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Design, Implementation and Evaluation of an Online Team and Activity-Based Introduction to Engineering Course

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Abstract

As the popularity of online education in engineering increases, project- and team-based classes taught in classrooms must be converted into equivalent online versions. In order to maintain equivalency, content and ABET outcomes must be considered. This is especially difficult when on-ground classes are based on hands-on team activities and projects. The scalability of courses also must be considered due to the growing demand for engineering courses in the online environment.

This paper will discuss the creation process, implementation and evaluation of an online Introduction to Engineering course adapted from a largely team- and lab-based on-ground version. The epistemic framework and structure of the course will be discussed, focusing on its teaming and hands-on nature. Specifically, the design and implementation of teamwork throughout the course will be described, with a focus on the final team project, which consists of members designing, building, and testing musical instruments amid constraints that limit their designs based on the designs of other team members.

The first two offerings of this 7.5-week course took place during Fall 2013 with more than 110 students, most of whom were non-traditional students working in an engineering-related industry. Since then, another ~400 non-traditional students took this online course in the following semesters. The course's effectiveness and students' perceptions of the course and their teaming experience will be addressed based on data collected from project deliverables and discussion boards from the first two offerings. Recommendations for similar courses and strategies that can be used to scale this team and activity-based course while maintaining course quality, effectiveness, and student learning experience will also be addressed.

Introduction

The demand for online higher education has been increasing, with nearly 33% of higher education students enrolled in at least one online class[1]. It is now imperative for postsecondary institutions to offer quality online programs, given the rapid growth of online education, its enormous potential for an affordable education that offers flexibility, and how it empowers the learners to become active learners[2-5]. Due to this demand, Arizona State University (ASU) has started to offer a fully online undergraduate Electrical Engineering program beginning Fall 2013. In order to maintain accreditation for this program, equivalent online versions of all core classes had to be designed. To this end, an online version of the Introduction to Engineering course was designed and implemented. This course is the first required engineering course in the online program. As a direct equivalent to the on-site version of the course, which is a 2 credit hour course with a 1 hour lecture and 3 hour lab offered during each 15-week semester, the course is largely activity based with a large team component. The 7.5 week online course has been offered twice during each semester since Fall 2013.

It has been considered a best practice for introduction to engineering classes to contain "hands-on", team based projects[6-10]. However, incorporating team based projects and providing "hands-on" laboratory experience is one of the major challenges of online courses[11-12], which causes majority engineering faculty members and administrators to "shy" away from online education[2-5]. University of Wisconsin Colleges offers an online project based introductory engineering course, the first and only one of this kind offered in the nation[13], however, one of the two team projects involved in this course did not have any "hands-on" aspect involved while for the other one team members each build the same design and a final design was required to be built by only one member of the team and sent to the instructor for evaluation[13]. Our introduction to engineering course, on the other hand, has been designed such that students work in teams and get involved in "hands-on" projects throughout the course (starting from the very first day of the class), with a focus on the final team design project, which consists of team members designing (using mathematical models), building, and testing musical instruments amid constraints that limit their designs based on the designs of other team members. In this paper the creation process and the implementation of this online course will be shared. Student comments from in course discussion boards and end of semester course evaluations are also included to give insight into the student perceptions of the course.

The rest of the paper is organized as follows. First, the background will be discussed. Then course description, content and how the course was designed and developed will be described. Next, the effectiveness of the course will be discussed in terms of student perceptions of the course and their ability to meet course learning outcomes as well as qualitative grade comparisons with the onsite version of the course that this online course was modelled after. Finally, concluding remarks, areas of future development (including scalability concerns), and suggestions for others who are developing similar courses will be given.

Background

Arizona State University has a long history of offering flexible study options to students. It started its distance-learning programs thirty years ago by offering programs to corporate sites through interactive TV networks and satellites. Since 2002, ASU Online has expanded to offer more than 70 undergraduate and graduate degree programs entirely online.

In April 2013, the Ira A. Fulton Schools of Engineering at ASU announced plans to offer its Bachelor of Science in Engineering (B.S.E.) degree program in Electrical Engineering entirely online. At the time of the announcement, it was the first and the only ABET accredited 100% online BS electrical engineering program in the nation[14]. While there are other online engineering programs, most BS degrees require on-campus labs and most of the 100% online programs are MS or engineering technology certificate programs. The goal is to provide the flexible, accessible online format to anyone who is motivated to pursue an electrical engineering degree. To provide students with an equivalent learning experience as the on-site students, the students will learn from the same faculty, engage with the same rigorous academic content, and benefit from the same services and resources (including the ability to join and participate in clubs). The 120-credit-hour degree program includes core engineering courses and a minimum of 45 upper division credit hours in specialty courses. All courses in the degree program are offered in a seven-and-a-half week format. The program started in Fall 2013 with enrollment of about 200 students as of spring 2014, within which 85% are non-residents. The program has been continuing to grow to meet with the demand for this degree.

The Introduction to Engineering course is the first engineering course of this online undergraduate Electrical Engineering and Engineering Management programs. The course was designed be have equivalent content and assessment compared to the on-site version but adapted to format suitable for online delivery. The instructors developing and teaching the online version were teaching a similar on-site version of the course during Fall 2013 semester.

Course Description

The 2-credit hour project-based Introduction to Engineering course is a freshman level course designed to introduce the engineering design process, basic engineering skills, and provide opportunities for students to learn about various engineering tools and software. This course is also designed to introduce basic oral and written communication skills, important for communicating technical information effectively. This course also emphasizes teamwork and hands-on learning, and a hands-on team project is incorporated which lasts throughout the second half of this course and culminates in a physical, fully-functional prototype that can be evaluated against criteria and requirements. Other topics covered in this course include, project management, engineering models and measurements, creativity, and examples of engineering applications.

