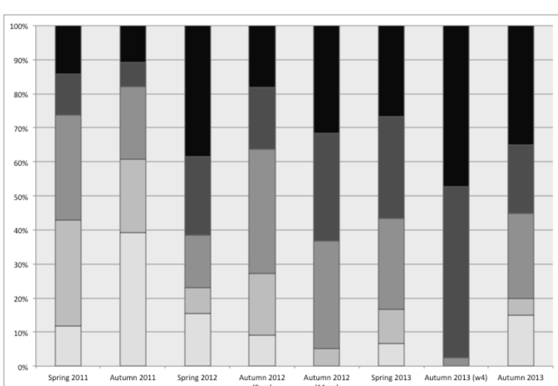
b. The instructor was concerned that I learned the material.



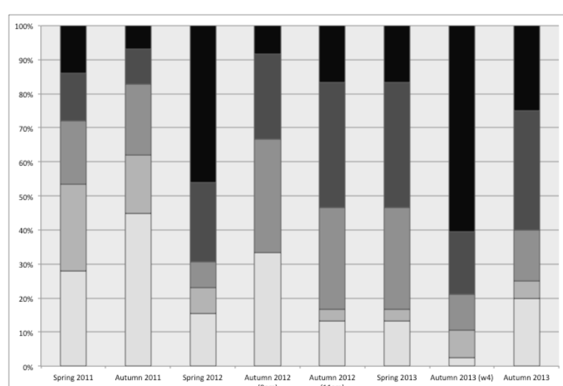
c. The instructor stimulated and motivated me.



d. The instructor was an effective teacher.



e. I would recommend this instructor to other students.



five questions (also reflected in anonymous, open-ended surveys, data not shown). One may speculate that the trend – an increase in student satisfaction from Autumn 2011 to Spring 2012 – captures the change in student satisfaction when the ‘one miss’ / ‘free pass’ policy was introduced. Overall, these results point to a number of tentative conclusions, namely: 1) the change from ‘traditional’ to ‘modified’ format resulted in a positive cost savings while maintaining student learning and achievement; 2) a high stakes mastery learning approach creates anxiety in students as reflected in lower satisfaction; and 3) the incorporation of a ‘one miss’ policy increases student satisfaction (but may also produce an unwanted result of lower student learning and achievement).

In the Autumn of 2012, the course was repeated using the ‘modified’ format with a ‘one miss’ policy, but two, identical parallel sections lecture were offered at either: 1) 8am on Monday and Wednesday; or 2) 11am on Monday and Wednesday. For every offering of the course examined in this manuscript, ‘required’ face-to-face lecture was offered at 8am. In the Autumn of 2012, one half of the students continued to participate in lectures at 8am, while one half of the students participated in lectures at 11am. A comparison of the grade distribution in Table 2 for the Autumn 2012 8am section versus the Autumn 2012 11am section suggests that the grades are similar with perhaps slightly higher performance at 8am with a greater proportion of students completing ‘optional’ assignments and earning a grade of ‘B’ or ‘A’. A comparison of student satisfaction in Figure 1 for the Autumn 2012 8am section versus the Autumn 2012 11am section shows a clear increase in student satisfaction at 11am. Although the small sample size (i.e., no more than 30 students in each section) and the presence of only a single experimental trial limit the confidence of any interpretation, one might suggest that an 11am time slot increases student satisfaction, yet results in less learning (i.e., students are more satisfied and less motivated to earn a higher grade at 11am as compared to 8am). Coupled with the comparison of grade distribution and student satisfaction among Autumn 2011 and Spring 2012, a general trend may be appearing that suggests that student learning (as measured by grades) is strongly related to the expectations of the instructor (i.e., students perform better under stress when higher stakes are involved; yet evaluations of the instructor are poor because of student anxiety).

In the Spring of 2013, the course was repeated using the ‘modified’ format. A comparison of the results of the grade distribution for Spring 2012 and Spring 2013 reported in Table 2 as well as a comparison of the results of student satisfaction for Spring 2012 and Spring 2013 reported in Figure 1 suggest very similar results and increase confidence that the variability observed in the grade distributions and the surveys of student satisfaction correspond to the changes made in each semester (i.e., the change to the ‘one miss’ policy or starting lecture at 8am or 11am).

