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MAKECOURSE-*ART*: DESIGN AND PRACTICE OF A FLIPPED ENGINEERING MAKERSPACE IN HIGHER EDUCATION

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The Makecourse-Art is a makerspace designed to promote undergraduate students' aesthetic design skills as well as functional design skills using an interdisciplinary team approach at the University of South Florida. To overcome the unique challenges of the Makecourse (earlier version) and to maximize students' design efforts working on an engineering project in the classroom, the Makecourse-Art incorporated a flipped classroom model utilizing two instructional methods with corresponding activities. First, the explicit form of instruction is delivered through asynchronous video lectures/tutorials, including topics such as Arduino programming, CAD modeling with the Autodesk Maya, Mudbox, and coding skills. Second, interactive team-based classroom activities are offered to students based on student-centered learning theories such as peer-assisted collaborative learning and problem-based learning. In this paper, we present the design case of the Makecourse-Art with detailed descriptions of the components, and explain the key design decisions, obstacles during the design process, and how the challenges were resolved. In addition, we provide step-by-step examples of students' engineering design experiences with visual images.

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INTRODUCTION

Since the rapid growth of community-based makerspace movement during the period 2000-2010 in the U.S. (Wilczynski & Adrezin, 2016), the academic makerspace in higher institutions has emerged as a new way of teaching and enhancing learning along with the science, technology, engineering, and mathematics (STEM) initiatives (Adams et al., 2017; Maves & Wilczynski, 2017). Especially, with the increased awareness of the critical role of design in engineering curriculum, many engineering programs have initiated the development of their own approaches to design and create unique makerspaces (Wilczynski, 2015).

In this paper, we describe the case of the Makecourse-Art at the University of South Florida, which was designed to promote undergraduate engineering students' aesthetic design skills as well as functional design skills. We particularly emphasize how we implemented a flipped learning approach, why the aspect of the "Art" was later added to the initial concept of the Makecourse, and further how it has improved engineering students design, learning, and motivational experiences. Among the four co-authors of the paper, the last two authors created the Makecourse (without "Art"), which was the earlier version of the Makecourse-Art. The first two authors were involved later in the design, development, and evaluation of the Makecourse-Art.

A design case refers to a description of a real artifact or experience that was intentionally designed (Boling, 2010). A rigorous design case includes detailed descriptions to characterize the design context, as well as the stakeholders that played key roles in the design process (Howard, 2011). In the following sections, we present the background of the Makecourse-Art, who was involved, and how it has been revised and reconceptualized over the years.

WHY "ART"?

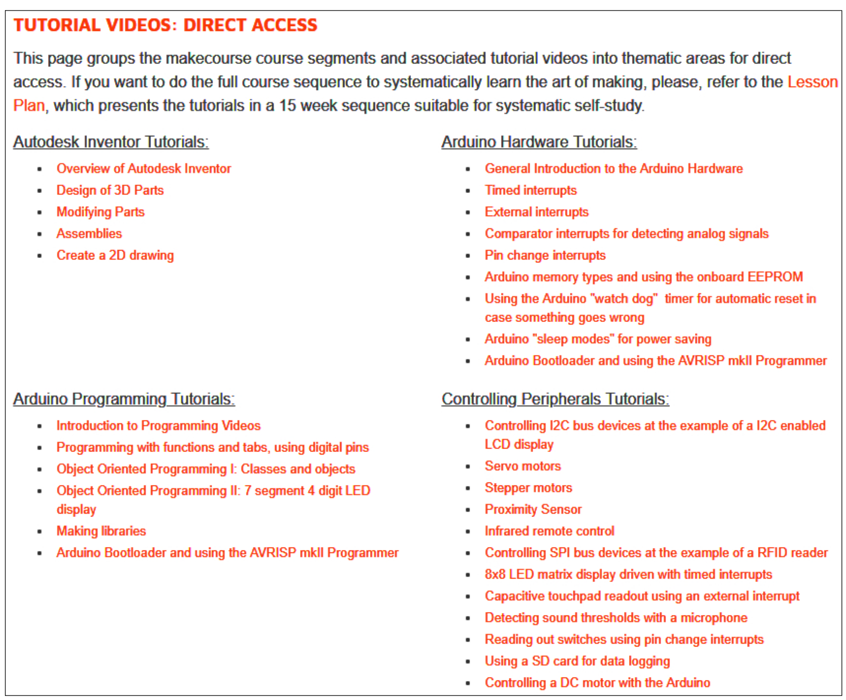
The Makecourse Without "Art"

The earlier version of Makecourse-Art was launched in 2014, minus the art component. Two of this paper's authors, instructors in the College of Engineering, designed the Makecourse changing the class format from traditional instructor-led to a maker-centered learning environment. Since the makerspace movement was widespread in engineering schools, the conversion was timely and crucial. In addition, the university already had provided a classroom, design labs, and tools/devices that were needed for engineering design tasks; hence, it seemed natural to make such a course revision. The initial purpose of the Makecourse was to provide only undergraduate students who majored in engineering with an active learning environment in which they could experiment and test their engineering design process through a series of authentic design tasks. These engineering students were expected to work individually to produce creatively engineered products and working systems. They also were required to learn essential design skills needed for the design of "Mechatronic" devices, which are the devices incorporating electronic, mechanical, and software-based components. At the end of the Makecourse, students submitted a final project packet including a functionally working system, a list of full parts, a complete manual for the product, and the itemized cost of the system.

Challenges of the Makecourse

As there were no books available that cover the entire design process of the essential components for the Makecourse (i.e. Mechatronic devices, Micro Controllers, programming tools, electrical engineering, and 3D modeling and printing), the initial conversations between the Makecourse instructors resulted in creating an online repository to provide students

FIGURE 1. The Makecourse site main page.



