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Flipping the Chemical Engineering Process Control Class with e-Lessons

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1. Introduction

This paper addresses a blended learning teaching method for an upper-level engineering course. The teaching and learning approach involves a “flipped course design”, with students preparing for class using e-Lessons and performing workshops during class. The course topic is Process Control, which involves automatic control tailored for chemical engineering and is typically offered in the third or four year. This fourth-year course was offered during the spring of 2016 to about 60 students at the Mork Department of Chemical Engineering at the University of Southern California. The students were studying a range of minors, e.g., petroleum, biotechnology, and nanotechnology; about one-third of the students were female. The students were in their last semester of their four-year undergraduate program and were taking a full complement of courses in parallel, including their capstone design course.

The U.S. National Academy of Engineering has recommended that universities experiment with novel models for baccalaureate education (NAE, 2005). Blended learning using a flipped class approach has attracted considerable interest in recent years for promises of increased active learning and deeper involvement in topics. A form of blended learning is the topic of this study.

A number of journal articles are available that address teaching core engineering courses, and this situation is true for the teaching of Process Control and Automatic Control. Most published papers (e.g., Edgar et. al., 2006; Khier, et. al., 1996; and Seborg et.al, 2003) address the course content and issues like whether frequency response should be included in the course, the proper role of dynamic simulation, and design of physical laboratories. Recently, a few studies have addressed teaching and learning methods that could be applied to any appropriate control course content. Rossiter (2014) describes blended learning using YouTube videos developed for students to prepare before class. The class was large and diverse, involving over two hundred students from several different departments; generally positive results were reported based on student feedback. Mason et.al. (2013) report on a well-designed experiment comparing flipped education with a traditional lecture-based approach in an upper-level mechanical engineering control course. Mason et.al. (2013) pre-class information was recorded in YouTube videos. They reported improvement with the flipped approach over the control group based on extensive testing and student feedback.

We intend to give a complete exposition of our study in this paper; however, the interested reader will want to experience the e-Lessons to gain a full understanding of the approach presented here. All of the e-Lessons, workshops for each lesson and many other learning resources are available at the following internet site; http://pc-education.mcmaster.ca/default.htm, which has been open for fifteen years and has been recently updated to include this new teaching material. The e-Lessons can be reached by selecting “Process Control Learning Support” in the menu bar at the top of the home page. e-Lessons are available for many of the textbook chapters. This site is open 24/7 and is available to all students and faculty without charge or password protection.

This paper begins with an explanation of the goals of the study. Both the teaching and learning goals and the technology goals are addressed; by technology goals, we mean the cost and technical complexity of the development and maintenance. Second, we proceed to an exposition of the teaching and learning method; at every stage, we present the application in this course. Third, we present evidence of changes (improvements) effected through this project. Fourth, we discuss the methods and results in light of some well-recognized principles of higher education. Finally, we present conclusions.

2. Project goals

The major goal was to apply the flipped class approach of blended learning to this university engineering course and evaluate the benefits, if any. Since we do not live in a world of unlimited resources, a second important goal was to find tools and methods that make a flipped class possible for the majority of university courses; the method should be low cost and involve simple software technology.

2.1 Teaching and Learning Goals

The main learning goal is to improve learning over that achieved by the standard lecture-based approach. In a lecture-based course, a considerable portion of class time involves knowledge transfer via lecturing, perhaps, mixed with some example problems. Students see the material for the first time during the class; so, they are challenged by the fast pace of knowledge transfer and have little opportunity for applying their learning or receiving constructive feedback from the instructor.

The proposed method for increased active learning during class time is to provide resources for knowledge transfer outside of the classroom, so that students arrive at the class prepared to apply and enhance their learning. During class time, students can work in small groups on applications prepared by the instructor. Also, the instructor can mentor the groups and present solutions during the class.

The proposed "flipped class" course design can facilitate improved knowledge transfer. Since the students arrive knowing the basic course topics, the instructor can address more complex issues that would overwhelm students in the conventional lecture-based class. The instructor can pose challenging problems, allow students to work for a short time to grasp the intricacies of the topic, and ultimately present a solution. If successful, the proposed approach will increase student knowledge acquisition, improve higher-level problem solving skills, and enable more contact between the students and instructor.

2.2 Technology Goals

We expect that teaching and learning progress can be made with unlimited resources, but universities have little extra funding to support undergraduate education. To have a broad-based impact on education, a new approach must not change the course budget; if low cost cannot be attained, technology applications in higher education will be limited to a few courses, typically attended by a large number of students.

First, the approach should require low-cost hardware, inexpensive software, and limited personnel time. Unfortunately, many novel approaches demand substantial resources. The cost for developing a MOOC is reported to vary from 70 K$ to 250 k$, not including presentation and maintenance (Tamburri, 2014; Hollands and Tirthali, 2014); another estimate for e-Learning was over $10k per hour of instruction (Chapman, 2010).) Second, the approach should involve technologies that can be mastered quickly by most faculty members, i.e., have a gentle learning curve. Third, the distribution cost should be negligible, usually involving posting on the Internet. Fourth, the learning materials should be easily maintained and updated; for example, repeating the production of an entire video to change a small part would not be practical.

We know that we will not be able to achieve the production quality of a science television program, such as “Nova” on PBS in the United States. That level is not practical for the thousands of courses at each university. Therefore, we have to strike a balance of cost and presentation quality that meets students’ needs while not exceeding the resources available. Since new software products are available for e-Learning, this could be the time where the technology corner has been turned, where the cost and complexity of software tools for developing learning materials have decreased sufficiently to bring them within reach of all faculty members. We will report on an approach that achieves a satisfactory balance of learning materials quality with cost and technical complexity.

3. Teaching and Learning Approach

The conventional lecture-based course has dominated university teaching for decades, if not centuries. Instructors know that there are deficiencies; simply looking out at the students in a lecture and gauging their interest level is sufficient to see limitations. However, students benefit from a coherent discussion of challenging material and the ability to test their learning and obtain immediate feedback to their questions, so substantial face-to-face time with some lecturing is likely required in any approach. We present an approach that has gained acceptance recently.

3.1 Blended Learning

The approach applied in this project is a version of “Blended Learning”, which is defined in the following. “Blended learning: a formal education program in which a student learns at least in part through delivery of content and instruction via digital and online media with some element of student control over time, place, path, or pace” (Wikipedia, 2016; MacMillian, 2017)”.

The distribution of time between media and distribution of physical location are shown in Figure 1. A typical, lecture-based course is shown as point “A” at the lower left, and a fully distance learning course is shown as point “B” in the upper right. A blended course balances features, usually having from 30-70% online content, and always having face-to-face interactions between students and instructor (Knewton, 2016).