The course learning objectives for this course are as follows, students will

1. apply the engineering design process;
2. use engineering tools, software and terminology;
3. employ engineering models, physical principles, measurements and data to solve problems;
4. work effectively in teams and recognize the importance of teamwork;
5. gain basic skills in technical communication (oral presentations, technical reports, presentation of data);
6. use basic project management techniques (scheduling, budgeting) to complete projects successfully; and

7. creatively solve an engineering problem.

For an online delivery format, the same topics are to be covered, and the same outcomes and learning objectives are to be met.

Course Design and Development

The course developers are comprised of an instructional designer, a web technologist, and three instructors teaching the on-site version of this course offered to mechanical, aerospace, electrical, and chemical engineering students at ASU Tempe campus. The development of this course took about two months over the summer of 2013 for the course to be launched and taught during the two 7.5 weeks of 2013 Fall A and B sessions. First, overall course structure and course components were discussed and determined; then delivery method and content for each component was designed, developed, and implemented; finally the course shell (via LearningStudio, the university's online course management system) was assembled and finalized. During the process, a team based design project topic was also selected and the project was designed and developed.

This online course is taught over 7.5 week sessions (it is taught over the first 7.5 week session and repeated over the second 7.5 week session during a 15 week semester) while the face-to-face version is taught once during each entire semester. For equivalency, the entire online course is structured into weekly units. Each week consists of two units. Each online unit is equivalent to one week of the face-to-face version of the course. This produces a fast-paced class, which will be discussed later.

Once the overall course structure was determined, the course developers met and discussed topics for the units and the order of the units. The course developers also identified a timeline for the project. Details of weekly units and project timeline can be found in Table A.1 in Appendix A.

Based on the feedback the course developers received after the course has been offered during 2013 Fall session A, weekly units have been reordered for 2013 Fall session B, the details of which can be found in Table A.2 in Appendix A. The main reason for the reordering was to more evenly distribute the workload over the semester and give students more time to work on the project. Units with time intensive activities were paired with units that did not require as much work. This seemed to have helped students better manage the workload and pace of the course.

The course developers agreed that for the first half of the course, each unit should contain a few short video lectures, discussion(s) via discussion board(s), hands-on activities (both individual and team based), suggested reading materials, and a quiz; and for the second half the focus is on the team based design project. The topics and activities presented in the first half of the class are meant to introduce the engineering design process, other engineering basics and to prepare the students for the design project in the second half of the semester. An example of a hands-on activity that students do in the first half of the course is given as Appendix B. Notice that there are parts of the activity that require collaboration between teammates. This was added to build in interdependence within the team early on in the course and allow the students to practice the teaming skills presented earlier in the course. The course developers also decided that students would be provided with a list of materials that are needed for the hands-on activities. Students could locate/borrow/purchase/order the materials on their own or order a kit assembled by the university bookstore which contains all the items that are needed. While for the team based design project, students could purchase or use any materials that they feel are necessary for a given budget. The required materials cost about $50, the same as the course fee for the on-site version. Care was also taken to design activities and a project which do not require the use of power tools (although, students are welcome to use them if they have them available).

Due to the amount of hands-on activities and teamwork involved in this course, the course developers decided that students' performance be assessed based on the following.

Table 1. Grade Breakdown for the Course

Item	**Points**	**Percentage**
Individual		
Quizzes	300	30%
Notebook Entries	200	20%
Participation	50	5%
Team		
Design project	450	45%
Total	1000	100%

In Table 1, notebook entries are individual reports of both individual and team activities and participation points are assigned based on individual participation in discussions via discussion boards. This is the same grade breakdown used in the on-site version of the course, although some of the modes of assessment were changed to fit the online environment better (for instance, using discussion boards for Participation rather than attendance in lectures).

Once these have been determined, the three instructors then each focused on a few units, designed delivery methods and course content, and implemented the course content. Details of course content will be discussed in the following section.

Finally the course shell was assembled and finalized. The entire course shell was structured into the following: Course Home; Project Documents (where all project related materials and documents are located); and Weeks 1 through 7.5. Under Course Home, course syllabus, instructor introductions, student introduction discussion board, course tour video, course materials, course schedule, teams, as well as hallway conversations discussion board (for students to ask and answer questions) are included.

Course Content

Course content for this online course will be introduced and described based on the following categories: teamwork, engineering design process, basic engineering skills and tools, electrical fundamentals, team based design project, and engineering applications. Since many discussions and activities are used throughout this team and activity-based course to engage students, the focus will be given on these and details will be discussed as follows.

Teamwork

Working in teams in an online environment is challenging, especially when the majority of the online students are non-traditional students with work and family schedules to juggle. Because of this, the course developers decided to design the course such that all teamwork could be done asynchronously and that students could work in the same team throughout the course from the very beginning. Thus, as the students learn about basic team concepts in Week 1, student teams are formed and various team activities/assignments are used at the beginning of the course to help students become familiar with the teamwork environment (both the technology available to collaborate and get acquainted with each other). Teamwork is further reinforced during later weeks through other team activities/assignments before students work on the team based design project during the second half of the course.

Student teams of 3 or 4 are formed based on a set of criteria (e.g., gender, race, schedule, software skills, hands on skills, English skills, commitment level, leadership preference, etc.) using CATME SMARTER Teamwork[15]. Once teams are formed, students immediately engage in two team activities. First teams discuss and agree upon team norms which govern the expectations of team behavior. Then another activity is used to help teams identify effective mechanisms for communicating in an online environment. To help teams with communication, various tools like Google Docs, Google Plus Hangout, Skype, IM, are introduced to students.