TUTORIAL VIDEOS: DIRECT ACCESS

This page groups the makecourse course segments and associated tutorial videos into thematic areas for direct access. If you want to do the full course sequence to systematically learn the art of making, please, refer to the Lesson Plan, which presents the tutorials in a 15 week sequence suitable for systematic self-study.

Autodesk Inventor Tutorials:

- Overview of Autodesk Inventor
- Design of 3D Parts
- Modifying Parts
- Assemblies
- Create a 2D drawing

Arduino Hardware Tutorials:

- General Introduction to the Arduino Hardware
- Timed interrupts
- External interrupts
- Comparator interrupts for detecting analog signals
- Pin change interrupts
- Arduino memory types and using the onboard EEPROM
- Using the Arduino "watch dog" timer for automatic reset in case something goes wrong
- Arduino "sleep modes" for power saving
- Arduino Bootloader and using the AVRISP mkII Programmer

Arduino Programming Tutorials:

- Introduction to Programming Videos
- Programming with functions and tabs, using digital pins
- Object Oriented Programming I: Classes and objects
- Object Oriented Programming II: 7 segment 4 digit LED display
- Making libraries
- Arduino Bootloader and using the AVRISP mkII Programmer

Controlling Peripherals Tutorials:

- Controlling I2C bus devices at the example of a I2C enabled LCD display
- Servo motors
- Stepper motors
- Proximity Sensor
- Infrared remote control
- Controlling SPI bus devices at the example of a RFID reader
- 8x8 LED matrix display driven with timed interrupts
- Capacitive touchpad readout using an external interrupt
- Detecting sound thresholds with a microphone
- Reading out switches using pin change interrupts
- Using a SD card for data logging
- Controlling a DC motor with the Arduino

FIGURE 2. The video tutorials on the Makecourse site.

with the collection of learning materials (see Figure 1). In addition, to maximize the efficiency of the class time to work on experiments and testing, the instructors felt the imperative need to secure enough time for students to learn engineering concepts and tools/devices prior to coming to the classroom. Therefore, the Makecourse instructors determined to use a flipped classroom approach by adding online video lectures with voice narration to the online repository of the course.

Naturally, students were directed to view the instructional videos before joining the class activities so that instructors did not have to spend much time to demonstrate how-to skills. The instructors also wanted to use videos of themselves showing the learning goals and necessary design skills to help the students feel more familiar, comfortable, and motivated when they came to the classroom. Figure 2 presents the list of video tutorials on the Makecourse site. All students were required to bring a laptop to the class with the required software packages installed. Software used in the Makecourse was freely available with open source or educational license available from the university. Students also were required to purchase the course kit to ensure that they had the same hardware and tools that they could test and build in the classroom.

The Makecourse With "Art"

The first semester of the Makecourse was well accepted by the engineering students. They reported positive comments in the course evaluation regarding the format of the course that allowed them to initiate their design ideas and creation activities. However, the course instructors found that the final design projects submitted at the end of the first semester lacked high quality visual design. It soon became an issue to resolve because aesthetic design skills are one of the necessary competencies for novice engineering students to grow as expert designers (Goodman, Ewen, & Harriman, 2015). Although the functionality ratings were high in the final project evaluation, the aesthetic design skills were rated medium or less by the instructors.

The initial plan the course instructors devised was to include the aesthetic design component into the existing Makecourse so the course would maintain its format with added artistic components. It seemed a good plan until they realized the difficulty of locating and validating the resources for aesthetically enhanced visual design. As an effort to solve the problem, the course instructors convened with the director of the advanced visualization center at the university and the faculty of the instructional technology program who are the other two co-authors of this paper. After several meetings discussing the issues regarding possible ways to deliver the aesthetic design skill lessons, the team decided to reformat the next version of the Makecourse based on the following rationales.

First, while the design frame of the Makecourse was derived from the STEM-focused activities, it lacked the component of multidisciplinary collaboration using the project-based approach. To expand the STEM-focused activities to include creative aesthetic design components in the Makecourse, our team recognized the need to break the engineering boundary through the tenets of a STEAM approach. Adding "Art" to STEM has been suggested as an effective approach to improve STEM learning (Henriksen, 2014) because the combined approach can support both critical thinking skills and creativity (Clayton & Svihla, 2015), which are necessary for aesthetic design skill development. Successful engineering products in the market are evaluated for both technical functions and ergonomics/user experience. As an approach to promote aesthetical consideration in the engineering design process, Faste (1995) at Stanford University suggested managing an interdisciplinary program with the engineering division and the art department. He asserted that the collaborative approach would promote engineering students' awareness of the importance of aesthetics. There has been a recent movement towards introducing aesthetics in the engineering classroom by converging with other non-engineering disciplines (i.e. National Academy of Engineering [NAE], 2015). Therefore, our first design consideration for the next version of the Makecourse was to use the STEAM approach and create interdisciplinary teams in the Makecourse.

Second, the Makecourse was intended to promote individual design skill development. Each engineering student studied necessary lessons independently through the video lectures and worked on an individual project in the classroom. However, in real life as an engineer, communication among project members including design artists is vital. Hence, our second consideration was to provide both engineering and arts major students with opportunities to work in a team so that they could learn, practice, and improve their communication while collaborating on a team project.

Third, since the flipped learning approach worked well for students, we did not find any reason to go back to the traditional approach. However, we also agreed that pedagogical aspects of the approach needed to be emphasized to better serve students' team efforts. Especially, we noted that two aspects of a good flipped learning approach should contain (a) explicit instruction via lecture videos and (b) collaborative classroom activities. We reviewed flipped learning models and learned that both aspects should be considered separately to fully integrate the flipped learning model into the next version of the Makecourse.