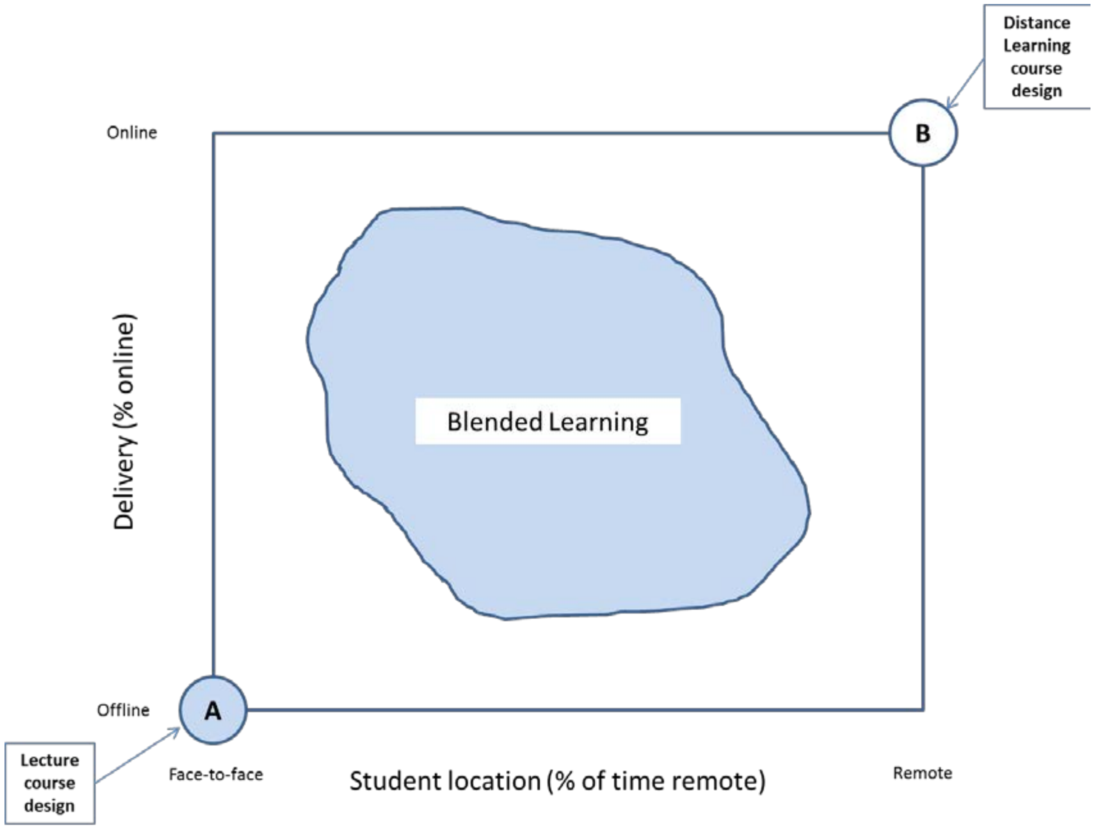


Figure 1. Schematic of the physical aspects of blended learning. Modified from Knewton (2016)

3.2 The Flipped Class

The blended concept does not define a specific course approach; further features are required for a specific course design. This project selected the flipped class, which is the most appropriate form of blended learning for higher education. A review of research on the flipped class is presented by Bishop, and Verleger (2013).

We'll begin with a description of the flipped classroom based on Figure 2 before discussing some features and reasons for its choice. This figure shows the activities performed by students for each lesson, i.e., each class. Students begin by reviewing a prescribed e-Lesson before class. The e-Lesson is discussed in the next section; for now, let's accept that it is a "lecture" that presents the basic required knowledge. During the subsequent face-to-face class, students work in small groups on workshop problems prepared by the instructor, and the instructor spends time circulating among the groups mentoring their problem solving. At intervals, the instructor convenes the class to discuss solutions, comment on student approaches, and solicit questions. This cycle is repeated throughout the course.

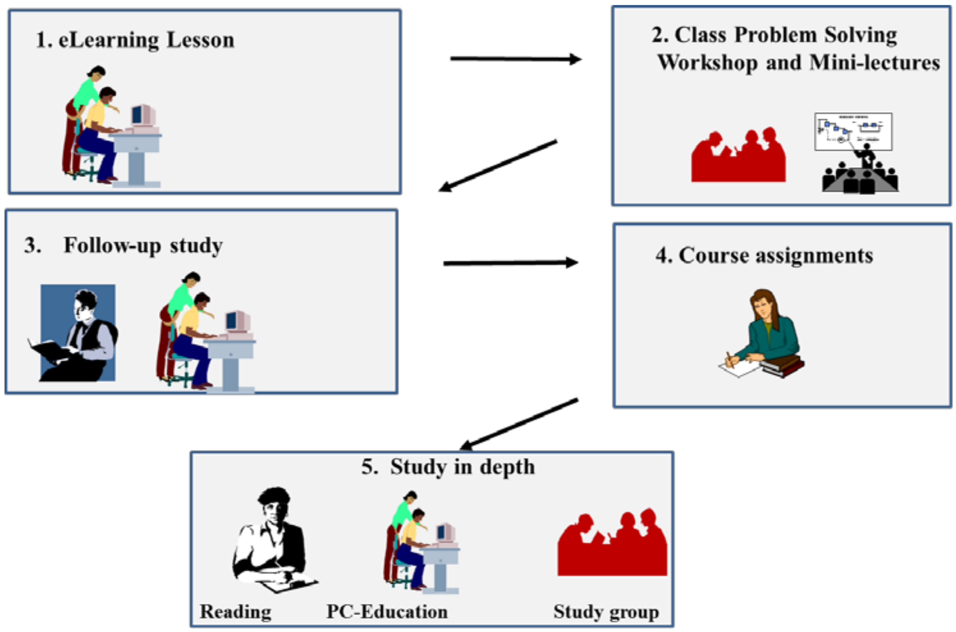


Figure 2. Activity sequence in the flipped class for each class/e-Lesson.

This flipped approach can be successful if students are prepared by completing the required e-Lesson-based learning before class. To ensure preparation, a short graded quiz can be given to evaluate their learning. Since these quizzes contribute to their course grade, the quizzes provide sufficient motivation for class preparation. Even the possibility of a quiz, which might occur only a few times during the semester, has the desired effect.

Naturally, the course involves graded assignments to be completed outside of class. These can be designed to direct attention to the most important principles and practices in the course. Also, students will invest time for the preparation before term and final exams.

We note that the textbook has not been eliminated. It provides a key resource by providing thorough presentation of complex topics. The instructor can direct students to the book by including assignment questions that require reference to the book.

Simply flipping the class activities does not necessarily achieve the desired improvement in student learning, as stated clearly in the following. "Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter" (Talbert, 2014).

The e-Lessons and class time must be structured to provide the best learning for the integrated activities consisting of personal e-Learning and workshop group problem solving. Most importantly, the face-to-face class time must be structured to provide an active learning experience. In this project, a large portion of the class time was reserved for problem solving, as will be discussed shortly.

3.3 The e-Lesson

The e-Lessons are accessed through an Internet site and can be performed at any time or place. They are "slide-based", as contrasted with a "video" of a lecture. Each slide is enhanced with animations and audio, along with a script of the audio. Typical slides are shown in Figures 3 and 4. Figure 3 shows a modeling example. The slide begins nearly empty, with only the process sketch and four words (variable, system boundary, and balance) showing. The visual content is displayed sequentially over about three minutes as the audio explains the modeling method. A cascade control design in shown in Figure 4. Part (a) develops the structure of the design, and Part (b) explains the advantages of the design with reference to the dynamic behavior of key variables. Again, the visual content is displayed sequentially as the audio explains key features.

Navigation is facilitated by the display template. Students control the transition between slides and can replay any or all of a slide. Also, they can jump back to review past slides, and they can jump forward, which is useful when returning to an e-Lesson for review or reference. Therefore, the lessons are completely self-paced.

We should note that this slide-based e-Lesson was selected over a "video" approach for several reasons. First, the slide-based approach gives students much more control over the presentation; they can stop, replay jump back (or forward) as they need. Second, the slide-based approach is easier to modify and maintain; redoing a slide animation or audio or adding and deleting is much easier than reshooting a 20-minute video. Third, the physical facilities, software and hardware demands are greater for the video production. Finally, the skills required for good videos are not always available to the faculty; often a production team is required, which increases cost.