Examples of other team activities used throughout the course (other than the team based design project) include a conceptual design activity, a hands-on bridge design activity (instructions for this can be seen as Appendix B), a dinner party planning activity, and other team discussions. To better understand the scope of the team activities in the class, the hands-on bridge design activity will be discussed in detail as an example. The hands-on bridge design activity is presented as a team assignment after the topic engineering models & measurements is introduced. The objectives of this activity are to learn to create orthographic technical drawings and to use technical drawings to communicate design ideas. In this activity, individuals design the lightest bridge which could support as much weight as possible based on a list of materials provided. Each individual creates a detailed technical drawing of their design and passes, through emails or in some other way, a digital copy of the drawing to another member in the team to build and test the bridge (details and instructions for this activity that were provided to students can be found in Appendix B). This activity is based around an activity done in the on-site version of the class. To demonstrate how the activities done on-site were modified for the online environment, Table 2 is provided as a comparison between the on-site version and the online version of this bridge design activity. Notice that the activity closely resembles that of the on-site version with the major difference being the mode of communication used between students. Creativity was needed during the redesign of the activity in determining how to get quantitative measurements for the weight supported by the bridge without assuming that the online students have a scale to measure arbitrary weights (the use of coins was adopted since the weights are fairly standardized and documented). It was also important to allow for feedback from peers to be given on the drawings so this was also incorporated into the online version of the activity.

Table 2. Implementation and Transformation of a Team Hands-on Activity from On-site Version to Online Version

	On-site Version	Online Version
Design Goal	Design the lightest bridge that span a 24’’ gap using materials listed that can support the largest amount of weight	Design the lightest bridge that span a 24’’ gap using materials listed that can support the largest amount of weight
List of Materials	• 1 sheet of newspaper • 2 8.5"x11" sheets of standard weight printer paper • 1 ft length of tape • 5 paper clips • 4 spaghetti noodles • 2 ft of string	• 1 sheet of newspaper • 2 8.5"x11" sheets of standard weight printer paper • 1 ft length of tape • 5 paper clips • 4 spaghetti noodles • 2 ft of string
Weight Used	Washers	Standard U.S. Coins

Support of bridge	Two lab workbenches that are 24’’ apart	Any leveled surfaces (books, tables, etc.) that are 24’’ apart
Design Process	Team members discuss design ideas and choose a design idea	Individuals in a team chooses a design idea individually
Engineering Drawing of Design	Team members take turns to create a drawing of the design	Individuals in a team creates a drawing of the design individually
Building Design	Each team (design team) passes the drawing and a list of materials (with quantities) to another team (contractor team) in the class, which builds the design	Each individual (designer) in a team passes a digital copy of the design and a list of materials required (with quantities) to another member (contractor) in the team, who builds the design
Testing Design	Each design team receives the design and takes turns to test it in front of the class	The contractor tests the design for the designer and sends picture(s) of the design and the testing setup, as well as testing results to the designer
Feedback	Each contractor team gives feedback face-to-face to the design team about the drawing	Each contractor sends feedback via email to the designer about the drawing

To ensure full participation among team members, teams are required to document their communication and process used to arrive at the teams’ final answers for each team activity/assignment throughout the course. This documentation most often took the form of copying emails or chat sessions related to that activity into a document for submission along with the final deliverable the team produced. This served to hold individuals accountable within the team and helped instructors work the team through team issues, should they arise. In addition, two peer evaluations are used to assess individual performance and contribution in teamwork using CATME SMARTER Teamwork[16-17].

Engineering Design Process

The engineering design process is introduced early in the course. Before the design process is introduced, students are asked to reflect on their own design experience and discuss the design process used by professionals in a discussion board. Then the design process and various design tools (such as brainstorming techniques, concept combination tables, and decision matrices) are introduced using three short video lectures. Students then have the opportunity to apply the design process to create a conceptual design and practice using various design tools for a scenario provided.

Students practice using the design process again later in the course when teams create a design to a real world problem for the team based design project.

Basic Engineering Skills and Tools

Four topics are included in this course to introduce basic engineering skills and tools: engineering models & measurements; MATLAB; project management; and technical communication.

For engineering models and measurements, descriptive and predictive models are introduced to students with a focus on visual models. The basics of measurements are also introduced including distinguishing between accuracy and precision and interpreting the meaning of a mean and standard deviation. Activities for this topic include a drawing activity, for which students practice creating detailed orthographic multi-view drawings of simple objects; a bridge design activity (discussed before under teamwork); and a temperature measurement activity, where students individually measure the temperature of a bottle of water as it cools down in an ice bath, in order to verify the mathematical model Newton's law of cooling (details of this activity are also included as Appendix C).

Basics of MATLAB are introduced to students in the form of short tutorials. A few exercises are used for students to get familiar with the MATLAB environment and practice implementing simple commands. Students also have the opportunity to verify the mathematical model Newton's law of cooling by processing and presenting data collected and graphically comparing it to the model using MATLAB.

Project management and various project planning tools are introduced to help students plan and manage projects effectively. Discussions and activities for this topic include risk management discussion and team dinner party planning. Students also practice using project planning tools to plan and manage the team based design project.

For technical communication, the focus is on oral presentation and technical writing. Students are given the opportunity to search and compare two journal articles on areas of Grand Challenges for Engineering[18]. A discussion board is also included for students to view and discuss a few short oral presentations. Students have the opportunity to make two oral presentations for the team based design project. To implement this in an online environment, individuals in each team are asked to each record a part of their team presentation and are encouraged but not required to edit all parts into a single video. They can either upload their video(s) directly to the course shell, or they can upload the video(s) to YouTube or Vimeo and post the link(s) to the video(s) to the course shell. Students also practice technical writing by creating two formal technical documents for the team based design project.

