



2023: VOLUME 11 ISSUE 1

DOI: 10.18260/3-1-1153-36038

Analysis of Flipped Classroom Techniques and Case Study Based Learning in an Introduction to Engineering Materials Course

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ABSTRACT

Students should be exposed to open-ended, complex design challenges during their courses to better prepare the students for the design challenges that they will encounter during their careers. This preparation may be achieved by combining flipped classroom instruction, case based learning in an active classroom, and authentic assessments. Between 2012 and 2016, these techniques were assessed in a second year introduction to engineering materials course. Iterations of the course examined flipped classroom instruction using assigned textbook readings and custom made YouTube videos. Classroom activities and final exams using case studies were also evaluated. Flipped classroom instruction using assigned textbook readings was shown to have a negligible effect on students' final exam performance compared to a traditional lecture delivery. The use of custom made YouTube videos and case studies had a positive impact on students' quiz and laboratory scores, indicating an improved alignment with the course's learning outcomes. The use of case studies during the problem analysis sessions led by teaching assistants was shown to have a negligible impact on students' final exam performance. Given the results of the quizzes and laboratories, the use of a flipped classroom approach with YouTube videos and active learning driven by case studies is recommended for teaching engineering materials. This pedagogical configuration exhibits improved alignment with the practical learning outcomes associated with engineering materials such as material selection, failure, and heat treatments.

Key words: flipped classroom, case-based learning, authentic assessment

INTRODUCTION

Undergraduate engineering programs are reputed as rigorous and demanding programs with high attrition rates. These programs typically use traditional teaching approaches that may impair



the training of engineers from diverse backgrounds; engineers that are necessary to solve the grand challenges of the 21st century (NAE 2008). To advance the training of diverse engineers requires a re-examination of engineering pedagogical approaches. Such a re-examination led to the creation of IMPULSE: Instilling Mature Problem-solving and Understanding of ill-defined Scenarios in Engineering.

IMPULSE combines pedagogical techniques from other fields to create a novel and enhanced learning experience for all engineering students. The combined pedagogical techniques are: flipped-classroom instruction from Physics, case studies from Business Administration, Law and Medicine, and classroom discussions from Liberal Arts. IMPULSE is intended to increase students' conceptual understanding and problem-solving, thus preparing the students for open-ended, realistic problems. The increased capabilities are important for engineering students because as Theodore von Karman, an aerospace engineer, said:

“Scientists discover the world that exists; engineers create the world that never was.”

When engineers devise solutions to ill-defined problems using limited information, they create the world that never was. Confidence in problem-solving is required by the engineer to propose a solution and a willingness to accept failure when the solution does not work; two attributes that students cannot acquire by passive listening in lectures and repeating homework problems with a priori knowledge of a “right” answer.

The development of IMPULSE occurred between 2012 and 2016, and this process is described in the context of current engineering education practices. The impact of IMPULSE is illustrated through analysis of student grades. Instilling mature problem-solving and understanding of ill-defined scenarios in engineering is achieved by using flipped classroom instruction, delivered via YouTube videos, to move the theoretical concepts outside the classroom. The lecture periods are focused on discussing the concepts that students find the most difficult, and integrating the concepts into realistic applications via case studies. The case studies also provide an environment where students learn to make the logical assumptions used by experienced engineers to solve open-ended problems. IMPULSE leverages technology such as YouTube, Moodle-based learning management systems, polling tools, and accident investigation resources to deliver an active learning environment.

Courses

Each component of IMPULSE is described according to function, connection to the broader engineering education practice, and impact on student learning. IMPULSE developed in MAAE 2700: Engineering Materials at Carleton University in Ottawa, Canada. The author taught the course over



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four iterations and implemented changes to the course delivery in response to student performance, alignment with the graduate attributes required by the Canadian Engineering Accreditation Board (CEAB), alignment with the course's learning outcomes, and student feedback. MAAE 2700 is taken by second year students in all degree programs offered by the Department of Mechanical and Aerospace Engineering. The course had three sections each year, two sections during the Fall term and one section during the Winter term. The author taught the Winter term section, and his classes included students that failed the course in the previous term. The class sizes for each Winter term are shown in Table 1.

Table 1. MAAE 2700: Engineering Materials - Class Sizes.

Term	Number of Students
Winter 2013	99
Winter 2014	104
Winter 2015	104
Winter 2016	120

The analyses presented within this paper use the scores from the course's laboratory reports, quizzes, assignments and final exam. The evaluations' weights toward the MAAE 2700 final grade are shown in Table 2. These weights were the same across all sections and iterations of the MAAE 2700.

Table 2. MAAE 2700 Course Evaluations and Weights.

Evaluation	Quantity	Weight (%)
Laboratory Reports	5	25
Quizzes	5	20
Assignments	5	5
Final Exam	1	50

LITERATURE REVIEW

IMPULSE applies flipped classroom methods, case based learning, and authentic assessments. Flipped classroom instruction using both YouTube videos and mandatory textbook readings was attempted during the development of IMPULSE. The results are compared to the literature on podcasts and textbook readings in engineering. The case study and classroom discussion component is compared to the literature on case based learning. The case study based final exams are compared to the literature on authentic assessments.



Flipped Classroom Instruction

Flipped classroom instruction (FCI) originated in the United States as a result of experiments with hybrid learning, active learning, and problem based learning (Lage, Platt and Treglia 2000). The Department of Mathematics at the University of Michigan in Ann Arbor found that students in an interactive setting made larger gains in understanding compared to a traditional lecture setting (Chai, et al. 2015). The use of FCI may impact teaching evaluation scores because students have reported an increased workload, variable quality in the pre-lecture materials, and misalignment between the pre-lecture content and the in-class activities (Khanova, et al. 2015). Physics educators combined FCI with just-in-time teaching and peer instruction to improve students' understanding of basic concepts (Mazur 2007) (Abeysekera and Dawson 2015).

The format for FCI requires students to use resources outside of class for a first exposure to the content of a given lecture. These external resources include videos, podcasts, online tools, and textbooks. The use of textbooks for FCI is tempting as most engineering courses have required textbooks; thus, an instructor new to FCI may implement textbook readings as the external component. Engineering students' use of textbooks was investigated by several researchers. Two studies indicated that students use textbooks in a limited fashion for reference information, finding equations, and locating examples, but not conceptual understanding of the content (Taraban, Hayes, et al. 2004) (Lee, et al. 2013). The researchers also found that less than 15% of students read textbooks for the purpose of learning beyond the lecture content (Taraban 2011). These findings suggest that the use of textbook readings for FCI has limited effectiveness for students' conceptual understanding despite the perceived convenience for the instructor.