Naturally, the animations and audio are synchronized, giving the impression of a well-planned lecture presentation. Animations enable material to be introduced sequentially and to show temporal relationships, as in the following examples.

- **Model derivation**: A mathematical model can be presented in stages, with each stage explained via audio and students given time to think how they would perform the next step. Key variables can be highlighted, relationship between the physical system (in a sketch) and the equation can be shown, and simplifications can be introduced sequentially.
- **Transient plots**: Variables can be plotted over several seconds to reinforce the transient nature of the system behavior.
- **Equipment behavior**: Key aspects of equipment behavior can be shown in an animation, for example, a valve stem affecting the opening for flow.
- **Calculations**: Calculations can be shown with time for students to think about the next step before seeing the result. An example is the process reaction curve experiment and modeling calculations.

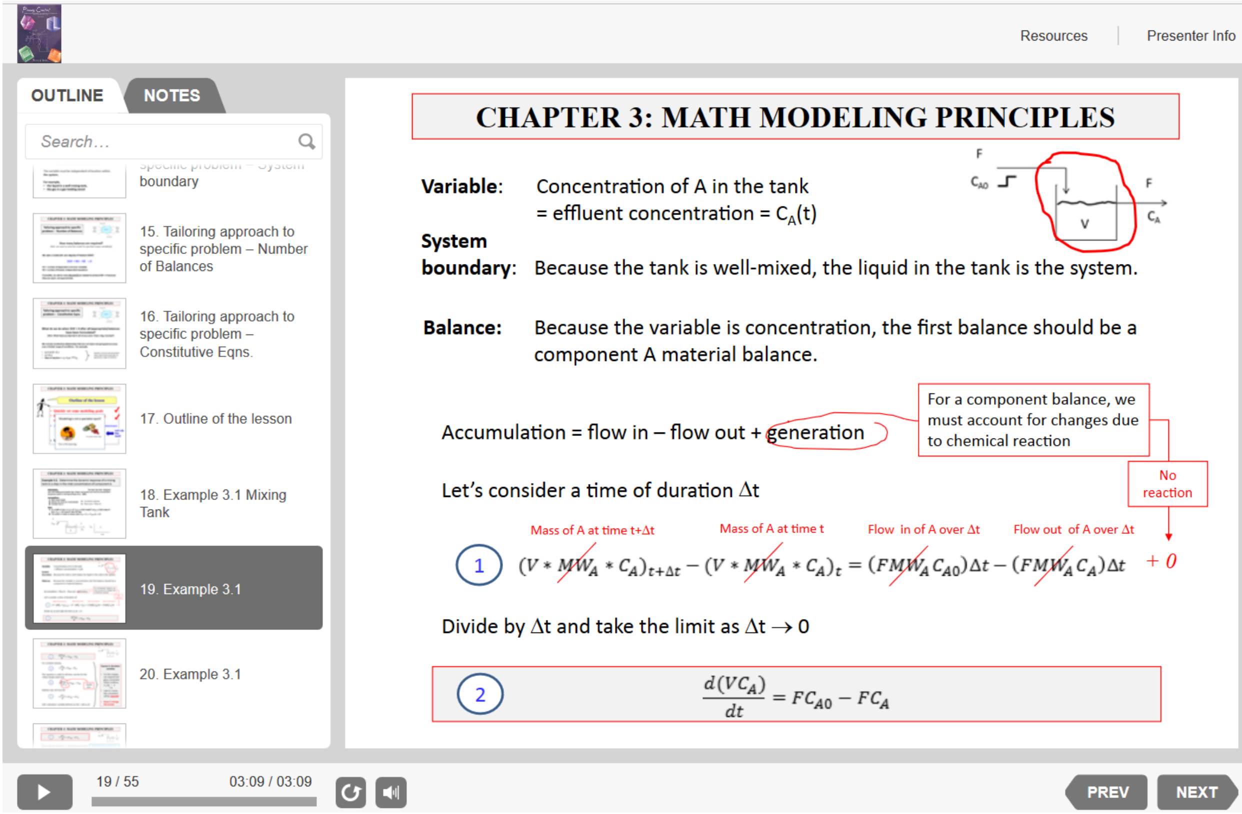
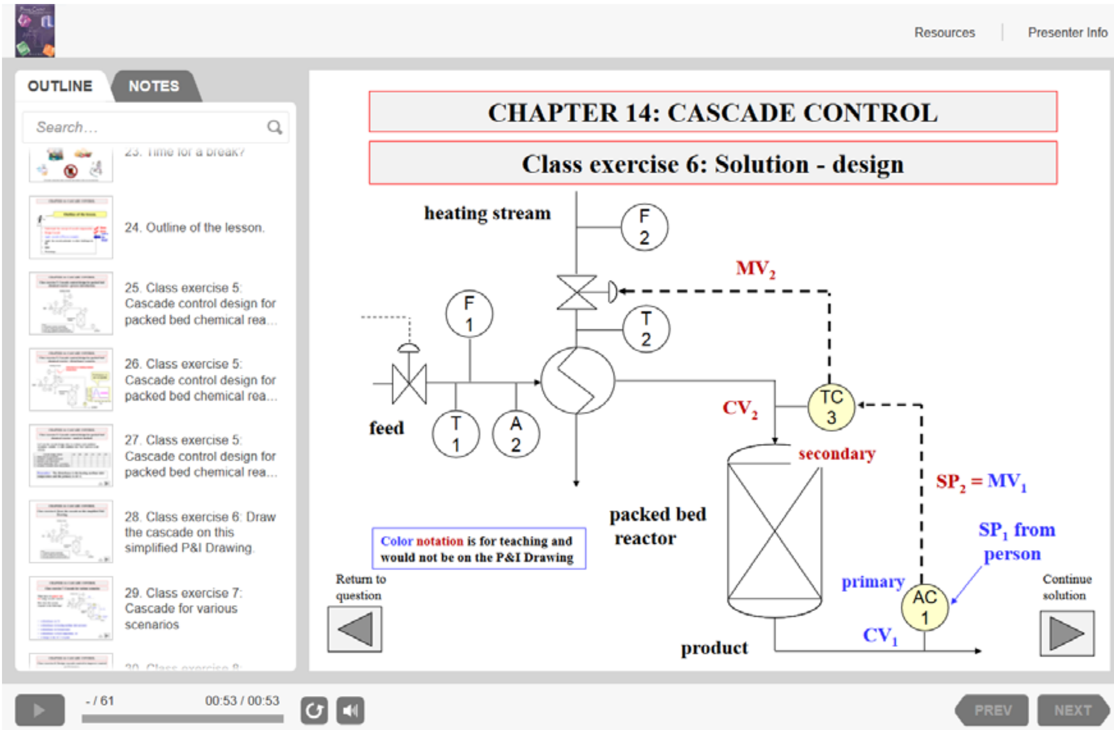