Lastly, for continuous improvement of the Makecourse, we realized the importance of exploring students' course experiences using both quantitative and qualitative methods. We made a plan to conduct a course interest survey and group interviews at the end of the semester in addition to the formal course evaluation. We were particularly interested

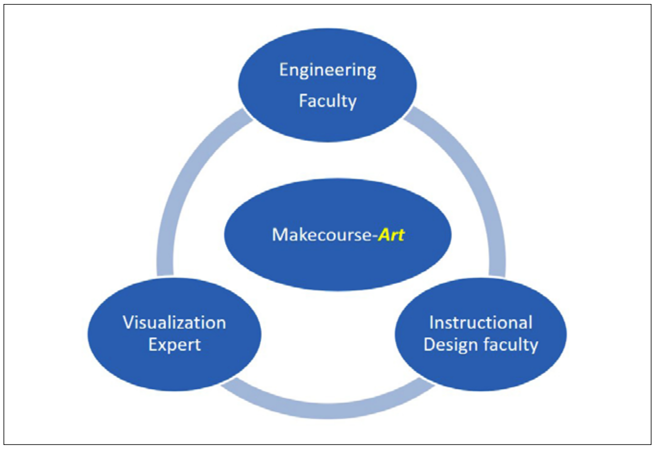


FIGURE 3. The Makecourse-Art design, development, evaluation team.

in understanding what challenges students experienced during the course and how they strove to overcome or resolve such challenges.

Based on the four rationales above, we shared our responsibilities in design and development (engineering instructors, visual design expert) and evaluation (instructional designer) to create a new version of the Makecourse with the "Art" component added to it (see Figure 3). The course was renamed the Makecourse-Art and was first offered in Spring 2015 to students in engineering programs and art programs on campus.

While the Makecourse (earlier version) was designed only for engineering students working on an individual project, the new Makecourse-Art (later version) was designed to incorporate collaborative team projects to promote both aesthetic design skills and functional design skills.

The primary goal of the Makecourse-Art was to invent, design, and build a well-functioning and aesthetically pleasing engineering project using 3D printing models. In the process, students were expected to learn in rapid succession the basics of digital manufacturing, CAD design, 3D printing, electronic control systems, and C++ programming while building a device of their own inspiration. In addition, the Makecourse-Art included aesthetic design-oriented course objectives to promote user-friendly and inspiring design through the creation of a beautiful, appealing and very well functioning product (Giesecke et al., 2000; Ollis, Neeley, & Luegenbiehl, 2004; Uddin, 2015). A particular interest of the Makecourse-Art was to integrate the notion of aesthetic design into engineering design curricula based on student-centered learning theories, and further engage them to acquire these design competencies.

THE DESIGN OF MAKECOURSE-ART

In this section, we describe the details of each component of the Makecourse-Art. We created the Makecourse-Art (a) to encourage students of both the College of Engineering and Arts to work together building engineering products with aesthetic appeal and perfect function and (b) to promote an understanding of each specific discipline by building a shared vocabulary and experiences through collaborative in-class activities. The Makecourse-Art is intended to help students collaborate inventing useful machines and devices and implementing those devices with a focus on aesthetic beauty. Furthermore, the designers of Makecourse-Art adapted two pedagogical models in the construction of the flipped classroom so operative interactions could occur through synchronous and asynchronous communications instructor to student as well as student to student.

We used Bishop and Verleger's (2013) flipped classroom model because it clearly explained how two instructional methods could be combined with matching activities. We

WEEK 5. SEGMENT 2: USE OF FUNCTIONS

This segment focuses on the introduction of functions to organize and streamline the Arduino code and to add structure to the code.

Goals:

- Learn the use of C++ functions.
- Learn the use of Tabs in the Arduino IDE.
- Learn to use buttons as input devices on the Arduino.

In-Class Project:

- Program the 8 bit binary counter using functions. Use a pushbutton to control the counter. This is discussed in the In Class Project video.
- Added activities: Add two buttons, one to activate a 'reset' function, the other for counting backwards. Do it using functions.

Materials for this segment:

- Read the Arduino.cc document about functions and the de-bouncing of buttons.
- Watch the videos on the right.
- Use the Fritzing and iCircuit files posted below the videos.

FIGURE 4. Video lecture/tutorial description.

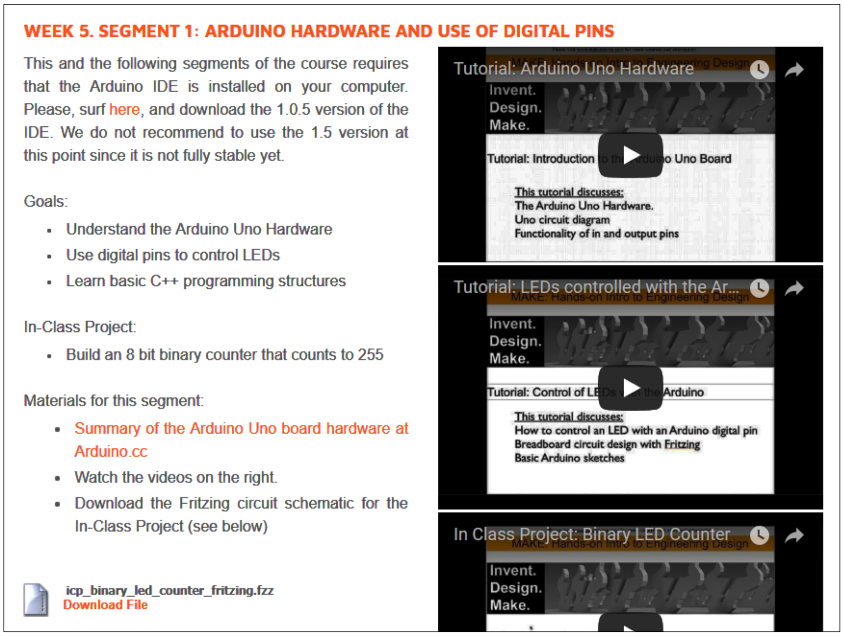


FIGURE 5. Examples of Arduino video lectures on the course Web site (a downloadable file is presented on the bottom of the lecture page).