Electrical Fundamentals

As the first engineering course for the online Electrical Engineering program, this course also introduces basic electrical quantities and fundamental circuit laws to students. Besides learning theories, students also have the opportunity of both simulating circuits and verifying the simulations by physically building the circuits and taking measurements. Students use online simulation tools to simulate simple circuits and they use a list of materials and tools purchased to practice building simple circuits on a breadboard and measuring basic electrical quantities using digital multi-meter. They then verify fundamental circuit laws by comparing theoretical calculations, simulation results and hands-on circuit measurements.

Team Based Design Project

For the on-site version of this course, a team based hands-on design project is implemented during the second half of the semester. The design project is used to give students an opportunity to apply the engineering design process by creating a solution to a real-world design problem, and to practice skills such as teamwork, communication, project planning, etc. Students work in teams of 3-4 to design, build, and test a functional prototype for a given design challenge. Examples of design projects implemented include a solar car design project, a renewable energy design project, an autonomous waste sorter design project, etc.

Implementing a team based design project in an online environment is very challenging. The project needs to be properly designed such that the same goals are achieved, for example, team collaboration is required throughout the project and each individual in a team has the opportunity to apply the design process and build and test the design. The course developers designed a "Band-in-a-Box" design project, for which each student team needs to design, build, and test a design consisting of a few musical instruments such that one of the three selected songs (of different levels of difficulty) could be played by the team. This project is designed such that each individual in the team designs and creates one instrument amid constraints which limit their design based on the designs of other team members. These constraints include a limiting total size of the collection of instruments, and limited amount of materials that can be used by the team (such as string or pipe which would be desirable for use in a variety of different instrument designs). Each instrument needs to be able to play one part of the song that the team selects. As a final product of the project, all parts of the song need to be combined into a mixed audio track. The physics behind string, wind, and bar percussion instruments are presented in lecture videos earlier in the semester. Within their set of 3 or 4 instruments (depending on the number of students in the team) all three of these types of instruments must be represented. Each instrument should cost as little as possible and no more than $15 and all materials students use should have costs associated with them, even if the materials are recycled. Activities earlier in the semester give the students practice using the governing equations which they are then expected to use to calculate design parameters such as lengths of strings, pipes, bars, etc. for their final project. It is in calculating and sharing these calculations that the team should realize the effects of the constraints on their designs. For instance, they will find that the size of the container constrains the lowest instrument and, as a team, they can determine which instrument type will best be able to meet the size constraint while being able to play the lowest notes. This forces the team to make design trade-offs which they are requested to reflect upon in the reports.

Students are also provided with sheet music, a listing of all the notes needed to be played in each part, and a table relating the note names to the frequency of the note. Sound files (midi files) for the songs and for each individual part within the song are also provided so that the students can hear what they are required to play. With this information the students are able to specify technical design requirements such as the minimum and maximum frequency needed to be played. This also helps students address issues of playability as they realize that they must be able to play their part using their instrument (even if they have no musical experience). We do allow students to compile their track note-by-note, meaning that if they were not able to play it through in one sitting, they could still piece together the song in post processing. Students are also allowed to automate the song, for example, using a music box.

To demonstrate the design, each member in the team needs to record a part of the song played using the instrument designed and built by the member and different parts need to be edited and mixed into one final audio track. A free audio editing software available online called Audacity is used for recording, editing, and mixing tracks for the song. Links to tutorials available online are given to students to learn how to use the software. Audacity is also used to analyze their final prototypes. Students generate a spectrum using Audacity and compare the location of the peaks to the desired fundamental frequency. This helps them complete the design cycle by analyzing the performance of the prototype.

Their design prototypes are assessed based on a set of criteria: ability of each instrument to produce multiple tones; overall quality of the track (a different weighting factor is used for each song based on its level of difficulty); tone quality produced by instruments (based on maximum percent deviation from theoretical fundamental frequencies for high/low notes for each instrument); creativity and innovation; cost; aesthetics; and craftsmanship.

Various project deliverables are designed and used to help teams work through the steps in the design process. These deliverables include problem definition, project schedule, project proposal presentation and written documentation, progress report memos, final presentation and demonstration, and final report. These deliverables are the same for the on-site course although specific details about what to include in these deliverables will depend on the project. The deliverables are meant to align with the learning objectives of the course and help teams progress through the design process.

Other topics presented, such as acoustics, digital filters, and creativity, were meant to provide additional information that the students can draw upon during the design process in their final design project. This includes mathematical models to predict lengths of bars and pipes for their musical instruments and techniques that can be used in post-processing to improve the recordings of their instruments (simple signal-processing).

Engineering Applications

While students are working on the design project for the second half of this course, a few examples of engineering applications are presented to students. The objective is for students to explore different fields of engineering that they could pursue with an engineering degree, various opportunities for engineers and possible career options. The following three topics are chosen for this purpose: mars rovers, solar energy, and Grand Challenges for Engineering[18].

Student Perceptions and Performance in the Course

The course learning outcomes have been assessed using the hands-on team-based design project, along with other tools, such as, quizzes and notebooks (individual reports of both individual and team activities). In this section, student demographics information will be presented and students' performance on the design project will be presented and discussed. In addition, during the final week of the course, an optional discussion board is used for students to reflect on their learning experience and comment on what they think has been most useful from this class and what they would hope to apply in their future classes and/or career. These comments are used to gain insights on students' perceptions about this course.