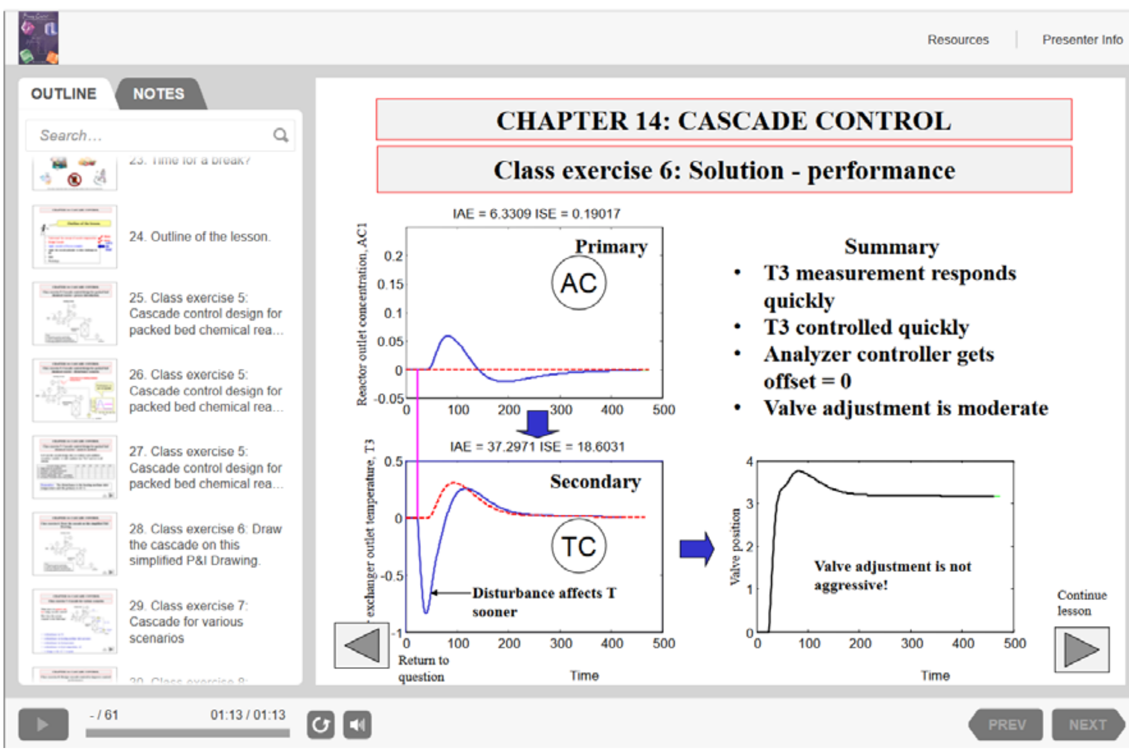
Figure 3. Typical e-Lesson slide showing mathematical modeling.

- **Control designs**: The designs can be introduced in a stepwise manner, with clear audio explanations.
- **Video**: Videos can be integrated where appropriate, for example, to show the behavior of a pneumatically actuated control valve.

The e-Lesson is not meant to be comprehensive (nor is any class lecture). Students do not attain mastery of the topic via the e-Lesson; they build their initial knowledgebase and are prepared to participate in subsequent class workshops that extend and enhance their learning. Material is selected based on its central role in the development of principles and practice. The typical scope is one-half to one textbook chapter, which will require about one hour for the students to complete.



(a)



(b)

Figure 4. Typical e-Lesson slide showing (a) Control structure design and (b) Analysis of dynamic behavior.

The organization of a typical e-Lesson is shown in Figure 5, which is similar to a class lecture. However, the e-Lesson has several key advantages.

- **Asynchronous and Self-paced**: The students can visit the e-Lesson when they want and in a location of their choice. In addition, they can stop, repeat, jump back, and discuss issues with friends. (Students are encouraged to view the e-Lesson in small groups.) It is always available for review anytime during the course. In fact, they are available after the course, when they begin professional practice.
- **Graphics**: The graphics are clear. In contrast, visual aids are not easily seen by many seats in a typical classroom.
- **Duration**: The "twenty-minute" rule for length of lesson was not observed. However, students have the option to take a break(s) during the e-Lesson; break points are suggested.
- **Participation**: Exercises are included during the workshop class to encourage students to begin their problem solving. Complete solutions are provided.
- **Quiz**: A digitally-mediated quiz containing numerous short-answer (true-false, multiple choice) questions is provided after the new material has been presented in each e-Lesson. This quiz is not graded, and solutions are given for all responses. This approach is based on research demonstrating that students gain more from testing than from the equal amount of time re-studying (Roediger and Karpicke, 2006; Karpicke and Roediger; 2008); this is often referred to as the "testing effect".
- **Reflection**: The students have time to think about the new material and can raise questions via email or a course LMS, at the beginning of the subsequent class, or during office hours.

As stated previously, the class activities must be coordinated with the prior preparation using e-Lessons. Therefore, let's proceed to the next section on class activities.

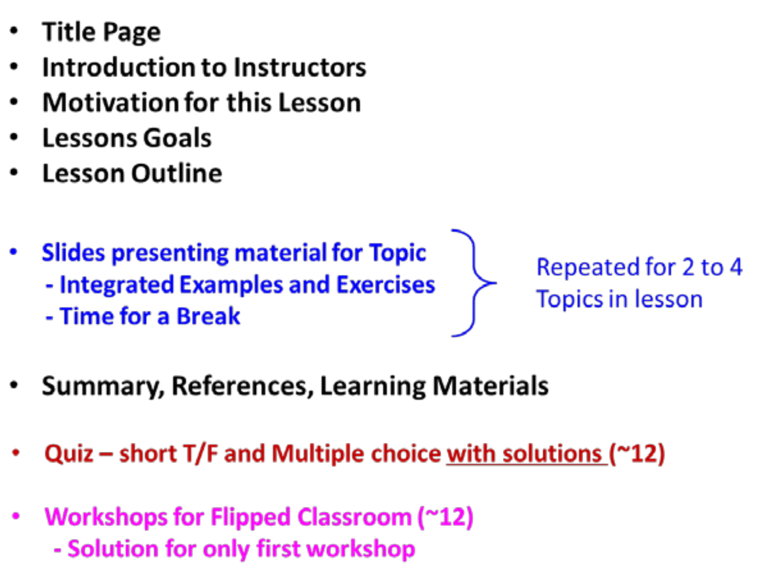


Figure 5. Typical e-Lesson Organization

3.4 Class Activities

The complementary classes are designed to provide an active learning environment that builds on the e-Lessons, as shown in Figure 6. We note that the majority of the time in each class is dedicated to workshops that involve active learning, because active learning has proven to improve understanding and retention (Prince, 2004). The workshop questions are selected by the professor, and students work in small groups to solve the questions. Typically, the class reconvenes several times to discuss solutions to one or more problems before proceeding to later problems. While the students are preparing their answers, the instructor (and perhaps, teaching assistants) is assisting groups by mentoring them on their problem-solving approach and principles needed for the problem. After the workshop, solutions are posted on the course LMS site.

Workshop questions vary in form and depth. A few require short answers like true-false, multiple choice, or fill-in the blank. These simple problems ensure that some basic knowledge is in place. However, most questions involve problem solving requiring mathematical development, calculations, changes to drawings, and so forth; these more complex problems are similar to the issues encountered in engineering practice. Because of the complex nature of the problems, the use of feedback with clickers was not integrated into the workshops (Harlow, et.al, 2016). We note that the classroom design should enable students to form informal groups and the instructor to easily move among the groups; the classroom had a flat floor and individual desks that could be easily moved by students.