FCI using YouTube videos fits within the use of electronic resources for instruction such as podcasts. Students find podcasts at least as useful as traditional supplemental materials such as written handouts, and the majority of students will download or view podcasts. Students use podcasts for reviewing or preparing for assignments and tests (Copley 2007). Students found podcasts more useful for reviewing than textbooks or their notes (Evans 2008). Audio podcasts used as primers before lecture were found to have a positive effect on student performance (Popova, Kirschner and Joiner 2014). More recent research examining flipped classrooms with videos for business majors showed an overall positive response to the use of videos (Guy and Marquis 2016).

The extent of the 'flip' in the FCI, as reported in the literature, varies widely. An early paper from 2000 describes FCI as "Inverting the classroom means that events that have traditionally taken place *inside* the classroom now take place *outside* the classroom and vice versa" (Lage, Platt and Treglia 2000). This description does not quantify how much content is exchanged between inside and outside the classroom. One quantification is that key concepts of a topic are presented in an instructor created video to assist the students with their homework (Milman 2012). Following the



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focus on presenting key concepts is a more elaborate definition that FCI uses pre-class activities to introduce concepts in a structured manner with a mechanism to hold the students accountable. Further, this definition has an emphasis on clear communication, both in class and throughout the course, via Internet technologies (Baytiyeh and Naja 2017). Another definition, with less focus on transmitting key concepts, is that FCI includes moving the transmission of information outside of the classroom, classes use active, group learning, and there are pre and post class activities for the students to complete (Abeysekera and Dawson 2015). A survey of the literature led to a definition that FCI uses individual, computer-based instruction outside of the class and interactive group activities within the class (Bishop and Verleger 2013). These definitions do not indicate the movement of traditional homework type assignments into the classroom. The result in some implementations of FCI is that the students encounter an increased workload outside of the classroom (Khanova, et al. 2015).

Case Based Learning

Engineering history demonstrates the need for case studies. The development of more formal engineering education began in the 1850s when early versions of engineering programs appeared at American, Canadian, and European universities. North American programs originated in a practical foundation given that most engineers were involved in railroad construction projects, thus shop and surveying skills were emphasized. Following the First World War, many European technical experts immigrated to North America and brought a more rigorous, mathematical based approach to technical education. The major change to a theory based engineering occurred after the second World War because of increased funding and an image problem for engineering (Petroski 2011). The media portrayed scientists as responsible for the war-time successes while engineers were largely unmentioned. Further, a US Presidential report commissioned in 1945 strongly emphasized science for future American technical pursuits (Bush 1945). The report led to the increased prevalence of engineering science in engineering programs, particularly for research-intensive universities. The science dominant form of engineering remained for the subsequent 50 years until the late 20th century when practical design skills regained a focus, coinciding with American accreditation changes.

The engineering science approach provides theoretical background; however, many undergraduate science problems have closed solutions. Engineering design problems are inherently open-ended with many possible, valid solutions, but students are ill-equipped and uncomfortable with open-ended problems. Confidence is required by the engineer to propose a solution and a willingness to accept failure when the solution does not work. Two attributes that students cannot acquire by passive listening in lectures or repeating homework problems with the knowledge that a “right” answer exists at the back of the textbook.



The in-class component of FCI uses a number of approaches or combinations of approaches, such as peer instruction, case based learning, or examples demonstrated by the instructor. The combination of FCI and case based learning is of particular interest because students taught by active learning techniques methods have demonstrated significant improvements compared to students taught by traditional methods (Freeman, et al. 2014). Active learning is a broad category of techniques that includes problem based learning (PBL) and case based learning (CBL). PBL and CBL techniques overlap, causing ambiguity about the distinction between the techniques in the literature. These techniques have been in use in the medical training field since 1969; therefore, the literature on both techniques is substantial (Nadershahi, et al. 2013). A survey was taken following a two-day medical school workshop about CBL and PBL that revealed that the majority of attendees still failed to distinguish between the two techniques (Daher, Singh and Kutty 2017).

One definition for PBL is that mastery of concepts and skills is achieved in the same context as the application (Donner and Bickley 1993). PBL has also been defined as focusing on the learner “discovering” a concept or skill with the learner guiding the process (Srinivasan, et al. 2007). Within engineering, problem-based learning (PBL) methods demonstrate better transfer of knowledge to real-life problems (Yadav, Subedi, et al. 2011). The study by Yadav et al raised a concern that using a PBL approach meant less content covered during the lectures, because their study did not include any activities outside of class. A similar concern was echoed in the medical field with studies suggesting that PBL only covers 80% of the content completed using a traditional curriculum configuration (Finucane, Johnson and Prideaux 1998) (Albanese 1993) (Berkson 1993). Using FCI potentially solves this concern as the content is still available for the students through a different medium. The researchers identified that students also feel they learn more through a traditional lecture approach because of student familiarity with the format. This student impression may be alleviated by FCI (Yadav, Subedi, et al. 2011).

CBL began in legal training and predates the use of PBL by over 70 years (Nadershahi, et al. 2013). CBL shares aspects with PBL such as the use of real-life problems and encouraging an inquiry based approach to learning. The notable distinction between the methods, reported in the literature, is that CBL is guided by the facilitator; therefore, the inquiry is less open compared to PBL (Srinivasan, et al. 2007). A further distinction is that CBL involves the advanced preparation of the learners so that the case study is not the first exposure to the content (Slavin, Wilkes and Usatine 1995) (Williams 2005). The effectiveness of CBL is an open question in the literature as the medical literature has not presented empirical evidence (Thistlethwaite, et al. 2012). An engineering study revealed that no significant improvements in student understanding were found between a traditional lecture and using case studies (Yadav, Vinh, et al. 2014). Despite the lack of improvements, students



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have reported an appreciation for the added realism achieved by the incorporation of case studies (Kassebaum, Averbach and Fryer 1991) (Yadav, Vinh, et al. 2014).

The classroom discussion aspect of IMPULSE provides the opportunity to discuss concepts and check the understanding that students received from the YouTube videos delivered through the flipped classroom component. The discussion of concepts and the application of theory is important to develop students' confidence. The discussions also guide students to more effective approaches to solve the homework problems, which are traditionally done outside of class meeting times (Taraban 2011). Engineering students will begin a homework problem by searching for a similar textbook or lecture note example, and attempt to fit the example problem's equations and process to the homework problem (Fata-Hartley 2011) (Randahl 2012). While this approach may produce the correct answer, students do not gain a deeper understanding of the concepts behind the engineering problem. The lack of understanding is demonstrated if a problem on the same topic is given, but in a different form, such as a case study. During class, the lack of understanding is quickly identified through polling students' answers at different stages of a case study.