Student Demographics

There were 71 students and 67 students enrolled in 2013 Fall A and Fall B sessions, respectively. While many more students have taken this class since this cohort, this paper is limited to the results from these two semesters. Future work will include subsequent cohorts.

Three major groups of students were enrolled in the Introduction to Engineering course. The majority of students were from Electrical Engineering (EE). Engineering Management (EM) students were the second major population because an online undergraduate program was started and this is a required course for the program. The rest of the enrolled students were designated as "Exploratory", those whose majors were outside of engineering. They either took this course to explore if engineering was a suited major for them, or they were trying to get into engineering, but they were not qualified to enter the engineering program at the time of enrollment. Table 3 has a breakdown of the students' majors.

Table 3. Student demographics by major

Majors	EE	EM	Exploratory
Fall A (Total: 71 students)	50.7%	22.5%	26.8%
Fall B (Total: 67 students)	43.3%	20.9%	35.8%

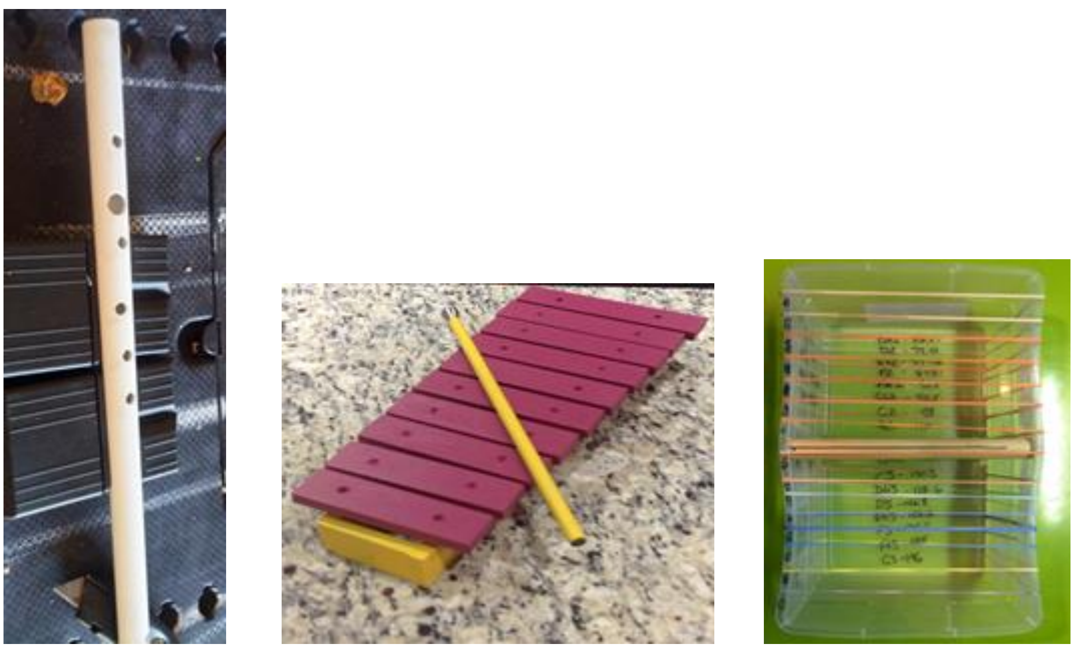
Withdrawal

There were 17 withdrawals from Fall A session and 12 withdrawals from Fall B session. This withdrawal rate is higher than desired. The reasons for this are unclear and require further investigation. Even though a similar version of this course has been offered on-site for a few years with great results, the instructors are still working on improving the new online version to better serve the needs of non-traditional online students. With revisions, the retention rate of the Fall B session is noticeably better than the Fall A session. Since making the changes, the D-F-W rate for the course has remained relatively constant at about 20-25%. While higher than desired, retention issues remain a large problem for online learning and have been the subject of many studies found in literature[19].

Outcomes of the Team-Based Design Project

The team-based design project was very successful for both sessions. Student teams creatively used mathematical models (physical principles and mathematical equations) and applied the design process to design, build, and test collections of wind, percussion, and string instruments amid design constraints. The majority of designs were very successful, i.e., the designs produced various tones with good quality (as demonstrated through comparisons of desired values with spectral results); were able to play one of the three songs provided; were aesthetically pleasing and creative; stayed within budget, and satisfied all design constraints. Two examples of student designs are included below in Fig. 1. The designs differ significantly between teams and, while some designs of individual instruments are more popular semester to semester than others, every offering of the course does produce unique designs.

(a)



(b)

Fig. 1. Wind, Percussion, and String Instruments from two "Band-in-a-Box" Project Design Teams

The "Band-in-a-Box" design project is used to assess most of the course learning objectives/outcomes. More specifically, outcome 1 has been assessed based on the success of the prototypes for the project; outcome 3 has been assessed based on the project proposal deliverable, for which students need to use physical principles and mathematical models to calculate required lengths of strings/pipes/bars, etc. for the instruments and provide justification of their design decisions; outcome 4 has been assessed based on peer evaluations of the effectiveness of the teams; outcome 5 has been assessed based on two oral presentations and two technical reports about the proposed designs and final designs; outcome 6 is assessed based on students' ability to create a detailed project schedule; and outcome 7 is assessed based on prototypes and final reports. Table 4 below shows student performance on this team hands-on design project from both sessions as compared to students from the on-site class. The students from the on-site version were from the same Fall 2013 semester in the 8 sections taught by the same instructors who taught the online course. It is important to note that the project deliverables were the same between all sections and similar rubrics were used in the assessment of these deliverables, however, the projects themselves were different between the sections. While qualitatively similar results were observed, that is the online students did not seem to perform any better or worse than the onsite students, a detailed statistical analysis has not been done to check for significance. What can be noted is the high overall performance on the project. Those who received an E for this team hands-on design project were inactive during the process of the project. Those who actively engaged in the project all mastered these course learning outcomes successfully. The similarity of grade distributions for the online version and onsite version do suggest that the project achieved similar results for both onsite and online students, although future work needs to be done to better quantify this. One proposed way to do this is through a direct comparison and coding of individual assignments (since similar assignments are given for both versions).