FIGURE 6. Two categories of CAD introductory videos and example project videos.

particularly focused on delivering explicit instruction via videos and designing interactive classroom activities.

Design of Explicit Instruction via Videos

The main form of instruction in the Makecourse-Art is delivered through asynchronous voice-over video lectures available on the course website (http://www.makecourse-art.com/). To successfully complete the engineering design projects in the classroom, the students are required to view four different topics of video lectures and complete at-home activities before coming to class for hands-on design activities. The videos introduce the basic concepts and topics that students need to learn: Arduino videos, CAD modeling videos, and coding videos. The size of each video lecture/tutorial was determined based on the number of small key tasks students can perform once they view the video. Hence, the length of the videos ranged from a minimum of 5 minutes to a maximum of 18 minutes, depending on the topic and tasks covered. Our goal of providing video lectures was to help students understand nearly every required task they would encounter when working on their design projects in the classroom. The students are strongly encouraged to find the appropriate videos and watch these before asking for help. They are also given the opportunity to ask questions when they work on design projects in the classroom. We used Camtasia, a video recording tool to create video lectures/tutorials and made them available via YouTube for easy access. To help students avoid unnecessary searches, we created a collection of YouTube videos for each topic on a separate Web page on the Makecourse-Art website. Each student can watch the videos individually and/or as a team, and the instructors are able to monitor the students' viewing history by checking the analytics (i.e. the number of views, the time of views, and the location of views) and by asking students pre-activity questions. If the students did not study the video lecture before participating in the class activities, the students are asked to watch it during the class.

Design of Video Resources

In order to complete an engineering project in the classroom, students must be familiar with topics such as Arduino programming, CAD modeling with the Autodesk Maya, Mudbox, and coding skills. We have designed sets of video lectures for students to learn each topic. We intentionally sequenced the videos in order to make them consistent with the design process involved. We also provided individual activity directions so students can use them to practice after they finish watching the video lecture/tutorial.

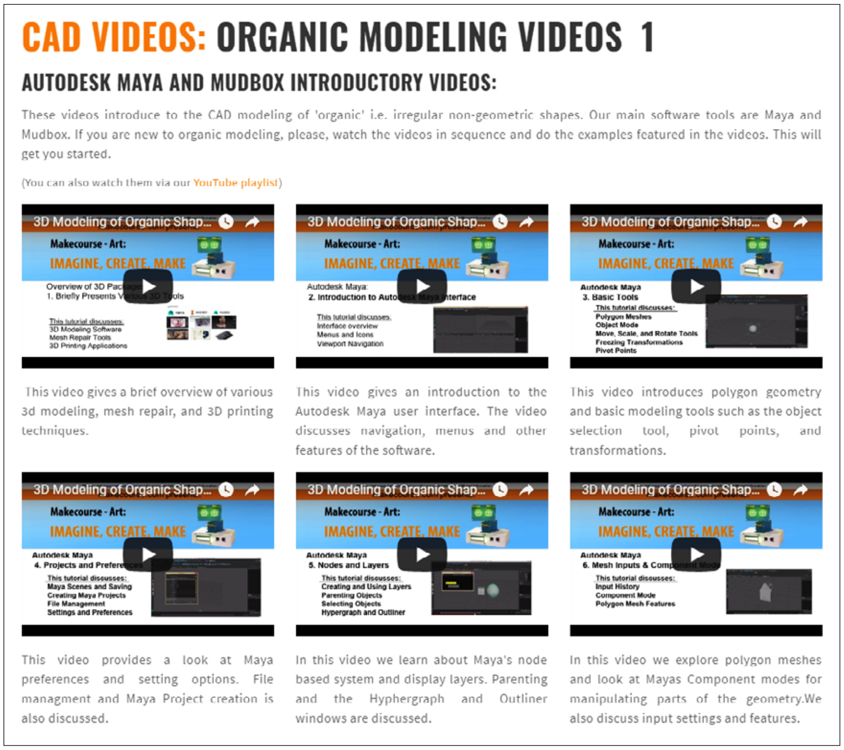


FIGURE 7. Examples of CAD introductory video lectures on the course Web site.

Arduino videos

Arduino video lectures/tutorials were created to cover key topics, such as Arduino hardware (11 videos), Arduino programming (15 videos), and controlling peripherals (13 videos), for students to build necessary knowledge and skills for Arduino circuit design. Each of the video lectures is presented with a description, goals, a link to the in-class project, and the required materials for the activity (see Figure 4). Programming sample files are also provided along with the video so that students can download and experiment with them, as shown in Figure 5.

CAD modeling videos

CAD modeling video lectures introduce modeling of organic shapes (i.e., irregular non-geometric shapes) (12 videos). Maya and Mudbox are the main tools used in the video lectures. For students who are new to organic modeling, the video lectures and example project tutorials (10 videos) are provided in sequence so the students can complete the examples explained (see Figures 6 and 7).