Authentic Assessments

Prior to 2014 in Canada and 1997 in the United States, engineering education programs were accredited through a process where the engineering schools demonstrated that certain topics were taught in compliance with the accreditation standards. In the Canadian context, this took the form of academic units that were assigned to a given course across multiple categories such as engineering science and design. From a practical perspective, engineering professors demonstrated that they had taught and tested a given topic by providing copies of the lectures notes and evaluations. Whether or not the students departed the course with the expected knowledge and skills was not known.

The accreditation approach subsequently changed to an outcome based process using graduate attributes. The graduate attributes are demonstrations of the knowledge and skills with which students leave a given engineering course. The accreditation process now sets expectations as to the attributes that students should have at the end of the course, and an engineering program under accreditation review must demonstrate that these attributes are present. Some attributes are easy to demonstrate such as Graduate Attribute 1: Knowledge because this attribute is tested via conventional exams and homework problems. Other attributes such as Graduate Attribute 4: Design are more difficult to demonstrate with homework problems because students must demonstrate the ability to develop alternate solutions to open-ended problems rather than the closed problems that appear in homework sets. The Canadian Engineering Accreditation Board (CEAB) has left the means to demonstrate the attributes up to each engineering school, and various approaches have appeared in the engineering education community as shown by the special sessions at the Canadian Engineering Education Association's annual conferences.



The third component of IMPULSE are authentic assessments that duplicate engineering conditions to realistically assess the graduate attributes. Case studies fall within the types of problems defined by authentic assessment for use in case based learning, and apply to both formative and summative assessments. Authentic assessment is defined as placing cognitive demands on the students that match what is expected of a practitioner in the field, and includes the needed competencies, knowledge, and skills (Gulikers, Bastiaens and Kirschner 2004). For an authentic assessment to function properly, the assessment must match the educational level of the student otherwise overloading the student is possible (Gulikers, Bastiaens and Kirschner 2004). Simultaneously, the assessment should be sufficiently challenging as more difficult assignments produce better quality work from students (Koh and Luke 2009). From a formative assessment perspective, authentic assessments require that students acquire knowledge while learning to think critically or question the knowledge. This process is unsettling and ambiguous to students because more self-regulation is expected of the students; therefore, more support and interaction with the teacher is required (Vu and Dall'Alba 2014) (Litchfield and Dempsey 2015).

The authentic aspect of authentic assessment is considered subjective and is tied to students' approaches to studying, and teaching styles. Students will vary their study approach according to the assessments specified in the course syllabus; most students will read the evaluation section of a syllabus first (Litchfield and Dempsey 2015). For authentic assessments to operate effectively, writing-intensive courses are recommended where frequent feedback is provided by the teacher and encourages reflection by the students on real-world applications (Zilvinskis 2015). The real-world applications should be clear to the students because if a student does not perceive the authenticity then the impact of the assessment on the student's learning is less (Gulikers, Bastiaens and Kirschner 2004) (James and Casidy 2016).

To guide the development of authentic assessments, a number of frameworks are proposed (Keller 2010) (Ashford-Rowe, Herrington and Brown 2014). The frameworks have a number of common elements, with the Wiggins framework being the most concise example:

1. realistic,
2. requires judgement and innovation,
3. students must work in the subject,
4. duplicates what practitioners encounter,
5. assess a range of knowledge and skills, and
6. opportunity to practice and receive feedback.

EDUCATIONAL FRAMEWORK

The educational framework of IMPULSE was motivated by creating a learning environment to improve students' comprehension of engineering materials. Further, the framework was developed



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to achieve the course objectives identified for Introduction to Engineering Materials by the department. These objectives were associated with particular student outcomes. Each iteration of the course had the same learning objectives. Students were expected to

1. Sort materials into categories using physical observation methods
2. Design a heat treatment procedure with written justification of the method.
3. Apply laboratory techniques to analyze the failure mechanism of an unknown specimen.
4. Design a simple structure with the correct material with full justification in writing.

These learning objectives led to a set of learning outcomes that students had to achieve by the end of the course. At the end of the course, students would be able to

1. Classify materials by type
2. Formulate the appropriate heat treatment to achieve a desired property
3. Describe interatomic bonding and crystal structures
4. Analyze the failure mechanism of a material
5. Select the appropriate material for a given application

The outcomes of the course included practical items such as formulating appropriate heat treatments, failure mechanisms, and material selection. These items are frequently encountered by practitioners and designers when developing a new product; therefore, these outcomes motivated the overall framework. The outcomes also motivated the evolution of the course assessments because the practical outcomes were originally addressed only by the laboratory experiments. The quizzes and final exam lacked a connection to practical applications of the course material. The metric used by the author to quantify an improved comprehension was an increase in the scores achieved on the quizzes, laboratory reports, and final exam. This metric is subject to several limitations which are discussed in detail in the Limitations subsection.

The quizzes mapped to learning outcomes 1, 3, and 4. The MAAE 2700 quizzes were generated from end of chapter problems from the textbook; therefore, the author considered how students learn from textbook problems. Previous studies showed that students use a backward inference approach, i.e. match equations to required variables, rather than an expert approach, or forward inference, that considers the larger context of the question and alternative methods (Taraban, Craig and Anderson 2011). The researchers recommended that instructors listen in on students as students attempt to solve a problem, and encourage think aloud exercises in class (Taraban, Craig and Anderson 2011). This recommendation paralleled the reported improvements achieved by active learning (Freeman, et al. 2014); therefore, the incorporation of an active learning element was pursued.

The laboratories mapped to learning outcomes 1, 2, and 4. Last, the case studies mapped to all five learning outcomes with a primary focus on 2 and 5 as these outcomes are more open-ended.