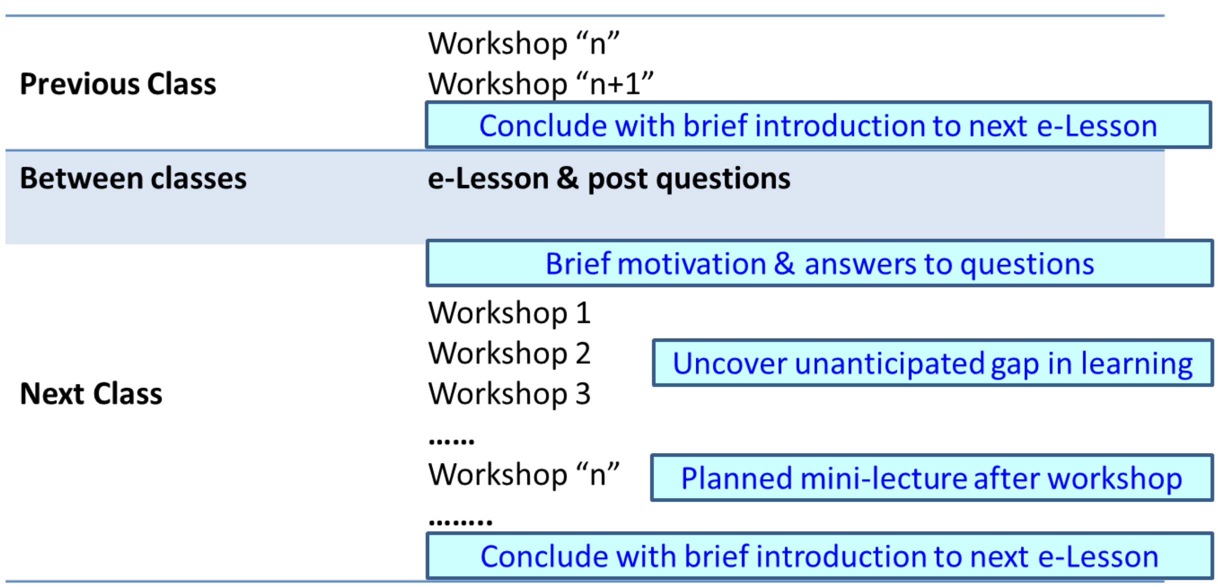


Figure 6. Workshop class organization. Boxes represent mini-lectures.

Not all information should be transmitted using e-Lessons and workshops. A place remains for mini-lectures. We note that begins with a mini-lecture that can include responses to student questions from the e-Lesson. Also, since instructors know which topics are especially challenging for students, a mini-lecture can be planned after a workshop problem that involves the challenging topic. Therefore, the lecture is not dead; it has been shrunk, partitioned, and focused!

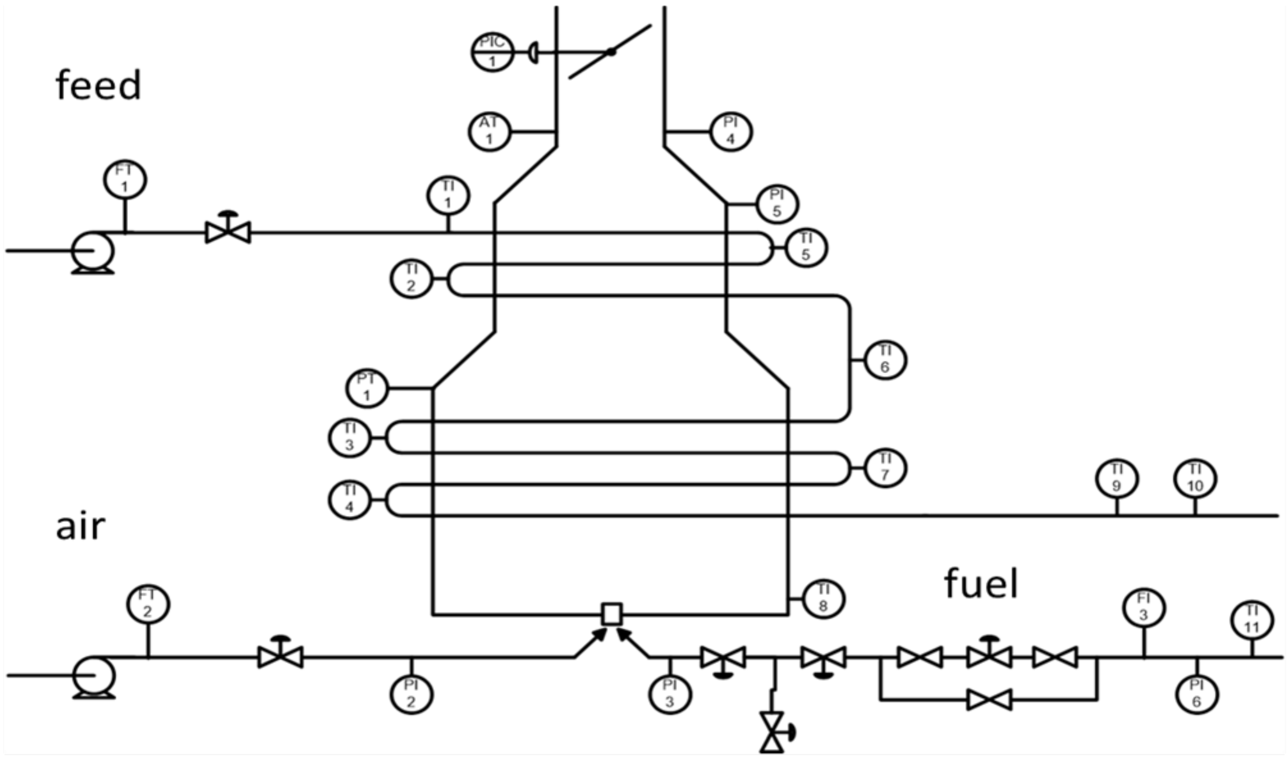
Each e-Lesson contains about twelve proposed workshop problems. Instructors can use these or personalize the course by formulating other problems. Depending on the problem complexity, students can complete three to six problems during an eighty-minute class.

The workshop offers the environment where highly complex topics can be addressed. In engineering courses, these topics often require extensive prior knowledge and complex analysis. If such problems are addressed in assignments, students are overwhelmed and become frustrated. In the workshop environment, the instructor can provide initial guidance, mentor groups personally, and interject helpful hints when students cannot progress with their solutions. Examples of these types of problems in a chemical engineering process control course are given in the following.

- Identifying control objectives for a given process design
- Identifying control approaches (none, manual, on-off, modulating, emergency) for a given process design
- Evaluating and troubleshooting dynamic data from a control loop
- Designing cascade, feedforward and multiple-loop control systems

An example workshop on control objectives for a process fired heater is given in Figure 7. Undergraduate students cannot perform this analysis well without guidance, because they do not know enough about a fired heater. However, the analysis is important, and they can gain a lot by trying, following instructor-provided guidance, and recognizing the important of goal-setting in a problem solving method. This one slide summarizes ten slides that introduce the process, show a picture of an industrial heater, summarize economics of a heater, and present the solution for each of the seven categories of control objectives. These types of analyses are essential when students complete their capstone design project, not to mention when they begin engineering practice!

The class activities emphasize student-student and instructor-student interactions. This study involved a moderate class size of 59 students with only the instructor (no teaching assistants) available to mentor student groups, and no conclusion can be drawn for very large class sizes.



1. Safety: Ensure that a flame exists at the burner; if not, stop the fuel flow immediately

2. Environmental Protection: Prevent smoke from exiting the stack.

3. Equipment protection: Prevent high pressure in fire box by adjusting the damper in the stack.

4. Smooth operation production rate: Control the feed rate at the desired value; ensure that it is above the minimum value.