Table 4. Student team hands-on design project grades distribution and comparison with the on-site version

	Online-Session A	Online-Session B	On-site Version
Total number of students	54	55	309
Mean Grade (out of 100%)	78.5%	85.2%	87.3%
% of A's (above or equal to 90%)	33.3%	60.0%	50.5%
% of B's (between 80% and 90%)	40.7%	18.2%	43.0%
% of C's (between 70% and 80%)	7.4%	10.6%	3.2%
% of D's (between 60% and 70%)	1.9%	3.6%	1.0%
% of E's (below 60%)	16.7%	7.3%	1.9%

Student Perceptions of the Course

At the end of the course, the students were invited to reflect on what they learned through the course. A discussion board prompt asked them, "What did you find most useful from this class? What did you learn that you hope to apply in future classes or in your career?"

The most common responses were related to the engineering design process, team concepts, and creativity which match the course learning objectives (specifically learning objectives 1, 4, and 7), although complete coding of these quotes is still being done. Some examples of quotes from students which demonstrate the skills they felt were the most important include:

"This class has given me a glimpse into the design process, the concept of working together as a team and has taught me that I too can be creative, all I have to do is work at it. This will not only help with the rest of my classes here at ASU but also in my current career and my future career."

"This class has been great. I learned a lot about the engineering process and how to work as a team that is all in different places. "

"The whole team concept of this class was great! I have already begun to use some of the team skills I learned in this class, and have even taught them to a Christian boys group that my son and I go to."

"The part about this course that surprised me the most was working in my team. I was extremely skeptical about our ability to function as a team being geographically separated and having crazy schedules. It came out to be much easier than I was expecting. I learned about Google Docs which our team used to keep communications flowing. This is something I have now incorporated into my office with great results. "

The hands-on nature of the team design project as well as the course in general, has been a highlight based on students' comments as well.

"*......This class was definitely one of the most dynamic and unexpected joys I've had in my college career and the design and creation of my marimba will always hold a special place in my heart. I took it into work to show it off and everyone got a kick out of playing it. It's a great feeling being able to bring joy to other people with a product that you build from the ground up. ……*"

"I liked the hands on aspect of the course allowing us to build something with our hands in addition to learning theories. ......"

Based on students' performance on the team design project as well as their reflection on their learning through the team design project, which is a major component of this online course, the project has been proven to be a very successful tool in providing an active learning environment in an online setting, which has been considered a best practice for introduction engineering classes taught face-to-face[6-10].

These quotes also seem to indicate student satisfaction with the course. There is also some preliminary indication from course evaluation survey results to indicate that overall students are satisfied with the course, but a complete quantitative analysis of these results still needs to be completed and is an area of future work. The major complaints about the course, though there were not many written complaints in either the course evaluations or the end of semester reflection discussion board, were related to the workload. An example of this can be seen in the following quotes:

"This course was not at all what expected. There was quite a bit a work associated with this course. I believe I have invested more time in this course than in any other course I have ever taken...except for Reactor Physics. I am sure the rest of my team experienced the same. I work 50hrs per week and attend ASU online full time plus I have a family."

"I think this course required far too much effort for a 2 Credit course. I easily spent more time on this material, especially with the labs and final project deliverables than I did with my 3 Credit calculus course."

This has been a major issue during the development of the online course since the on-site course is based around a 1 hour lecture and 3 hour lab for 15 week semester and the online class condenses this into a 7.5 week term. To help students understand the expectations for the time spent in the course the guideline of at least 9-12 hours per week was made more prominent (it was stated in the syllabus) in both the course syllabus and in emails sent to students before the start of the class. This was determined to be a similar amount of total time spent for the course by our on-site students and so the online course was designed with this in mind. The course evaluations administered at the end of the semester did ask students to self-report the number of hours spend on the course per week. Despite the complaints about the time requirements of the course, the average number of hours per week spent on the course was just over 12 hours (standard deviation was about 4 hours). This indicates that, while on the higher end of the intended time range, the course is about on target for how much time students are expected to spend on the course. However, the response rate for the course evaluations was low (about 24%) and the time increments for students to indicate was fairly large and so an area of future work might be to study this aspect of the course in more detail through reviewing records of time spent on the course shell and a better tool for self-reporting of time spent on the course.

An important “unpublished” goal of an introduction to engineering course, in the authors’ opinion, is to stimulate students’ interests in engineering and motivate students to become successful engineers. Many students have commented on how this course has successfully achieved this goal. For example,

“This was probably one of the most enjoyable classes I've taken so far. I had some uncertainties about whether I wanted to pursue engineering further and those uncertainties have been settled. The instructors were great and I had a terrific team, it's been a highlight.”

“My longterm interest in engineering was confirmed.”