The learning outcomes aligned with four CEAB graduate attributes. The attributes, with specific details, are enumerated in the following. The first attribute is Knowledge Base (CEAB graduate attribute 1), and was frequently assessed by the quizzes:

1. Engineering material's crystal structures and microstructures
2. Elastic and plastic deformation
3. Tensile properties
4. Relationship between imperfections and properties
5. Failure modes and prevention methods
6. Common engineering material's property and processing methods
7. Other subjects included in the course topics

The second attribute is Problem Analysis (CEAB graduate attribute 2) which was a main feature of the laboratories and the case studies:

1. Utilize the knowledge learned to analyze lab experimental errors.
2. Ability to make assumptions to solve problems in the assignments
3. Compare lab results with the published data

The third attribute is Investigation (CEAB graduate attribute 3) which also featured in the laboratories and case studies:

1. Using laboratory equipment, investigate the type of unknown material based on hardness and microstructure analysis
2. Select heat treatment procedure to characterize material's response to cold working, temperature and cooling rate

The last attribute is Communication (CEAB graduate attribute 7) and primarily appeared in the laboratories:

1. Prepare lab reports
2. Study lab manuals and text book
3. Follow instructions provided by lab supervisors

The author's motivation was also to increase students' interest in Engineering Materials, a course typically considered boring by students at the author's institution. The author selected CBL because of the potential to add realism to the course (Yadav, Vinh, et al. 2014), and reported studies indicated that case studies are effective at improving students' higher order cognitive skills (Sankar, Varma and Raju 2008) (Bradley, et al. 2007) (Yadav, Vinh, et al. 2014). To enhance the realism, the author applied the Wiggins' framework from authentic assessments in the development and selection of the case studies.

The case studies were primarily used during the lecture periods. These case studies were not graded; rather, the case studies were used to provide feedback to the students about

Grain size and shape is important for accident investigations



W. Reitz, Metallurgical Investigation into an Automotive Fire,
ASM International, 2006, 2:18-21

Figure 1. Example case study used during a crystallography and grain size lecture in the 2015 iteration of MAE 2700.

their ability to apply a given concept. The cover slide of an example case study is shown in Figure 1¹.

This case study originated from an ASM International case study involving the investigation of an RV fire. The case study included micrographs of various metal specimens that investigators collected from the remains of the RV (Reitz 2006). The metal specimens included aluminum and copper. The objective for the students was to determine where the fire started in the RV. This case study was selected because it met all the requirements of the Wiggins' framework

1. the accident was real,
2. the students had to apply judgment to their interpretations of the micrograph evidence,
3. the students had already worked with micrographs as this case study was scheduled after a laboratory about grain size,
4. the students duplicated the work of the actual investigators, and

¹ The PowerPoint slide deck and the discussion guide are available as multi-media attachments to this paper



5. the students received feedback from the author regarding their interpretations.

The reported decrease in content coverage for CBL (Finucane, Johnson and Prideaux 1998) was a concern for the author because of the required content stipulated by the engineering accreditation board. To maintain the same content coverage, the author turned to FCI, using the definition articulated by Abeysekera and Dawson (Abeysekera and Dawson 2015). Videos were prepared by the instructor to provide transmission of information while interactive, group activities were completed in class. Pre and post activities were attempted in some iterations, with their effectiveness reported. The transmission of the information before class was intended to reduce the cognitive load of the students leading to their enhanced understanding of engineering materials content. During the first attempt using assigned textbook readings, described in the Evaluation of Flipped Classrooms in IMPULSE, the author encountered the same issues reported by Taraban regarding students' use of textbooks (Taraban 2011). The subsequent selection of YouTube videos was driven by the results of Copley that students will use podcasts to help prepare for assignments and exams (Copley 2007). The YouTube videos used the slides originally created for lecture and are available via².

EVOLUTION OF IMPULSE

The MAAE 2700 evaluations were laboratory reports, quizzes, and a final exam. The laboratory reports and quizzes were graded by the teaching assistants (TAs), while the final exam was graded by the instructor. When FCI with CBL was attempted for MAAE 2700, each offering had a different modification with respect to the course evaluations, the activities in the classroom, and the problem analysis (PA) sessions run by the TAs. The author attempted to maintain the same total work load (class time + laboratory + PA sessions + bi-weekly homework assignments + pre-class content) for each subsequent iteration of MAAE 2700. As described in the following, most work load balancing was achieved via the classroom activities, the homework assignments, and the pre-class activities. For reference, the modifications of all four course offerings are summarized in Table 3.

Table 3. IMPULSE Evolution During MAAE 2700.

Iteration	Offering	Quizzes	Final Exam	Content Delivery	Classroom Activities	PA Activities
Baseline	2013	Paper	Short and Long	PowerPoint slides in class	Examples	Examples
Textbook	2014	Paper	Short and Long	FCI with textbook readings	Examples	Examples
YouTube	2015	Paper	Case Studies	FCI with YouTube videos	Case Studies	Examples
Electronic	2016	Online	Case Studies	FCI with YouTube videos	Case Studies	Case Studies

² <https://www.YouTube.com/playlist?list=PLFMmHHEEHpM-eofM-xQxgVOBMfpcRnt6Mz>



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The final exam format for 2013 and 2014 was the same with short and long answer questions. The exam format changed for 2015 and 2016 to use case study based questions. The quiz format was identical for 2013, 2014, and 2015. In 2016 the quizzes switched from paper based to online; however, the questions were the same. The laboratory experiments were identical for all four iterations. The quizzes and the 2013 and 2014 exams were aligned with the conceptual learning outcomes of the course. The laboratories and the 2015 and 2016 exams were aligned with the practical learning outcomes of the course.

2013

The first offering in 2013 was identical to previous sections of MAAE 2700 taught by other instructors. Two 1.5 hour lectures per week were delivered using PowerPoint slides adapted from the course textbook (Callister and Rethwisch) and instructor materials provided by Wiley. Five laboratory experiments were developed by past faculty to complement the course material, and involved sample preparation with polishers, microscopic examination of grains, impact tests, and aging³. The experiments used a dedicated teaching laboratory, were three hours in duration, were completed in teams of four students, and were supervised by a specially trained teaching assistant.

The course featured a PA session for three hours where students reviewed questions from bi-weekly assignments for the first two hours, and wrote a quiz during the last hour. The PA session was supervised by a teaching assistant who also graded the quizzes. The assignments contained approximately 30 problems drawn from the end of chapter problems of the course textbook. The assignments were graded by completeness rather than accuracy of the answers, and were intended to be the primary study material for the quizzes. During the PA session, the TA would only review the most challenging problems during the first two hours. Solutions to the problems were not posted. The quizzes contained five problems, also drawn from the end of chapter problems of the textbook.

The laboratory and PA sessions alternated weeks so that during any given week, students had 6 hours of MAAE 2700 class and laboratory or PA time. At the end of the term, students wrote a three hour final exam that was graded by the course instructor. The final exam used short and long answer questions that were similar to the quizzes, and to the bi-weekly assignment problems.