In the Autumn of 2013, the course was repeated using the ‘modified’ format. For the Autumn of 2013, student satisfaction was evaluated after both the fourth week of class as well as at the end of class during the fifteenth week. A comparison of the results of the grade distribution for Spring 2012, Spring 2013, and Autumn 2013 reported in Table 2 as well as a comparison of the results of student satisfaction for Spring 2012, Spring 2013, and Autumn 2013 reported in Figure 1 show very similar results across all three course offerings and further increase confidence that the variability observed in the grade distributions and the surveys of student satisfaction correspond to the changes made in each semester (i.e., the change to the ‘one miss’ policy or starting lecture at 8am or 11am). Surprisingly, the results of student satisfaction were significantly different between week 4 and week 15 of the Autumn 2013 course offering (i.e., Figure 1). Due to the nature of the overall course calendar, a substantial portion of the content is provided to the students during the first half of the semester, and a significant effort is invested as part of module 0 to explain blended-learning, the flipped-classroom, and the mastery grading approach. As the semester progresses, students have less face-to-face interaction with each other and with the instructor. Perhaps the reason why student satisfaction dramatically drops between week 4 and week 15 has more to do with faculty contact and less to do with the approach used in the course or with the attitude or practices of the instructor. To evaluate changes in student performance over the semester, Table 3 provides summary statistics for the three, in-class quizzes administered during Autumn 2013. The results indicate that students remain interested in the course as reflected in a limited reduction in the total number of students participating in the optional quiz. Furthermore, the average scores on the quizzes increase over the semester, reflecting that the students continue to learn the material.

Table 3. Summary statistics for three, in-class quizzes from Autumn 2013.

Statistic	Drinking water quiz	Wastewater quiz	Air pollution quiz
Number of students participating in the optional quiz	48	42	40
Mean	45	57	59
Standard error	3	3	4
Maximum score	100	100	100
Minimum score	18	26	12
Median	39	56	64

Although the data is limited, one might speculate that the 'modified' format used in this course garners great student interest and enthusiasm due to the novelty of the approach and the high degree of expectation placed on the students. As the semester progresses, the students become increasingly distracted by the demands from competing courses offering in the 'traditional' format. Future research may be undertaken to explore this interesting result.

To indirectly assess the potential impact of the 'traditional' format versus the 'modified' format on long-term student recall of the materials covered in "2601: Fundamentals of Environmental Engineering," an ungraded quiz was administered on the first-day of a follow-up course on drinking water and wastewater treatment. Typically, students complete the follow-up course during their junior year, and typically enrollment in the follow-up course is limited to those students pursuing a baccalaureate degree in environmental engineering. Exhibit 4 provides a list of questions used in the assessment. The questions include recall of definitions, recall of concepts, and the use of the concept of mass balance to perform a calculation. The questions correspond to learning objectives included in "2601: Fundamentals of Environmental Engineering," and performance on the assessment provides at least some degree of indirect measure of the effectiveness of instruction in course using the 'modified' format.

Exhibit 4. Questions administered in a follow-up course on drinking water and wastewater treatment typically completed by juniors majoring in environmental engineering.