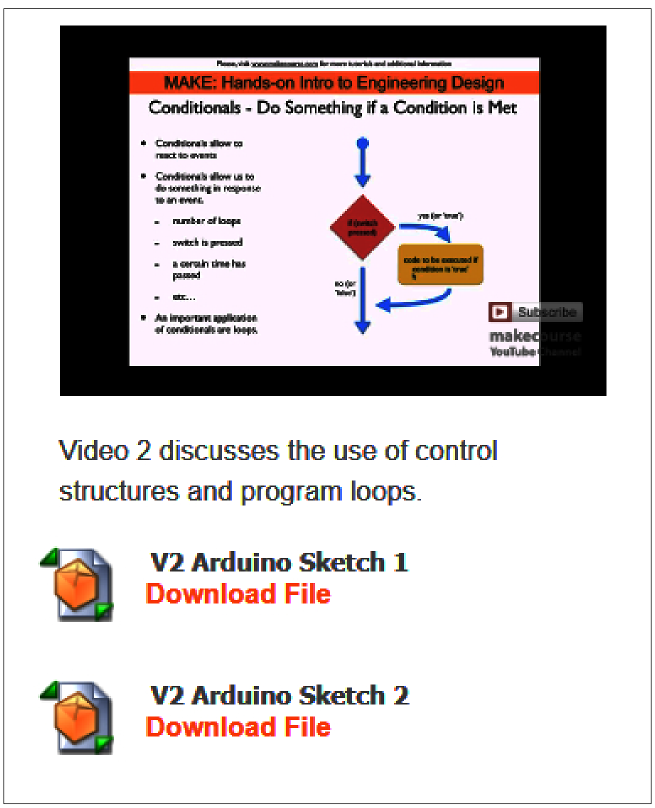


FIGURE 8. Examples of coding video lectures with sample files for home activities.

Coding videos

Coding videos discuss the basic commands and functions of the Arduino C++ language (9 videos). The Arduino sketch files (programing codes) developed are posted below the videos as applicable. They are posted as .zip compressed files, so students are required to unpack the files and then place the resulting folder with the ".ino" file into the 'sketches' folder of their Arduino installation (see Figure 8).

Design of Interactive Classroom Activities

Student teams in the Makecourse-Art are required to build a unique, artistic and creative animated object of their design during the course. All the projects must contain moving parts designed and simulated using Autodesk Maya and printed with 3D printers (see Figures 9, 10, and 11). The students can make use of the Arduino kits and endow their designs with displays, LEDs, remote control, RFID tag activation, audio components or other features. While each project must be unique, the student teams are encouraged to help each other and collaborate to implement their designs.

As Bishop and Verleger (2013) stated, the design of in-class activities is the key to successful flipped learning. In-classroom activities in the Makecourse-Art are based on student-centered learning theories such as peer-assisted collaborative learning and problem-based learning.

FIGURE 9. 3D printing lab located at the Advanced Visualization Center.

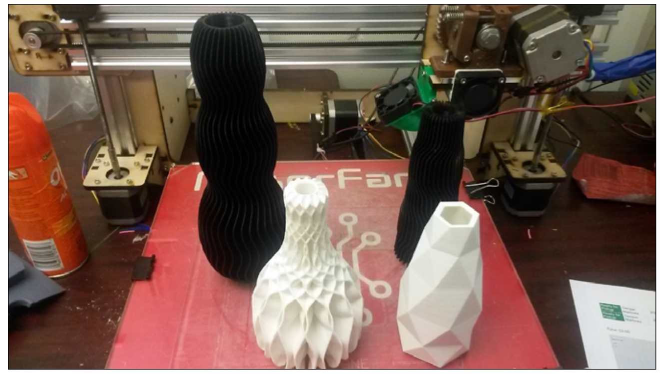


FIGURE 10. Product prototypes designed with 3D printing.

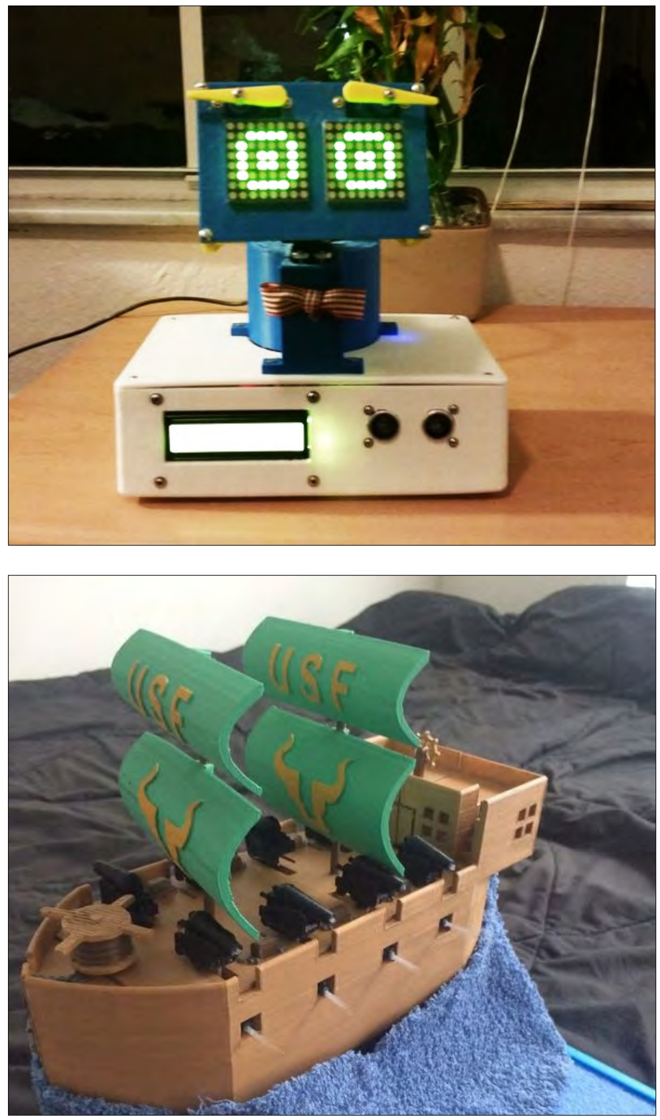


FIGURE 11. Samples of completed projects.