Subsequent offerings of MAAE 2700 retained the same scheduling arrangement of two 1.5 hour lecture periods per week and alternating laboratory or PA sessions.

2014

During the 2014 offering, the flipped classroom format was applied. The lecture content was moved to outside of class and the homework assignments into class. The PA sessions and final exam format

³ These laboratories are available by request to the author.



were left unchanged compared to the 2013 offering. The students were provided with a schedule of readings to complete prior to each lecture. The students also completed three conceptual questions prior to each lecture through the course management site. The conceptual questions were drawn from the bi-weekly assignments and enabled the instructor to tailor each lecture to focus on the concepts that the students found most challenging. The lectures began with a summary of the concepts that the students read, followed by example problems taken from the bi-weekly assignments.

2015

The 2015 offering maintained the flipped classroom format from 2014; however, the pre-lecture textbook reading assignments were replaced by video recordings of the 2013 slides using Camtasia. The videos were posted on the course management site and YouTube. Students were provided with a schedule of videos to watch prior to each lecture period. The pre-class conceptual questions used in 2014 were eliminated because the student response rate to these questions drastically declined over the period of the 2014 offering. Instead, each lecture period began with a series of interactive exercises completed in groups to provide feedback to the instructor about the conceptual understanding of the class. Some of these exercises were drawn from the bi-weekly homework assignments, while other exercises were more applied. For example, during the module about mechanical properties, the instructor had the students conduct stress-strain tests using large marshmallows, a ruler, a paper plate, and a graduated cup of water. The students placed the marshmallow on the paper plate (to avoid damaging the lecture hall tables), with the ruler adjacent. The students placed the empty cup of water on top of the marshmallow, and measured the displacement of the marshmallow as water was poured into the cup. The students computed and plotted a stress versus strain curve for the marshmallow. This exercise evaluated the students' understanding of stress, strain, and modulus of elasticity.

Depending on the results of the conceptual exercises, the instructor had a catalogue of additional examples involving the same concepts. Some examples were further questions from the bi-weekly assignments, while others were additional case studies. An example case study that was used, at the end of the failure modes module, to evaluate students' understanding of temperature effects on metals involved a helicopter accident where the tail boom broke. The students were given the following description sourced from a Transport Canada accident report⁴:

“The Bell 214B1 helicopter (registration C-FWQU, serial number 28029), operated by Black Tusk Helicopters, was carrying out heli-logging operations in Ramsay Arm, British Columbia. At about 0800 Pacific daylight time, the helicopter was in a 200-foot hover and starting to pick up the 11th

⁴ The accompanying PowerPoint slides and discussion guide are available as multi-media attachments



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load when the two pilots noted a loud growling sound from within the helicopter. Immediately, the flying pilot discontinued the lift and released the load from the longline hook. He then flew the helicopter back towards the nearby service area to have the noise investigated. About 20 seconds later, just as the helicopter entered a high hover above the service landing site, the growling noise stopped, the low oil pressure warning lights for the two tail rotor gearboxes illuminated, and the helicopter rotated quickly to the right. The pilot was unable to stop the rotation using the tail rotor control pedals and the helicopter made two or three 360-degree turns to the right. The pilot rolled off the throttle on the collective stick and attempted to land in trees adjacent to the service area. The helicopter descended upright and struck several trees before landing hard on the uneven terrain. The flying pilot, seated in the left hand seat, was seriously injured and the co-pilot received minor injuries. The helicopter was substantially damaged during the landing and there was no fire. The emergency locator transmitter activated at impact and survived the crash.”

During 2015, the final exam format also changed and case study problems replaced the previous textbook style problems. The new exam problems challenged the students to apply concepts and calculations in context, and to interpret the meaning and accuracy of the results, similar to the laboratory reports and the course’s learning outcomes. An example final exam problem is shown in Figure 2.

The 2015 PA sessions and laboratories remained the same as in 2014.

2016

The format and organization of the 2015 offering was repeated in 2016, with three modifications. The first modification was the introduction of the WileyPlus site which enabled the assignments and quizzes to be done online with immediate feedback and coaching. The assignments on WileyPlus were reduced in length compared to the previous course offerings; however, the questions remained the same as in previous iterations. Further, questions from each assignment were still completed in class similar to 2015. WileyPlus also enabled the second modification, the use of case studies during the PA sessions. The TAs no longer had the assignments to review or the quizzes to invigilate; therefore, the full three hours of the PA sessions were used to discuss three or more case studies designed by the TAs with feedback from the instructor⁵. The increased number of case studies provided more opportunity for the students to practice this style of problem in preparation for the final exam. The third modification was that the laboratory experiments experienced scheduled equipment upgrades that provided additional automation to relieve an increase in class size.

⁵ An example of a TA developed case study is available as a multi-media attachment.



Question 2

[20 points]

Following your success at Beaver Rod & Rail and a recommendation from Clarke, you have an interview at Whirlygigs Inc for your next internship. Whirlygigs Inc manufactures helicopter components, and your interviewers include the director of the engineering division. The director gives you the following case from early in Whirlygigs' corporate history.

A sightseeing company purchased a Whirlygig for use in city tours. The model that they purchased used AISI 4340 steel in the construction of the rotor blades, and the yoke that connected the rotor blades to the main rotor hub. The steel of the yoke was shot-peened and a 100 μm layer of chrome applied for improved strength and environmental protection. After many years of service, one of the rotor blades detached at the yoke as shown in Figure 4.

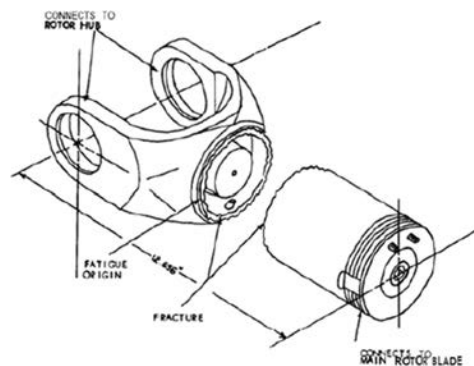


Figure 4. Fatigue and fracture point on yoke.

The yoke was inspected a few days before the blade detached, and the inspection used equipment that could detect cracks as small as 0.254 mm in length.

Figure 2. Example final exam problem from the 2015 iteration of MAAE 2700.