5. Product quality: Maintain the product effluent temperature at the desired value by adjusting the fuel flow to the burner.

6. High profit: Achieve high efficiency by preventing large excess of air to burners. (There is a "happy medium", not too little or too much air.)

7. Monitoring & diagnosis: Measure temperatures along the tube to identify abnormal conditions, like coking in tube.

Figure 7. Control objectives for a fired heater

3.5 Guidance on Course Delivery and Management

Professors know how to manage a course, so only a few comments are needed here. We'll start with a few "do's".

- **Student guidance**: Students will need some guidance on the modified course presentation, how to navigate the e-Lesson, and expectations for the workshop classes. The WEB site for these e-Lessons includes a brief e-Lesson with user guidance. In addition, a WEB page includes a clear definition of tasks before and during each class; a typical definition is given in Table 1; this experience confirms results by Mason et.al. (2013)
- **Focus**: The instructor should remember that the e-Lesson is not comprehensive; it focusses on the basic concepts and practices. Assignment questions can be used to focus on other topics that need coverage.
- **Quiz grading**: Some graded quizzes are needed to ensure that students prepare by viewing the e-Lessons before class. Some flexibility in the grading is advisable, for example, counting the highest "n" from "m" quiz grades.
- **Workshop**: As has been reported by many authors, instructors initially underestimate the work involved in preparing workshops for the face-to-face time. Recall that students appreciate solutions that are posted after the workshops.
- **Interactions**: Take advantage of the workshops to get to know students and to understand their perspectives, questions, concerns, and interests.

  Based on experience, we also have a few "don'ts".

- **Attendance**: Do not give credit for merely attending class workshops; this sets a low bar for expected performance, one that students will recognize.
- **Participation**: Do not give credit for merely participating in workshops, such as is sometimes done for use of clickers. Again, this is too low an expectation for students preparing to work as professionals.
- **Contact time**: Do not cancel face-to-face class time. The purpose of blended learning is to increase the productivity of the classes, not to eliminate classes!

Table 1. Guidance for student preparation (Only part of the semester table is shown)

Class date	Complete before class	Activity during class	Textbook material	Assignment (due at beginning of class)
Jan 12	N/A	Course management	N/A	--
Jan 14	Chap 1	Chapter 1 Power Point	Chapter 1	--
Jan 19	Chap 2	Workshop Jan 19	Chapter 2	--
Jan 21	Chap 3, Part I	Workshop Jan 21	Chapter 3 Pg. 49-69	Assignment 1
Jan 26	Chap 3, Part II	Workshop Jan 26	Chapter 3 Pg. 69-88	--
Jan 28	Chap 4, Part I	Workshop Jan 28	Chapter 4 Pg. 97-110	Assignment 2
Feb 2	Chap 4, Part II	Workshop Feb 2	Chapter 4 Pg. 110-125 Skip Section 4.5 *	--

4.0 Evaluation of the Flipped Class

This first experience with the flipped-class format was used in over 90% of the classes; e-Lessons for the last few topics had not yet been prepared. The students did not have much, if any previous experience in the flipped-class format. It was new to the students and instructor.

We should always gather data on the effects of our teaching and learning. Here, we report on three measures, student learning performance, student satisfaction, and the cost and technology required.

4.1 Student Learning Performance

An appropriate method for evaluating the effect of the new course delivery on student learning would be to offer it twice in parallel, with students randomly assignment to two sections receiving different delivery formats. This experimental design was not possible; however, some comparisons can be made.

All performance comparisons were based on examinations; student performance on assignments was not analyzed in detail, but a review did not determine any substantial difference in grades. One term exam was exactly the same as given previously at a different university with the same instructor with a lecture-based format and using the same textbook. The students participating in the flipped class achieved a higher average grade, by about 10% out of 100%. A "similar" (but not identical) final exam was given at the same university to students receiving (a) the traditional lecture style in 2015 and (b) the flipped class in 2016. This comparison showed no clear difference; their means were within 1%.

Second, a more qualitative evaluation of performance involved the material covered in the subsequent years, (a) 2015 lecture-based and (b) 2016 flipped. The course using the flipped class covered more material on engineering practice without undue acceleration or skimping on the earlier fundamental principles. Some examples are given in the following.

- **Design**: More methods of control design (loop pairing) and workshops on realistic designs were included in the course.
- **Simulation project**: A simulation workshop on loop pairing for a fired heater was included as a mini-capstone project. In prior lecture-based courses, this instructor has never been able to use this exercise in an introductory process control course. (It was used in an advanced technical elective following the required course.)
- **Safety**: A workshop was included on the control-for-safety topic. The video, prepared by the U.S. Chemical Safety Board (USB, 2008) presents the BP Texas City Accident. Again, this instructor was not able to include this workshop in previous courses.

The increased depth of study via a flipped class approach confirms results by Bland (2005) and Mason et.al. (2013).

The results on learning performance are in no way definitive. Almost certainly, there is evidence that the students in the flipped class performed at least as well as the lecture class. This result is consistent with the meta-study by Lack (2013) which found little proven improvement for flipped learning, but the result is not consistent with the meta-study by Means et.al (2010) that found significant performance improvement. Data from a single course is unlikely to prove definitive.

4.2 Student satisfaction

Measures of student satisfaction are much easier to obtain than objective evaluations of student learning. Two quantitative measures will be discussed here, a survey tailored to address the flipped class (e-Lessons and workshops) and the formal university course evaluation. The instructor was not able to require students to complete these evaluations, and the low response rates of 30-40% could bias the results.

4.2.1 Tailored survey

The tailored survey consisted of short answer questions and a concluding opportunity to briefly write about any topics students selected. The survey was distributed using a course management system (Blackboard). In general, the results were very positive, with most students preferring the flipped class/e-Lesson. The survey questions with results are summarized in Appendix A, and some of the key responses are summarized in the following.

- **e-Lesson and textbook**: 72% of the students used the e-Lesson much more frequently than the textbook. Only 16% used the textbook to the exclusion of the e-Lessons.
- **e-Lesson design**: The e-Lessons were designed using a “slide concept” (compared with a “video”), with students taking an action to advance slides. Around 90% of the students found this design satisfactory, while offering suggestions for minor modifications.
- **Animations and audio**: Around 90% were satisfied with the presentation using slides with animations and audio.
- **Headshot**: 95% of the students found that videos of the instructor talking were unnecessary or even distracting.
- **Workshop**: 79% of the students prefer the class workshops over lectures

The results on slide design appear to confirm that the “slide-based” approach provides satisfactory visual and audio presentation for the students. Also, students seemed to like the content display and navigation. There were no comments that any students wanted more videos. Clearly, students preferred active workshops to lectures, although some students requested “a little more lecturing”. Although no comments requested shorter e-Lessons, while a few complained about the time required to prepare before class.

A few results were not anticipated.

- **Notes**: Each screen provided a script of the audio that was available on the slide sidebar by toggling from the slide outline. 84% of the students used these notes frequently or occasionally. We did not anticipate this high use of the notes, which were provided to satisfy accessibility requirements by most e-Learning standards.

- **Two instructors**: Some of the classes involved two instructors providing audio to provide a more natural "discussion" of the topic; professors who tested the prototype liked this approach. In contrast, 84% of the students found no value in this approach.

  The bottom-line question elicited support for the flipped class design in this project.

- **Future course**: When asked whether they would prefer a blended or a lecture-style delivery in a future course, 74% of the students selected the blended delivery, with an additional 5% having no preference.