Peer-assisted collaborative learning

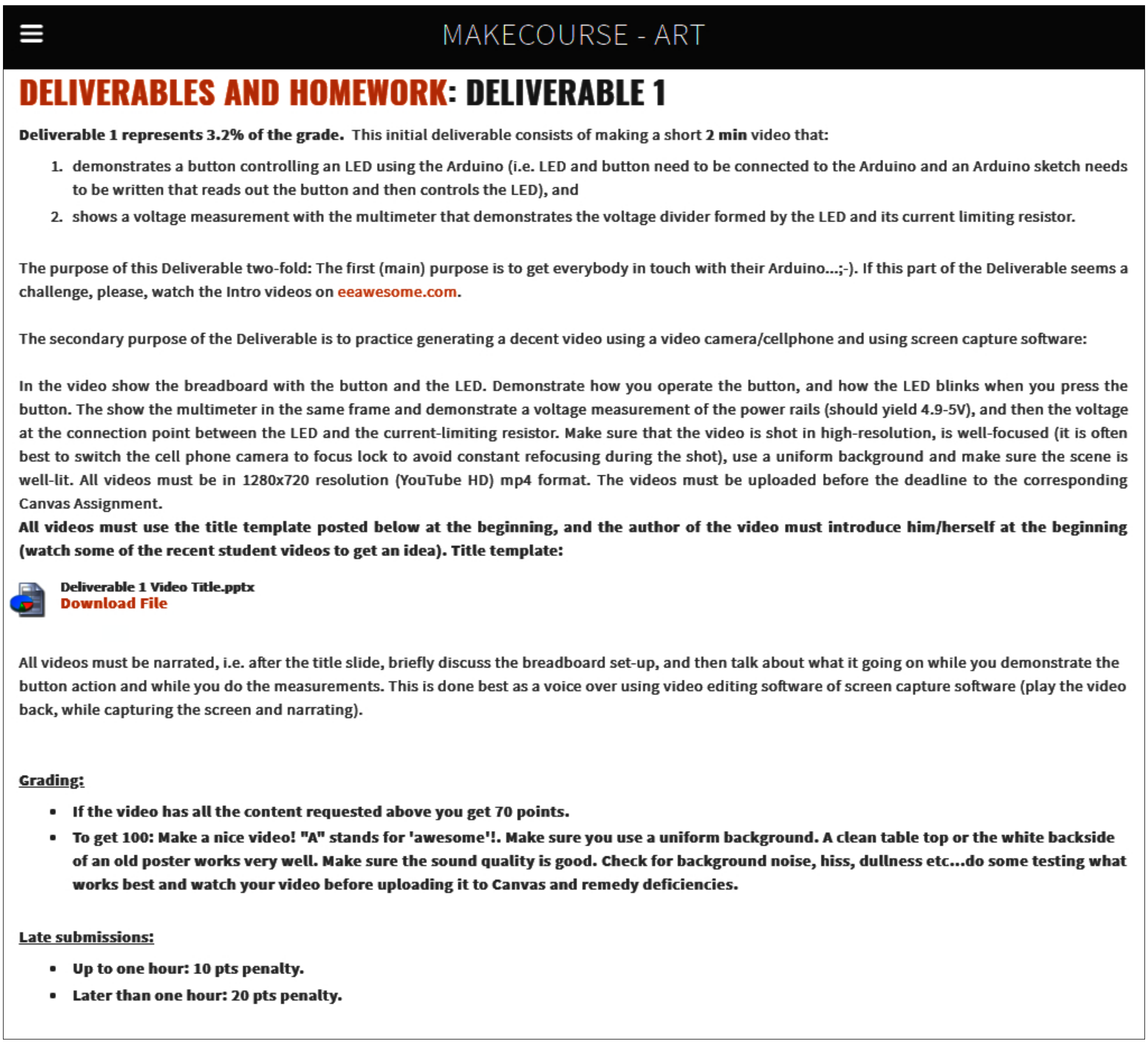
The students work in a team to complete weekly engineering design tasks. The course culminates with an art exhibit during which the resulting design projects are presented at a public art exhibition site (instructables.com). The accompanying instructables and presentation videos are shared in the final project so all students can understand the details of the design process.

Problem-based learning

The design tasks students work on in teams in the classroom are designed using an ill-structured, problem-based approach. It allows the students to be flexible when determining the scope of their engineering projects and further help them identify possible design issues associated with their own work.

Each week, students complete in-class activities and work on the course deliverables as presented below:

- Week 1: Students buy their course kits at the engineering office.
- Week 2: Students learn basic geometric modeling using Autodesk, Maya, and Inventor. They create a model of a static robot using basic geometric polygon meshes (Deliverable 1 due).
- Week 3: Students build an Arduino setup to control 8 LEDs with the potentiometer (Deliverable 2 due).
- Week 4: Students share and discuss, in artistic terms, the design and outcome of their project.
- Week 5: Students use the proximity sensor to determine the distance to an object and then show the measured distance on the LCD display (Deliverable 3 due).
- Week 6: Students work on organic Modeling by using Maya and Mudbox (Deliverable 4 due).
- Week 7: Students learn to use the infrared (IR) remote to control a servo motor (Deliverable 5 due).
- Week 8: Students demonstrate proper fitting and assembly of 3D printed parts.
- Week 9: Students design and build an assembly that has features actuated by a motor and/or servo.
- Week 10: Students show a bouncing dot on the 8x8 LED display that is reflected by the boundaries of the display.
- Weeks 11-16: Students work on the final project (Deliverables 6&7 due).