Limitations

The evaluations of modifications to the educational framework were completed using the students' scores on the quizzes, laboratory reports, and the final exam. The teaching evaluation scores were also considered; however, the comments were not considered. The University transitioned the delivery of the teaching evaluations from paper based to online between 2013 and 2016. The on-line teaching evaluations had a 50% lower response rate, than the earlier paper based evaluations; therefore, the feedback from the students was limited. The scores represent a complete data set; and can reveal the students' reflections on the modifications in the aggregate. The scores do not reveal specific students' thoughts about the modifications, nor do they reveal other factors such as student interactions with the TAs, and student demographics.

Each iteration of the course had four TAs: one TA supervised the laboratory experiments, while the other three TAs ran the PA sessions. Depending on the annual TA assignments from the department, the course received a range of experienced to novice TAs. Certain TAs had supported multiple sections of the courses under various instructors which increased their familiarity with



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the course concepts and assessments. During each iteration of the course, the author evaluated the student scores by laboratory section and PA section as part of the author's computation of the final grades. The evaluation by section was to determine if a TA was overly strict or overly generous in awarding points for the laboratory reports and quizzes. Applying the Kolmogorov-Smirnov test between sections for a given year indicated no significant differences. Student demographics were not tracked at the course level; therefore, the author did not have this data available to evaluate the effectiveness of course modifications. As a consequence, any conclusions regarding the effectiveness of the educational framework include the caveat that student demographics may influence the results.

METHODOLOGY

The statistical evaluation of the four iterations of IMPULSE uses a multi-step process executed in MATLAB R2019a. This process is applied to three sets of data available from each iteration of IMPULSE in MAAE 2700. The data sets are laboratory scores, quiz scores, and final exam scores. The first step of the statistical evaluation is the application of the Kolmogorov-Smirnov test to determine if a given data set is normal. A normalcy test is required to determine the correct statistical test to compare two sets of data from different iterations of IMPULSE. All p-values used 0.05 as the threshold for statistical significance. Descriptive statistics are provided for each data set.

As shown, all data sets returned non-normal distributions; therefore, comparisons between data sets used Kolmogorov-Smirnov tests. These tests returned the p-value indicating the likelihood that any two distributions are the same.

STATISTICAL EVALUATION OF IMPULSE ITERATIONS

The statistical methods described in Methodology are applied to each iteration of IMPULSE. The first subsection provides the descriptive statistics for each year's data sets. Subsequent subsections compare the data sets 2013 to 2014, and 2015 to 2016. Last, a comparison of the teaching evaluation means is provided to give some insight about the students' opinions of the iterations.

Descriptive Statistics for Each Year

The descriptive statistics for 2013, and the p-value of the Kolmogorov-Smirnov test, are shown in Table 4.

**Table 4. Descriptive Statistics for 2013.**

Data Set	Mean	Median	Skewness	Kurtosis	Normalcy P-value
Quiz Scores	6.46	7.0	-0.98	3.51	0
Laboratory Scores	7.58	7.75	-1.48	7.08	0
Final Exam Scores	63.4	66.5	-1.25	4.75	0

From the skewness data, each data set is shown to be moderately to highly skewed to the left meaning that more scores are below the average. The kurtosis scores indicate that the distributions are tail heavy. The interpretation of the skewness and the kurtosis of each data set is that the data sets do not follow a normal distribution. This conclusion is confirmed by the p-value returned by the Kolmogorov-Smirnov test for normalcy as the 0 values indicate that the data sets are non-normal. Similar conclusions are reached for the 2014, 2015, and 2016 data sets as shown by the results in Table 5 to Table 7.

Table 5. Descriptive Statistics for 2014.

Data Set	Mean	Median	Skewness	Kurtosis	Normalcy P-value
Quiz Scores	7.59	8.0	-1.53	5.55	0
Laboratory Scores	8.67	9.00	-2.85	17	0
Final Exam Scores	60.1	63.0	-0.24	2.85	0

Table 6. Descriptive Statistics for 2015.

Data Set	Mean	Median	Skewness	Kurtosis	Normalcy P-value
Quiz Scores	7.14	8.0	-1.39	3.96	0
Laboratory Scores	8.58	8.75	-3.78	23.4	0
Final Exam Scores	58.3	63.0	-1.35	4.74	0

Table 7. Descriptive Statistics for 2016.

Data Set	Mean	Median	Skewness	Kurtosis	Normalcy P-value
Quiz Scores	7.61	8.0	-1.42	4.48	0
Laboratory Scores	8.30	8.5	-1.63	8.51	0
Final Exam Scores	62.6	66.0	-1.44	5.58	0

Results for Required Textbook Readings - Baseline (2013) vs Textbook (2014)

To assess the effectiveness of FCI using assigned textbook readings compared to a traditional lecture format, the quiz scores, laboratory scores, and final exam scores are compared. The



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descriptive statistics for the 2013 and 2014 data indicate that the distributions are non-normal; therefore, non-parametric tests must be used. The Kolmogorov-Smirnov test is applied to the laboratory scores, quiz scores, and final exams with the results reported in Table 8.

Table 8. Kolmogorov-Smirnov test results for Baseline compared to required Textbook readings.

Data Set	Baseline Mean	Textbook Mean	Normalcy P-value
Quiz Scores	6.46	7.59	<0.001
Laboratory Scores	7.58	8.67	<0.001
Final Exam Scores	63.4	60.1	0.066

The statistical comparison indicates that the FCI with required textbook readings had a statistically significant effect on the quiz scores and the laboratory scores, but not on the final exam scores. Considering the median values for the quiz and laboratory scores reported in Table 4 and Table 5, the required textbook readings have a positive effect as the medians are increased.