Define: Pathogen; Hydraulic residence time; BOD; Sludge age; Biosolids

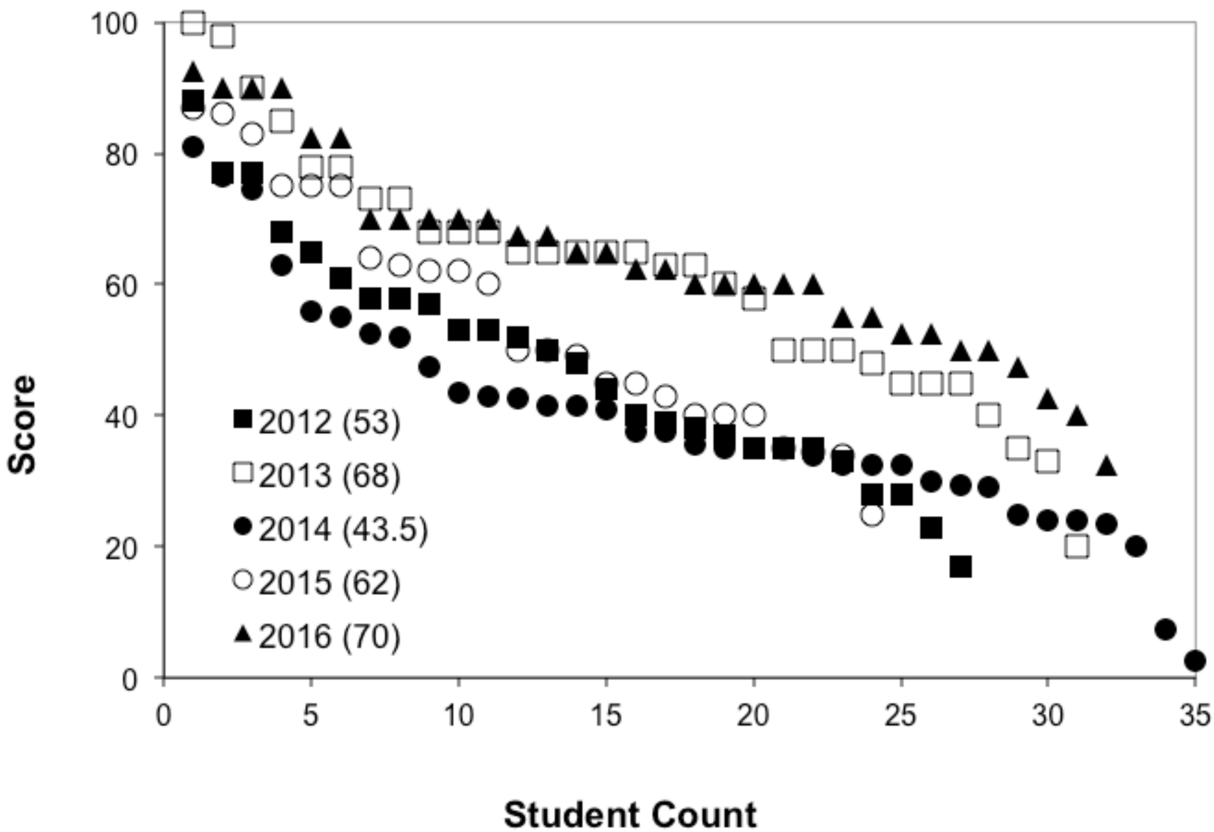
Describe: (a) How fecal coliform bacteria indicate the potential for disease transmission;
(b) The difference between coagulation and flocculation;
(c) Typical steps of a municipal wastewater treatment process;
(d) Why raising pH can result in the softening of water; and
(e) The goal of drinking water treatment.

Solve: Use a mass balance approach to determine the net BOD in a downstream flow after mixing river water with a combined sewer overflow. [End Exhibit]

The results of the ungraded quiz administered on the first-day of a follow-up course on drinking water and wastewater treatment are provided in Figure 2. The figure includes cumulative, rank-ordered scores of individual students. The students who completed the ungraded quiz in the follow-up course in 2012, would have participated in the 'traditional' format for "2601: Fundamentals of Environmental Engineering." The students who completed the ungraded quiz in the follow-up course in 2013, 2014, and 2015 would have participated in the 'modified' format for "2601: Fundamentals of Environmental Engineering." The students who completed the ungraded quiz in the follow-up course in 2016 would have participated in the 'traditional' format for "2601: Fundamentals of Environmental Engineering" as the course was once again offered using the 'traditional' format.

A number of trends may be observed in Figure 2. First, approximately 30 scores are available for each year. Second, the pattern within any year seems to follow the general trend of a precipitous drop among the first ten scores, a leveling off among the middle ten scores, and finally a second precipitous drop among the final ten scores. The legend to Figure 2 includes the year the ungraded quiz was administered as well as the score of the tenth best student. A comparison of all scores among the years shows that scores among students in 2013 and 2016 were the highest, while scores among students in 2014 were among the lowest. A comparison between the final grades for "2601: Fundamentals of Environmental Engineering" provided in Table 2 with the results provided in Figure 2 provide no obvious correlations. Although the results from this ungraded quiz administered in a follow-up course represent only a subset of the total student population in "2601: Fundamentals of Environmental Engineering," there is no immediate evidence to suggest that the 'modified' format produces students with any greater or any lesser long-term knowledge as compared to the 'traditional' format. Therefore, based on the preponderance of evidence presented in this paper, one might readily hypothesize that a blended, flipped, mastery approach results in clear cost savings – in the form of less need for physical classroom space and instructors for face-to-face content delivery – while maintaining student learning outcomes – in the form of similar scores on low stakes assessments evaluating long-term recall of facts, concepts, and the application of materials balance.