Scalability of the Course

Currently, class size of this online course is relatively small (with about 55 students completing the course in each session offered in the Fall 2013 semester). The three instructors have co-taught this course for both sessions and equally shared the teaching load. Instructors’ responsibilities include, interacting with students, answering student questions, helping students with course material and assignments, giving feedback to student work and designs, dealing with team issues, grading major assignments, etc. In the meantime, a grader has helped grade other assignments and a UGTA (Undergraduate Teaching Assistant) has been utilized to interact with students via discussion boards and help students with questions. Currently the model that has been used by the instructors is that each instructor has focused on a third of the teams (about 5 or 6 teams for each session) in the class. This model is beneficial in two ways. For one, this is easier for each instructor to keep track of the teams’ progress, issues, and their designs for the design project. For another, with over 50 students in the class and no face-to-face meetings, it is very difficult for students in the class to get individual attention and interaction with the faculty but with this model each small group of students have a dedicated faculty member to turn to for help and more student-faculty interaction is involved. Currently, this course is taught in addition to normal teaching loads of the 3 instructors and so splitting the responsibilities reduces the workload on each individual. However, this course could be run by a single faculty member who is dedicated to the class (with the current grading and UGTA support).

The authors feel that a few strategies can be used to scale this activity and team-based online course while maintaining its quality, effectiveness, and student learning experience. First of all, with more students this course can be divided into sections of 30-40 students. A few Teaching Assistants (TAs) could be utilized, each focusing on a few sections. And the instructor could mainly focus on managing the course and mentoring the TAs. This is similar to the model that the instructors have used for both sessions, except with a slightly bigger size. A training module could be developed to train the TAs before they become responsible for the sections. This is the model used for the on-site version of the class and has proven effective in scaling for that version. The online version would have the additional advantage of not needing the classroom space that the on-site version has and limits further scaling of the on-site version. Another strategy that could be used is to have one section with a large number of students but students could be divided into a few cohorts. For example, each five teams in the class could form a cohort and all class discussions could be done within the cohorts. Either TAs or UGTAs could be utilized to each focus on a few cohorts. The difficulty with this format is that the discussion boards become rather large and finding the appropriate threads for each cohort is more confusing for students. The advantage of this format is that there are more students to receive help from and the insights from students in any of the cohorts could, at least in theory, be viewed by anyone in the class so the opportunity for peer learning is increased.

Some of these scaling strategies are being put into practice for the Spring 2015 A session where a single instructor, 2 graders (20 hrs/week each) and a UGTA will run this course with double the numbers of students compared to the cohorts studied in this paper. The learning management platform has also been changed to Blackboard for this offering due to LearningStudio being phased out at the university. This also gave an opportunity to make some changes to some of the activities and course structure to improve the student experience and student-instructor interaction. Details and results from this course redesign will be saved for future work, but this course has proven to be scalable with minor adjustments.

Conclusions

An online introduction to engineering course has been designed, developed, and taught during the two 2013 Fall sessions at Arizona State University. This online course was designed to be directly equivalent to the on-site version of the course, which is a 2 credit hour course with a 1 hour lecture and 3 hour lab and thus it is largely activity based with a large team component. Various hands-on activities and teamwork components have been designed and included from day one with a focus on a large team-based design project. This course is deemed successful as is proven by results from student comments. It is also proven to be very effective at meeting its stated objectives. The scalability of this course has also been discussed and the authors believe that it can be easily scaled using appropriate strategies which are currently being implemented. This course is an example of how teamwork and hands-on activities can be incorporated in engineering courses delivered online with both small and large class sizes.

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Appendices

Appendix A: Weekly Units for 2013 Fall session A and session B

The following tables show the schedule of the course offered in 2013 Fall session A and B, respectively.

Table A.1. Weekly units for 2013 Fall session A

Weeks	Weekly Units	Project Timeline	Notes
Week 1	Unit 1 - Working in Teams	Teams are formed	
	Unit 2 - Engineering Design Process		
Week 2	Unit 1 - Engineering Models & Measurements		
	Unit 2 - MATLAB		
Week 3	Unit 1 - Electrical Fundamentals 1		Basic electrical quantities and fundamental circuit laws
	Unit 2 - Electrical Fundamentals 2		Electronic RC filters and basic digital filtering
Week 4	Unit 1 - Acoustics	Team based design project is introduced: problem definition	Sound and physics of musical instruments (to prepare students for the design project)
	Unit 2 - Project Management	Project planning	

Week 5	Unit 1 - Technical Communication	Project proposal	
	Unit 2 - Creativity		
Week 6	Unit 1 - Engineering Applications 1 - Mars Rovers		
	Unit 2 - Engineering Applications 2 - Solar Energy		
Week 7	Unit 1 - Engineering Applications 3 - Grand Challenges for Engineering	Final presentation and demonstration of project	
	Unit 2 - Reflection		
Week 7.5	Final Report Submission	Final report	

Table A.2. Weekly units for 2013 Fall session B

Weeks	Weekly Units	Project Timeline
Week 1	Unit 1 - Working in Teams	Teams are formed
	Unit 2 - Engineering Design Process	
Week 2	Unit 1 - Engineering Models & Measurements	
	Unit 2 - MATLAB	
Week 3	Unit 1 - Acoustics	Team based design project is introduced
	Unit 2 - Creativity	

Week 4	Unit 1 - Electrical Fundamentals	Problem definition
	Unit 2 - Project Management	Project planning
Week 5	Unit 1 - Technical Communication	Project proposal
	Unit 2 - Engineering Applications 1 - Grand Challenges for Engineering	
Week 6	Unit 1 - Analog and Digital Filtering	
	Unit 2 - Engineering Applications 2 - Mars Rovers	
Week 7	Unit 1 - Engineering Applications 3 - Solar Energy	Final presentation and demonstration of project
	Unit 2 - Reflection	
Week 7.5	Final Report Submission	Final report