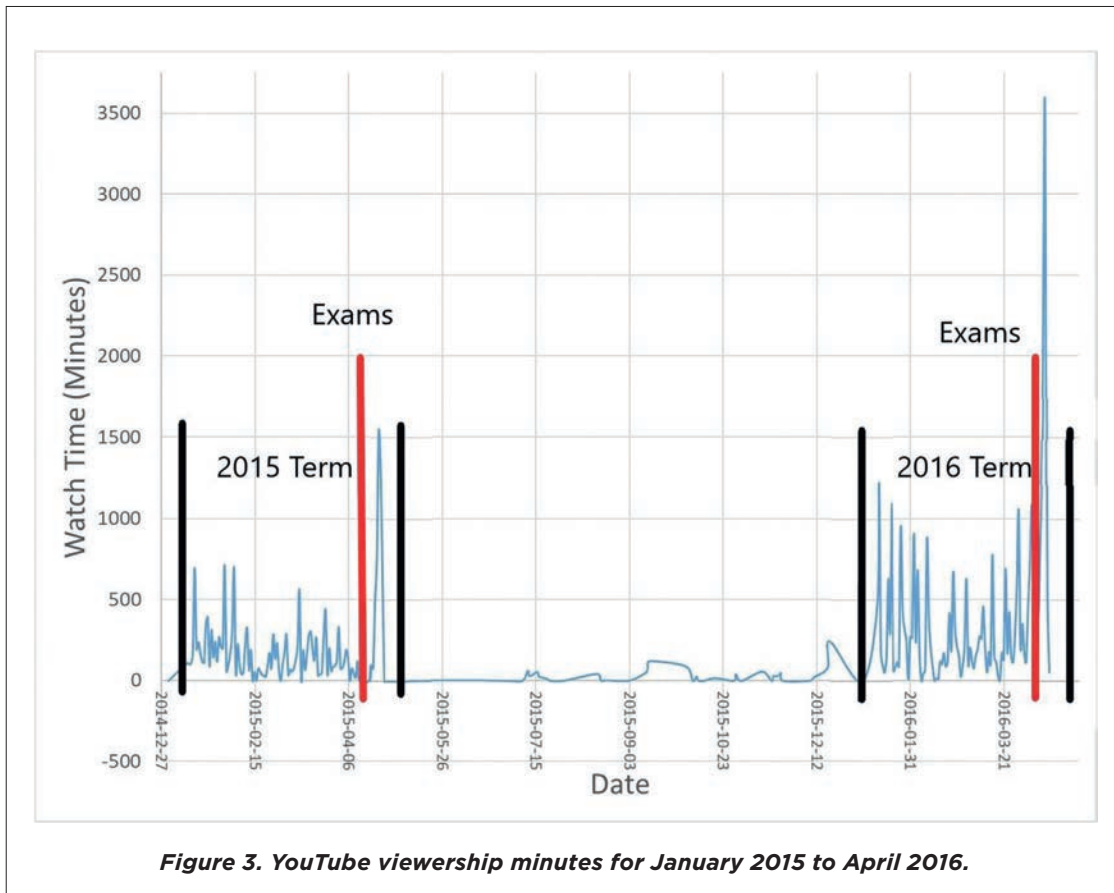
A possible reason for the lack of a positive effect on the final exam is that students' study habits for the final exam may have been the same for both years. The lack of textbook use identified by Taraban (Taraban 2011) suggests that students only read the textbook when required prior to each lecture; a similar requirement did not exist prior to the final exam. The lack of improvement is expected because students' use of textbooks does not include conceptual understanding of the content (Lee, et al. 2013).

Results for Required YouTube Viewings and Classroom Case Studies - Baseline (2013) vs YouTube (2015)

The effects of using FCI with YouTube videos and case studies during lecture periods may be determined by comparing the 2015 course offering to the 2013 course offering. This comparison will only use the quizzes and laboratory scores as the final exam in 2015 was significantly different than the 2013 final exam. The 2015 final exam used case study inspired questions that were open-ended, while the 2013 final exam used questions similar to the textbook problems. The quizzes and laboratories were the same for both course offerings. The statistical results are shown in Table 9.

Table 9. Kolmogorov-Smirnov test results for Baseline compared to required YouTube viewings.

Data Set	Baseline Mean	YouTube Mean	Normalcy P-value
Quiz Scores	6.46	7.14	<0.001
Laboratory Scores	7.58	8.58	<0.001



The Kolmogorov-Smirnov results indicate a statistically significant difference between the 2013 and 2015 results. The higher median values for the 2015 laboratory scores and quiz scores indicate that the YouTube viewings and case studies improved students' understanding of the content. The improved understanding is expected as the case studies have increased alignment with the course's practical learning outcomes compared to the example driven classroom activities used in 2013.

The students' use of YouTube is confirmed through the viewership numbers for 2015 and 2016 shown in Figure 3. The black lines indicate the start and end of the 2015 and 2016 terms. Students used the videos for exam review as shown by the sharp spikes near 2015-04-06 and 2016-03-21, highlighted by the red lines.

Results for In-Person Quizzes and Laboratories - Textbook (2014) vs YouTube (2015)}

A key change between 2014 and 2015 was the use of YouTube videos as part of the flipped classroom component of IMPULSE. The quizzes and laboratories remained the same, and the use of in-class case studies remained the same between the two iterations of IMPULSE. Comparing



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the score distributions of the quizzes and laboratory reports provides a method to determine if the case studies may be implemented independently of the videos. The statistical results are shown in Table 10.

Table 10. Kolmogorov-Smirnov test results for required Textbook readings compared to required YouTube viewings.

Data Set	Textbook Mean	YouTube Mean	Normalcy P-value
Quiz Scores	7.59	7.14	0.078
Laboratory Scores	8.67	8.58	0.143

The results of the Kolmogorov-Smirnov test indicate that there is no statistically significant difference in quiz scores and laboratory scores between the 2014 and 2015 iterations of IMPULSE. These results suggest that the case studies may be implemented without the need for custom videos.

Results for Online Quizzes - YouTube (2015) vs Electronic (2016)

Between the 2015 and 2016 offerings of MAAE 2700, the key change was moving the quizzes and assignments from the problem analysis sessions to an online system. The online system provided individual coaching to the students as they completed the assignments, so the students received immediate feedback rather than waiting for their scheduled problem analysis session. Comparing the quiz performance indicates if the move to an online system had a negative or positive effect on the students' performance. The statistics are provided in Table 11.

Table 11. Kolmogorov-Smirnov test results for quizzes using YouTube (2015) compared to Electronic (2016).

Data Set	YouTube Mean	Electronic Mean	Normalcy P-value
Quiz Scores	7.14	7.61	<0.001

The p-value indicates that there is a statistically significant change between the 2015 and 2016 iterations of IMPULSE for the quizzes. The median scores for both iterations are the same; however, the kurtosis values indicate that 2016 was more tail heavy. The heavier tail indicates that the online quizzes were not an advantage to the students.

Results for Additional Case Studies During PA Sessions - 2015 vs 2016

In 2016, the changes to the problem analysis sessions enabled students to routinely practice solving case study based questions. Previously, students completed a selection of homework problems led



by the teaching assistants; therefore, the focus of the PA sessions was on the mechanics of certain computations rather than the fundamental concepts. The change to case studies may be evaluated by considering a Kolmogorov-Smirnov test applied to the final exam scores, as shown in Table 12.