Based on the feedback from the students participating in the survey, the results show a clear preference for the blended delivery using a "slide-based" approach, with only about one in five of the students preferring the lecture-based approach. Responses to a "free-form" question showed about the same split, with most responses requesting a little more lecturing and offering suggestions to improve the workshop questions.

4.2.2 University course evaluation

As is typical in most universities, students had the opportunity to complete a standard evaluation containing questions formulated without instructor input, so that the evaluation did not focus on the blended delivery. The same instructor taught the same course in lecture style during the previous year; therefore, a comparison between evaluations for lecture and e-Lesson delivery seems relevant. About 40% of the students completed this survey.

The evaluation consisted of eighteen questions, each requiring a ranking on a five-point scale (1-5) with the score of 3 described as "average". The flipped course scores were the same or higher for *all eighteen questions*. The flipped class was on average higher by 0.22, with a value of 4.2. This difference was significant at the 95% confidence level when applying a paired t-test.

4.2.3 Informal feedback

Some additional feedback was gathered through informal discussions with students, which is naturally not completely unbiased, but is useful. This course was offered in the fourth year, when students are interviewing for jobs and visiting potential graduate programs. When combined with the usual illnesses and sports activities, students have many legitimate reasons for missing classes. The students seemed to like e-Lessons (along with posted solutions for the workshops) as a way of making up for absences.

4.3 Low cost and technology goal

The major impediment to a flipped classroom is the e-Lesson production. If a faculty member requires a technologist to build these e-Lessons, the cost will be prohibitive. However, commercial software developers have been creating innovative products to radically reduce the effort in building slide-based e-Learning lessons. In this project, all e-Lessons were initially constructed with MS PowerPoint ™, including figures, text, animations, and slide transitions. Each lesson was converted to HTML5 for posting on the internet by a commercial software tool; in this case, we used iSpring Pro ™ (iSpring, 2016). (The author has no commercial interest in this product and no relationship with it or any of its employees.) It is important to emphasize that the conversion of PowerPoint to HTML5 was accomplished "with the push of a button"; no coding is required by the lesson developer. If you can prepare PowerPoint, you can prepare an e-Lesson for the internet.

Each slide in the resulting lesson is displayed with an easy-to-use template that provides navigation, sound control, an outline display, and so forth; a typical slide display is shown in Figure 3. The academic cost for this software depends on some options, with the lower-end product costing about $250 (US) for a single, life-time academic license.

The audio can be recorded using the iSpring™ product. However, we preferred the Audacity™ software (Audacity, 2016) for its editing capability; this software is free. We made use of few videos. The videos were developed using MS MovieMaker™ (Microsoft, 2016). The camera and microphone in a typical PC are not adequate for preparing audio or video. We used a Logitech camera and microphone combination that cost about $100 (US). The videos and audio are linked to the appropriate slides using iSpring™.

We will offer some comments on the time to develop e-Lessons using this approach. The basis is PowerPoint™, and we assume that all instructors are familiar with the time to develop PowerPoint slides. Also, the slide development time depends on the complexity of slides, which is a decision made by each instructor. Therefore, this discussion will concentrate on the conversion of PowerPoint slides to an e-Lesson. The time-consuming task in converting the slides to an e-Lesson involves the preparation of the audio script, editing the audio, and synchronizing the audio with the animations. A summary of the development times are given in Table 2. The times are additive; if the developer chooses to develop a script and edit the audio files, the development time is estimated to be ten minutes per minute of audio.

The software tools and e-Lesson development for this project were influenced by the intent to post the learning materials on the Internet. As when we prepare a textbook, the author offering learning materials for open use is expected to take great care concerning both content and presentation. For example, the decisions to prepare a script, edit all audio, provide clearly legible equations and annotations, and involve additional instructors increased the development time. (Note that a script is required to provide a text alternative required by many universities for learning disabled students.) None of these steps are required for e-Lessons or these specific software development tools.

Table 2. Development of Audio for e-Lessons

Development task	Development time in minutes per minute of audio
Record audio	2
Develop script	5
Filter and edit audio	3

The software tools and e-Lesson development for this project were influenced by the intent to post the learning materials on the Internet. As when we prepare a textbook, the author offering learning materials for open use is expected to take great care concerning both content and presentation. For example, the decisions to prepare a script, edit all audio, provide clearly legible equations and annotations, and involve additional instructors increased the development time. (Note that a script is required to provide a text alternative required by many universities for learning disabled students.) None of these steps are required for e-Lessons or these specific software development tools.

As an aside, the availability of drawings, videos, and animations through the Creative Commons license is invaluable when developing e-Lessons for engineering courses. We pass along the favor by making our e-Lessons available to anyone via the internet without charge.

The takeaway message is that software technology has advanced, enabling a faculty member to design and build e-Lessons based on PowerPoint with a very mild learning curve and at low cost.

4. Discussion

In this paper, we have presented a number of changes to the delivery of a one-semester course. Does this constitute a revolution? Let's consider all of the activities involved in the course, which are shown in Table 3, with the changes implemented in this project highlighted. It is clear that the course has many activities and that a large portion of them are not influenced by flipping (nor should they be). Therefore, the modifications do not constitute a revolution. However, the changes involve the key face-to-face class time and preparation for classes, so they are important, for both student learning and student satisfaction.

Next, we consider the question posed earlier, "Can we achieve the best of both worlds?" In blended learning, the two worlds are (a) face-to-face instruction and (b) digitally mediated instruction. When we consider the activities in Table 3 and the flexibility of combining workshops and mini-lectures in Figure 5, there seems every reason to think that an advantageous blend of these two worlds is possible. We must recognize that pleasing every student is not possible, see for example the roughly 20% of students that preferred lectures and a textbook to the e-Lesson/Workshop delivery. Some accommodation should be made for the minority viewpoint, as was done here with an online textbook, mini-lectures, and office hours.

Now, we consider the blended learning methods described in this paper in light of the "Seven principles for good practice in undergraduate education" proposed by Chickering and Gamson (1987), which is a touchstone for university education. A summary of the contributions to these principles is given in Table 4. The major improvements are in (1) student-faculty contact, (3) active learning, (4) prompt feedback, and (5) time on task. The first three (1, 3, 4) are the result of the class workshops. The fourth (5) results from improved, more intense preparation before the class.

Table 3. Activities for a Process Control Flipped Class Course.
(Dashed box with white background highlights course modifications for the flipped class)

Face-to-face	**Out-of-class Activities digitally mediated (Internet)**	**Out-of-class Activities not digitally mediated**
Class workshops and mini-lectures	**e-Lessons** **Quizzes**	Assignments: Selecting control objectives Modeling (fundamental and empirical) Controller tuning Control structure design
Office hours (instructor and TA) Physical Laboratories (Experiential learning) Video safety Workshop	Additional resources: Solved tutorial problems Instrumentation Links to other portals Email queries	Dynamic simulation (MATLAB) Reading textbook

Table 4. Seven principles for good practice in undergraduate education
(Light rows show significant influence of flipped class)

Principle	Contribution via this blended learning approach
1. Encourages contact between students and faculty	The workshop classes provide much greater contact as the instructor mentors groups while they problem-solve.
2. Develops reciprocity and cooperation among students	Students work is groups during workshops.
3. Encourages active learning	Workshops are entirely active learning.
4. Gives prompt feedback	Students can “struggle” with a complex workshop problem and receive immediate feedback and guidance during the class workshops
5. Emphasizes time on task	The e-Lessons must be completed by students before they productively participate in the workshops. This will require preparation before each class, rather than “cramming” before examinations.
6. Communicates high expectations	Blended learning does not necessarily set different standards. However, it requires students to take responsibility for their learning.
7. Respects diverse talents and ways of learning	The use of digitally mediated e-Lessons gives students a very different learning experience (with visualization, animation, audio, etc.) when compared with a textbook.