Appendix B: Example Hands-On Activity

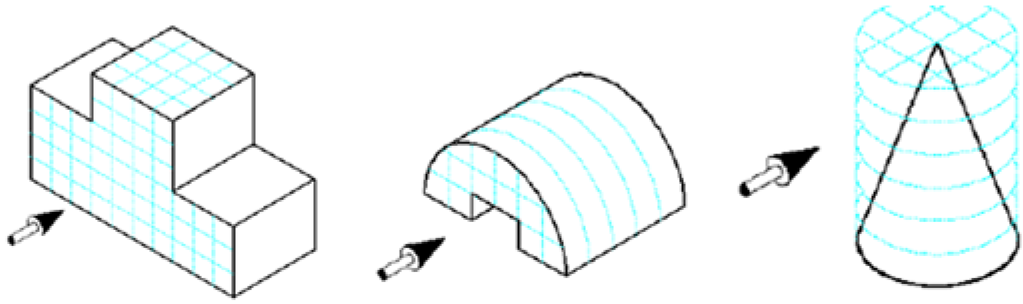
Below is an example of a hands-on activity included in this online course. These are the instructions given to students for the activity. Notice that there are parts that will be completed individually, but there are also parts that require collaboration between teammates.

Activity 2: Drawing Exercise, Bridge Design, and Temperature Measurement

Please complete all three activities using the format provided here. Once you are done, go to the dropbox to submit your completed Notebook Entry.

Activity: Drawing Exercise (Individual)

Create a **dimensioned** multi-view drawing of the 3D drawings below. The front side of the object is indicated by the arrow. The gridlines shown on the objects below indicate their size: the distance between blue lines is 1 inch.



(1) (2) (3)

Activity: Bridge Design (Individual)

Objectives:

- Learn how to draw a dimensioned engineering drawing (technical drawing)
- Practice using three orthographic views to represent a 3D object in 2D

Description

For this activity you will be designing a bridge that will span a 24 inch gap using the materials specified in the activity document found here. The catch is that you will not be building this bridge, but rather you will be drawing a 3-view engineering drawing and exchanging drawings with another team member. You will build your team member's design and they will build your design based only on your engineering drawing. You will then test the bridge that you built and report the results to your partner.

Procedure

Your goal is to design the lightest bridge possible that will support as much weight possible. The bridge must be able to span a distance of 2 feet (2 feet between the edges of the gap) and cannot be attached to the tables. You may only use the materials specified below in your design.

- 1 sheet of newspaper
- 2 8.5"x11" sheets of standard weight printer paper
- 1 ft length of tape
- 5 paper clips
- 4 spaghetti noodles
- 2 ft string

You should NOT build your design! You need to produce a dimensioned engineering drawing that will be used to build your design. You may label what each material is, but you cannot include instructions on how to construct the bridge. You may use magnified views of portions of the bridge to clarify details.

Your drawing should:

- Be drawn neatly, using a ruler or some other straight edge to create straight lines
- Include the three views required to define the bridge your team has designed
- Include all dimensions necessary to define the bridge design (be sure to indicate units)
- Be properly aligned

Once you are done, scan or take a picture of your drawing. **You should include your drawing in your Notebook Entry for this unit**. Make sure that all of the details can be made out. Choose one other person within your team to trade drawings with and email them your drawing before several days before the Notebook Entry due date. Once you receive the drawing from your partner, build the design in the drawing that was sent to you. **Do not communicate with each other about HOW to build the design or ask for clarification**. Build the design based on your best interpretation of their drawing. Do not redesign the bridge you are building, but build it to the specifications provided in the drawing.

Once you have built the design, place two objects (stack of books, tables, chairs, etc.) 2 feet apart and test the bridge. **Before testing, take a picture o the bridge on your testing set-up**. For weights, it is recommended to use coins. The weight of standard U.S. coins can be found here. Keep adding weight until failure of the bridge.

Record the amount of weight that was supported. Email your partner the picture of the testing set-up with their bridge design and the amount of weight that the bridge supported. Also include feedback on the drawing that you received, including suggestions on how to improve their technical drawing. You should work with your partner to determine when you need to get them this information by. **In your Notebook Entry, include the weight that your bridge (the one you designed) supported, the picture of the set-up used to test the bridge you designed, and the feedback given to you.**

Appendix C: Example of Basic Engineering Skills Activity

Below is an example of a hands-on activity that students do in the class which allows for demonstration of an ability to take measurements and compare those results with theory (done in a later activity involving MATLAB). Specifically topics related to measurement uncertainty are addressed (resolution of measurement devices) and units. These topics were discussed earlier in lecture videos and reinforced through this activity. These are the instructions given to students for the activity.

Activity: Temperature Measurement (Individual)

Objectives:

- Practice taking measurements accounting for measurement uncertainty
- Collect data to compare to mathematical model (comparison will be done in MATLAB unit)

Description and Procedure

You will be taking measurements of the temperature of a bottle of water as it cools in an ice bath. Before proceeding, watch the *Newton's Law of Cooling video.*

What you will need:

- bottle of water
- stopwatch (your phone is fine or you can use this online stopwatch)
- a bowl filled with ice/water mixture (but mostly ice)
- thermometer (a meat thermometer or mercury thermometer will work best as long as they can measure low enough temperatures...see images below)
    - If you do not have access to a thermometer that can go low enough to do the cooling experiment, you can do the same experiment with warming by putting it into boiling water. Just be very careful with the hot water.


- **In your Notebook Entry for this unit, note the resolution of your thermometer** (what is the spacing between tick marks).
- Measure the temperature of the ice bath and the temperature of the water in the water bottle before putting it into the ice bath and **record these values in the Notebook Entry for this unit**.
- Put the thermometer in the water bottle, then put the water bottle into the ice bath.
- Measure the temperature of the water every 30 seconds for 15 minutes.
- **Record the measured temperature and time values in a table in your Notebook Entry for this unit.** Make sure to include appropriate units.
- Enjoy a nice cold drink of water.