MAKECOURSE - ART

DELIVERABLES AND HOMEWORK: DELIVERABLE 1

Deliverable 1 represents 3.2% of the grade. This initial deliverable consists of making a short **2 min** video that:

1. demonstrates a button controlling an LED using the Arduino (i.e. LED and button need to be connected to the Arduino and an Arduino sketch needs to be written that reads out the button and then controls the LED), and
2. shows a voltage measurement with the multimeter that demonstrates the voltage divider formed by the LED and its current limiting resistor.

The purpose of this Deliverable two-fold: The first (main) purpose is to get everybody in touch with their Arduino...;-). If this part of the Deliverable seems a challenge, please, watch the Intro videos on eeawesome.com.

The secondary purpose of the Deliverable is to practice generating a decent video using a video camera/cellphone and using screen capture software:

In the video show the breadboard with the button and the LED. Demonstrate how you operate the button, and how the LED blinks when you press the button. The show the multimeter in the same frame and demonstrate a voltage measurement of the power rails (should yield 4.9-5V), and then the voltage at the connection point between the LED and the current-limiting resistor. Make sure that the video is shot in high-resolution, is well-focused (it is often best to switch the cell phone camera to focus lock to avoid constant refocusing during the shot), use a uniform background and make sure the scene is well-lit. All videos must be in 1280x720 resolution (YouTube HD) mp4 format. The videos must be uploaded before the deadline to the corresponding Canvas Assignment.
All videos must use the title template posted below at the beginning, and the author of the video must introduce him/herself at the beginning (watch some of the recent student videos to get an idea). Title template:

Deliverable 1 Video Title.pptx
Download File

All videos must be narrated, i.e. after the title slide, briefly discuss the breadboard set-up, and then talk about what it going on while you demonstrate the button action and while you do the measurements. This is done best as a voice over using video editing software of screen capture software (play the video back, while capturing the screen and narrating).

Grading:

- **If the video has all the content requested above you get 70 points.**
- **To get 100: Make a nice video! "A" stands for 'awesome'!. Make sure you use a uniform background. A clean table top or the white backside of an old poster works very well. Make sure the sound quality is good. Check for background noise, hiss, dullness etc...do some testing what works best and watch your video before uploading it to Canvas and remedy deficiencies.**

Late submissions:

- **Up to one hour: 10 pts penalty.**
- **Later than one hour: 20 pts penalty.**

FIGURE 12. Deliverable #1 instructions, guidelines, grading rubrics, and resources.

DELIVERABLES	DESCRIPTION
#1 (due week 2)	Deliverable 1 consists of making a short 2-min video that demonstrates a button controlling an LED using the Arduino (i.e., LED and button need to be connected to the Arduino and an Arduino sketch needs to be written that reads out the button and then controls the LED) and shows a voltage measurement with the multimeter that demonstrates the voltage divider formed by the LED and its current limiting resistor.
#2 (due week 3)	This deliverable consists of making a short 2-min video that demonstrates a 3D printed part designed with Autodesk Maya (or a software package of your choice that allows the design of organic objects).
#3 (due week 5)	At this point in the course, the functionality and artistic concept of the project design needs to be fully established. All the mechanical components and organically modeled parts have been fully designed and simulated in Inventor and/or Maya. Furthermore, the features and components of the electronic control system have been conceptualized. A block diagram of the control system has been developed. Submit a 3-min video that presents the design of the device featuring an animated Maya 3D model and a description of the electronic control system that you plan to build. Make a block diagram. Explain the electronic components and talk about how they interact to provide the projected functionality of your design.
#4 (due week 6)	At this point in the course, the functionality and artistic concept of the project has been discussed in Deliverable 3. The focus is now on the implementation of the control system. Your 3-min video will discuss the initial design of the control system. Build part of the system that you discussed in the Deliverable 3 video, and make it work on the breadboard. Example: If you use a servo to turn something in your project and you use three LEDs, hook up the servo and the LEDs to the Arduino and make them do what you need them to do in your project. Then, discuss the circuit and how things work. Give a short discussion of your Arduino sketch that makes everything tick.
#5 (due week 7)	This deliverable represents a milestone toward the realization of the final project: At least one of the organically sculpted parts of the project must have been printed and finished (painted, acetone smoothed, etc.) at this point. The 3-min video will discuss one or more organically sculpted parts of your project. Discuss how it was designed in Maya or similar sculpting software and what function it has in your project. Use the (updated) 3D model of your project in the video to discuss the part(s).
#6 (due week 11)	This deliverable represents a significant milestone toward the realization of the final project: The control system hardware has been fully developed at this point, and the Arduino sketch is close to finalization. The 3-min video will discuss the fully developed control system of your project. All major parts need to be demonstrated. Start the video by reviewing your (updated) 3D model and the (updated) control system block diagram. Then, show the corresponding breadboard setup. The parts do not need to be integrated with the 3D printed parts yet, but all components must perform their function. Example: You are using a couple servos to move some parts of your project when someone approaches the device. In the video, the two servos would be hooked up to the Arduino together with the proximity sensor. You would demonstrate the servo action by moving your hand in front of the proximity sensor. Voice over narration would explain how the presented demonstration connects to your project.
#7 (due week 16)	This deliverable represents a significant milestone toward the realization of the final project: The Arduino sketch has been fully developed at this point. The 3-min video will discuss the fully developed Arduino C++ program that drives your project. All major parts of the software need to be discussed. All program lines need to be commented. Start the video by reviewing your (updated) 3D model and the (updated) control system block diagram. Then, show a flow diagram of your code that gives an idea how decisions are made and how the various points of the control system interact with each other and the observer of your project.

TABLE 1. Required deliverables and descriptions of each deliverable.