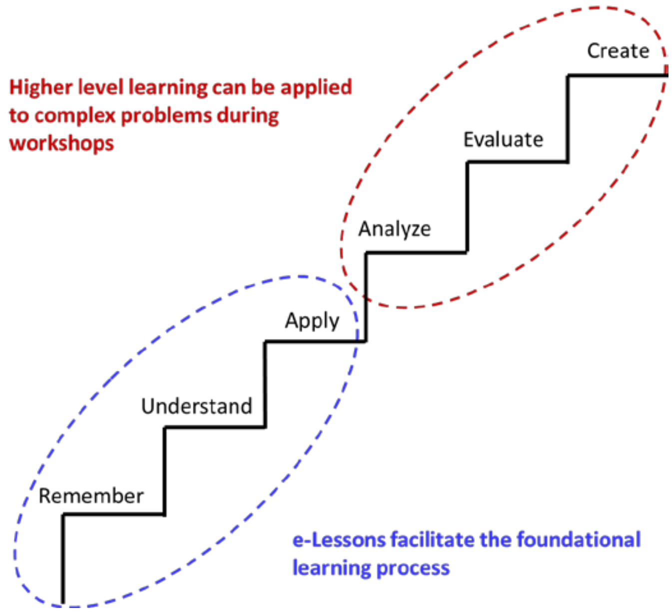


Figure 8. Taxonomy of Cognitive Learning. Originally due to Bloom et.al. (1956) and revised by Andersen and Krathwohl (2001).

Another important method for designing and evaluating education is Bloom's taxonomy (Bloom et.al. 1956). Here, we will consider the updated taxonomy of cognitive learning by Andersen and Krathwohl (2000) and Krathwohl (2002), which is given in Figure 8. Clearly, the taxonomy presents an ascending progression of student abilities built in a course. Engineering courses tend to be "knowledge heavy", so they address the lower levels well. The e-Lessons facilitate the acquisition of knowledge, which enabled the course to progress deeper into design and safety issues. We note that this progress was not accompanied by a higher workload for the students or an increase in stress, as reported by students in their survey responses.

As a personal observation, we believe that the blended delivery sets the tone for the course. The students are responsible for their own education, and the instructor is responsible for selecting course content, providing excellent learning materials and mentoring the students. The majority of these fourth-year students are willing and able to take the initiative when encouraged to use high quality learning materials.

Finally, we emphasize that the reader cannot fully appreciate the results of this study without visiting the Internet site and trying one or more e-Lessons, quizzes and workshops. The site is available at site home page; http://pc-education.mcmaster.ca/default.htm. The e-Lessons can be reached by selecting "Process Control Learning Support" in the menu bar at the top of the home page.

5. Conclusion

This one experience with the flipped class cannot provide definitive results applicable to all other classes and disciplines. The following conclusions seem clearly supported by evidence.

- Slide-based e-Lessons with animations and audio contained in a professional-looking template can be developed at low cost and with simple software technology.
- Students responded enthusiastically to the combination of e-Lessons and class workshops, i.e., the flipped class format of blended learning
- The flipped course progressed further to address higher-level learning, which for this engineering course involves design.
- Students missing a class can easy makeup the material using course learning materials.

The important issue of student learning was evaluated using the course examinations. No clear conclusion was possible, with the flipped course students achieving a slightly higher average on comparable examinations; as stated previously, the difference was not significant. However, the same type of questions were formulated for the comparison, therefore, the greater depth reached by the flipped class is not reflected in these examination results.

Thus, the design and implementation of a blended course with e-Lessons and class workshops is within the grasp of every faculty member. Each instructor will have to decide whether the course design is appropriate for their students and whether the development time is warranted.

We believe that this project was successful, providing a valuable learning experience for the students and a rewarding teaching experience for the instructor. We encourage readers to integrate these e-Lessons and workshops into their Process Control course and to experiment with the flipped class teaching approach.

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Appendix A. Survey Results

- **Question 1:**

  Which answer best describes your use of e-Lessons and the textbook during the course?

	Percent Answered
I used the e-Lessons almost exclusively.	15.789%
I mostly used the e-Lessons, but I referred to the textbook occasionally.	57.895%
I used both about equally.	10.526%
I used mostly the textbook, but I referred to the e-Lessons occasionally.	0%
I used the textbook almost exclusively.	15.789%
Unanswered	0%

- **Question 2:**

  Some e-Lessons involved one instructor, while others involved two instructors. Which did you prefer?

	Percent Answered
I preferred two instructors for livelier discussions.	15.789%
I have no preference.	68.421%
I prefer one instructor to eliminate distractions.	15.789%
Unanswered	0%

- **Question 3:**

  At the end of every e-lesson, you are directed to a quiz with short questions (and answers). Describe your use of the quiz.

	Percent Answered
I always/usually viewed the quiz as part of the e-Lesson.	36.842%
I always/usually viewed the quiz when reviewing for an examination.	21.053%
I occasionally viewed the quiz.	31.579%
I almost never viewed the quiz	10.526%
Unanswered	0%

- **Question 4:**

  Would you like to have a video of the instructor(s) along with each slide?

Answers	Percent Answered
I would like to see the instructor's expressions and interest in the topic.	5.263%
I am satisfied with the infrequent use of videos.	52.632%
I find videos of an instructor distracting; who needs a talking head?.	52.632%

- **Question 5:**

  Are you satisfied with the slide presentation - animations, audio, process drawings, and so forth.

	Percent Answered
I am generally satisfied, I can think of some improvements (please enter details in response to the last question).	15.789%
I am satisfied; changes would not improve my learning.	73.684%
I am not satisfied; improvements are essential (please enter details in response to the last question).	10.526%
Unanswered	0%

- **Question 6:**

  In the current design, the student decides when to advance to the next slide. Is this design satisfactory?

	Percent Answered
Yes, I like to decide how long I think about a slide.	89.474%
No, I would prefer the e-Lesson to advance automatically to the next slide at a time selected by the instructor.	10.526%
Unanswered	0%

- **Question 7:**

  Since students are prepared before class, the classroom activities were primarily mini-lectures and solving problems. Does this support your learning?

	Percent Answered
Yes, I prefer to solve problems and see the answers during class.	36.842%
The concept is good; the implementation needs some fine tuning (please describe improvements you propose in the answer to the last question).	42.105%
No, I prefer that the class time be used to review the material in the textbook in a classical lecture.	21.053%
Unanswered	0%

- **Question 8:**

  Each slide has "notes" that enable you to read the text that is identical to the audio for the slide. How have you used the notes?

	Percent Answered
I use the notes frequently.	52.632%
I used the notes occasionally.	31.579%
I never used the notes.	15.789%
Unanswered	0%

- **Question 9:**

  Suppose that you will be taking a course soon. You can select either one of two sections. One section uses e-Lessons and flipped classroom workshops, and the other is delivered using conventional lectures during class and no e-Lessons. The instructor, textbook and other features of the sections will be the same. Which will you select?

	Percent Answered
I would select the e-Lesson section.	73.684%
It wouldn't make a difference to me; I'd flip a coin.	5.263%
I would select the section with conventional course presentation without e-Lessons.	21.053%
Unanswered	0%