Table 12. Kolmogorov-Smirnov test results for final exams using YouTube (2015) compared to Electronic (2016).

Data Set	YouTube Mean	Electronic Mean	Normalcy P-value
Exam Scores	58.3	62.6	0.075

The resulting p-value shows that there is no statistically significant difference between the final exam scores in 2015 and 2016, indicating that the additional case studies during the PA sessions were not advantageous.

Impact of IMPULSE on Teaching Evaluations

The teaching evaluations provide a useful perspective on what the students thought of the development of IMPULSE. A full text analysis of all the students’ comments across all four years is outside the scope of the present paper; however, the average scores for the instructor and the subject provide some insight. Table 13 lists the average score for different metrics. The table is organized into two broad categories: Instructor and Subject. The Instructor category gives the scores achieved by the author while teaching the course. The Subject category gives the scores achieved by all instructors who have taught the course to date. Since the Introduction to Engineering Materials had three sections per year, this category gives some insight about how other instructors using more conventional techniques scored.

Table 13. Teaching Evaluation Scores.

Year	Instructor			Subject		
	Average	B	Response Rate (%)	Average	B	Response Rate (%)
2013	4.51	4.33	45.5	4.32	4.09	50.9
2014	4.35	3.90	30.8	4.31	4.03	44.6
2015	4.62	4.42	41.4	4.29	4.06	43.9
2016	4.37	4.17	66.4	4.19	3.86	44.2

Within each category there are three columns labeled Average, B, and Response Rate. The column “Average” is the mean score across all 12 questions asked on the teaching evaluation. The score is out of 5. The column “B” is the average score for the question “How do you assess your instructor’s performance in imparting the course material to the students?” and is also scored



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out of 5. The last column reports the percentage of students that responded out of the total enrollment for the course.

The scores for the Instructor reveal that the lowest scores occurred in 2014 which corresponded with the required Textbook readings iteration of IMPULSE. The highest scores were achieved in 2015 with the YouTube videos iteration of IMPULSE. The 2016 iteration scored lower for the question about instructor performance compared to 2015 and 2013 suggesting that students did not like the online quizzes.

Comparing the Instructor scores to the Subject scores indicates that the Instructor often scored higher than the average of the other instructors. The single occasion where a lower score occurred was in 2014 for the instructor performance question (B), 3.90 for the instructor compared to 4.03 for the average of the other instructors. This result suggests that students did not like the required Textbook readings of IMPULSE compared to a more conventional approach taken by the other instructors.

CONCLUSION

Instilling Mature Problem-solving and Understanding of iLI-defined Scenarios in Engineering (IMPULSE) is the combination of flipped classrooms, case studies, and class discussions intended to provide students with a better conceptual understanding of engineering and improve their abilities to approach open-ended problems. The flipped classroom component uses instructor prepared videos placed on YouTube and a schedule for students to watch the videos prior to each class meeting time. Within class, the students are tested on their understanding of concepts and led through case studies of varying difficulty derived from accident investigation reports. The case studies require that the students make appropriate assumptions and apply the theories seen in the videos to a real scenario. The case studies are completed in groups, with periodic class discussions so that students realize that multiple approaches exist for solving a problem. The realization of multiple approaches is important as an engineering design problem frequently has many possible solutions. The case studies also form the basis of the final exams where students must solve three to five case studies, and apply their knowledge and understanding from the course material.

IMPULSE was attempted in the Department of Mechanical and Aerospace Engineering at Carleton University for a second year mandatory course on engineering materials. Data collected from four iterations of IMPULSE between 2013 and 2016 are considered. This data includes final exam scores, quiz scores, and laboratory scores. Three major conclusions are possible from the data,

1. From the 2013 and 2014 data, assigned textbook readings result have a negligible impact on students' final exam performance which supports the literature's finding of poor use of textbooks by students for conceptual understanding.



2. From all iterations, the assigned textbook readings, YouTube videos and case studies improved quiz and laboratory performance indicating improved understanding of the course concepts. The improved laboratory performance is noteworthy because the practical course outcomes are directly expressed via the laboratory experiments.
3. From the 2015 and 2016 data, case studies during the problem analysis sessions had a negligible impact, thus the TA should focus more on examples that illustrate the mechanics of certain calculations.

Given the results of the quizzes and laboratories, the use of a flipped classroom approach with YouTube videos and active learning driven by accident case studies is recommended for teaching engineering materials. This pedagogical configuration exhibits improved alignment with the practical learning outcomes associated with Engineering Materials such as material selection, failure, and heat treatments. The transition from a traditional teaching mode to the use of flipped classrooms, YouTube videos, active learning and the use of case studies requires advanced planning, based on the reflections of the author. The process begins by determining the learning objectives of the course in the context of the graduate attributes and learning outcomes. Once the objectives are determined, the evaluations to assess those objectives must be selected such as final exams, quizzes, and laboratory experiments. These evaluations should be organized into a time line for the semester, with consideration given to availability of laboratories and teaching assistants. For example, the scheduling flexibility of the laboratory experiments for the author's course was restricted by the laboratory being used for multiple courses. The time line is then used to organize the key concepts and topics that must be covered prior to each evaluation, and the order of these topics in the available class sessions. Once completed, the time line will indicate the number of videos that need to be produced and the number of activities or case studies that need to be created. The recording of the YouTube videos requires at least a month of work, and the author often created these videos during the summer. The duration is dependent upon the format for the videos such as PowerPoint slides versus handwritten notes, and the preparation time to create the content. Case studies are found through the accident report databases worldwide such as the National Transportation Safety Board or the Transportation Safety Board of Canada. The author also found conversations with industry practitioners at conferences to be a useful source for case studies. The author created individual class agenda that document the videos the students were to watch prior to the class along with the associated page or slide numbers. The agenda also listed the intended class activities and case studies, with their required resources. The total time spent to alter a course is most of a summer; however, once converted, the work does not need to be repeated during subsequent offerings. Finally, the author observes that the work load associated with the course during the semester is lighter compared to traditional teaching.



ACKNOWLEDGMENTS

The author thanks Dr. Adrian Chan and Dr. Sheryl Schramm of the Department of Systems and Computer Engineering, Dr. Juan Salinas and Dr. Jeffrey Erochko of the Department of Civil and Environmental Engineering, and Dr. Anthony Marini, Dr. Samah Sabra and the staff at Educational Development Centre at Carleton University for the many discussions on best pedagogical practices and approaches.

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