Figure 2. Results of student scores on an ungraded assessment administered on the first-day of a follow-up course on drinking water and wastewater treatment typically completed by juniors majoring in environmental engineering. y-axis: Score earned on the quiz (out of a total of 100). x-axis: Cumulative number of students completing the assessment rank ordered from highest to lowest score. Legend identifies the year the follow-up course was offered, and the number in parenthesis identifies the score of the tenth highest student in each cohort.



Finally, students who earned a grade of ‘A’ in “2601: Fundamentals of Environmental Engineering” were invited to voluntarily enroll in a follow-up course with the same instructor. The follow-up course was “4099: Undergraduate Research.” According to the registrar, the course description for “4099: Undergraduate Research” states, “Designed for the undergraduate student who wishes to engage in research. Not for graduate credit. Not more than six (6) credit hours allowed for graduation credit. Subject and credit to be arranged with the instructor.” From among the approximately 450 students who completed “2601: Fundamentals of Environmental Engineering” with the instructor, more than 35 students who earned a grade of ‘A’ opted to voluntarily enroll in “4099: Undergraduate Research.” Each of these students, both individually as well as in part of small groups, provided in-depth, qualitative feedback on “2601: Fundamentals of Environmental Engineering” as part of face-to-face interviews completed during “4099: Undergraduate Research”. The overwhelming response of these students during the interview was:

1) many students enjoyed the ‘modified’ format. In particular, sophomores using the course as a ‘point of entry’ for studying environmental engineering appreciated the clear expectations and the ability to ‘contract’ their grade (earning no less than a ‘C’ and completing ‘optional’ assignments to earn a grade of ‘B’ or ‘A’, for the course). Also, seniors in civil engineering who had voluntarily opted to delay taking the course until later in their academic career appreciated the flexibility of the course format as a ‘survey’ of the field of environmental engineering.
2) a significant and vocal minority of students ‘hated’ the ‘modified’ format because, ‘they felt it placed all of the responsibility for learning on the students and did not require the instructor to teach the material’.
3) the instructor should continue to explore the ‘modified’ format using blended, flipped, and mastery approaches because, ‘different ways of teaching are interesting and that helps to keep students engaged in the material.’

Conclusion

Historically, a ‘introduction to environmental engineering’ course was offered using ‘traditional’ didactic class meetings supplemented with hands-on laboratory sessions to approximately 120 sophomore students in a Department of Civil, Architectural, and Environmental Engineering, annually. Four sections of didactic class meetings and six sections of laboratory consumed substantial classroom space and instructional full-time equivalents (FTE’s). As part of a cost-savings initiative, the course was substantially modified using blended, flipped, and mastery approaches. The long-term impacts of the ‘modified’ format on student learning were evaluated indirectly using a common quiz administered in the first week of a follow-up course on water and wastewater treatment.

In brief, a portion of didactic class meetings was replaced with pre-recorded, online digital lectures providing students with asynchronous, self-paced learning. Twelve remaining face-to-face class meetings were modified to include inductive learning because students reviewed instructional content before meeting face-to-face with the instructor. A modified mastery grading approach required all students to complete ‘required’ assignments before a published deadline to earn a grade of ‘C’, and ‘optional’ assignments could be completed by students to earn a grade of ‘B’ or ‘A’.

The take home messages for this paper include: (1) a substantial initial investment of time may be needed to create course content using blended, flipped, and mastery pedagogy; (2) group and individual written work, oral presentations, and essays can be used side-by-side with quizzes, a midterm exam, and a final exam to create an ‘all-you-care-to-eat buffet approach’ to earn grades; (3) implementing a ‘one miss’ policy for ‘required’ assignments helps to lower student anxiety over grades; (4) costs were reduced and student learning was maintained through blended, flipped, and mastery pedagogy; (5) many students enjoy the new approach because they appreciate clear expectations and a flexible course format; (6) some students strongly resist the modified format; and (7) a willingness to persevere despite trial-and-error is necessary as students adapt to the new approach.

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