Although students are required to purchase the engineering design kit, they are allowed to use any software of their choice provided they achieve the assignment objectives. The majority of students used the suggested software and followed along with the demonstration videos. The learning approach requires that both mechanical and organically three-dimensional sculpted models be created and 3D printed to achieve effective aesthetic design and functionality in the final project (Kaplan & Pyayt, 2016).

Course Deliverables

During the 16-week semester, students in Makecourse-Art are required to submit seven deliverables along with a final presentation at the semester's end. Each deliverable represented the key artifact that is necessary to the entire design process. Our decision to have seven deliverables was based on several practical reasons. First, because the Makecourse-Art utilizes a unique approach by having interdisciplinary teams work together, setting a clear timeline was essential for effective communication between the team members and for efficient time management with shared responsibilities. Establishing seven checking points allows students to estimate the required time accurately for a small design task. Focus can be channeled on completing these small, required tasks for each deliverable instead of targeting the final project, which could be overwhelming. It also ensured that students produce a quality design project as they could test and evaluate their deliverable, fixing any identified problems and technical errors before they occur at the final stage. Second, from the perspective of learning motivation, dividing learning tasks into small and manageable pieces has been suggested as one of the effective motivational regulation strategies (proximal goal setting) to help students experience success more quickly and frequently (Schwinger, Steinmayr, & Spinath, 2012). Instead of starting with one huge unmanageable task, successful completion of a series of small tasks helps students feel a sense of achievement and continuing motivation. Third, we intended to offer repeated opportunities for students to understand and prepare their professional quality deliverables. To be part of a professional engineering community, students need to learn how to package their project and deliver a quality presentation. In creating a deliverable for each stage of the design process, we expected students to develop their understanding of an engineering design portfolio and the necessary items to be included. They would learn how to professionally explain their design process including the materials and programs that they used.

Each deliverable contains a video clip presenting the team's working design for the project and a verbal narration of the design details. An example of instructions, guidelines, goals, grading policy, and resources for Deliverable 1 is presented in Figure 12. All the deliverable descriptions are presented in Table 1. The students submit assignments via CANVAS, a learning management system managed by the university. The students work independently as a team and could seek help from the instructors on specific project functions, such as programming and 3D CAD modeling. The instructors provide just-in-time information to support and guide students to complete weekly design projects.

Each team's completed design tasks are evaluated based on pre-determined criteria for the quality of the video presentation and the actual design artifacts. The evaluation also considers how the completed tasks met the presented objectives of the design. Categories such as quality, functionality, originality, uniqueness, and aesthetic design are used to evaluate a completed task.

WHAT STUDENTS ACTUALLY DO IN THE MAKECOURSE-ART

Smith (2010) suggested that multiple views at different ranges including the images of a designed artifact are needed to present a rigorous design case. In this section, we attempt to visually demonstrate students' design experience in the Makecourse-Art using visuals. We share the sequenced design process of one particular project in this section.

Since each team works on one final project, communication among team members is key to success of the course. Class time in week 4 is reserved for students to share and discuss their design and project, using art terms such as color, shape, design, appearance, and expected user experiences. To complete the project, students need to actively engage in communication. They are encouraged to ask questions while working on their projects. When they encounter a problem, students first discuss and try possible solutions among themselves and address issues to the instructor. To create videos, students use mobile devices such as smart phones or tablet computers to record their design process. Screencast tools also are allowed to capture their product logic structure, wiring schema, and 3D designs from the screen.

Figures 13 through 21 show the process of a student team's engineering design experience in the Makecourse-Art. Although it does not cover every detail of the requirements in each step, we believe the explanations help visualize what students actually do in the Makecourse-Art.

First, students brainstorm possible ideas and prepare necessary materials for the project. Figure 13 presents the materials used to create the project.

Second, students work in a team to create the logic of the engineering design (see Figure 14).

Third, students create wiring schematic to design the structure of electronic circuit (see Figure 15).

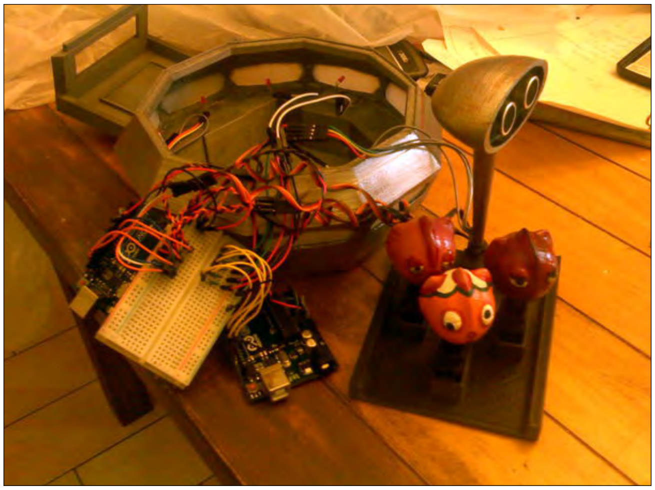


FIGURE 13. Disassembled product showing the used materials.

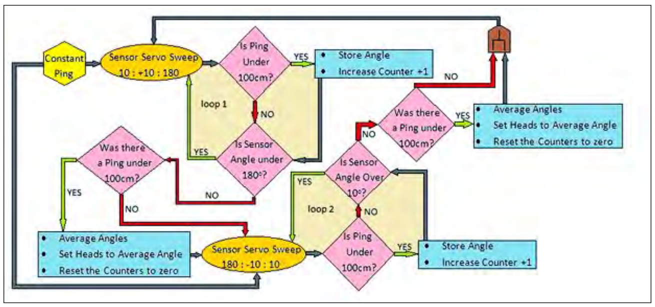


FIGURE 14. Logic structure of the product.

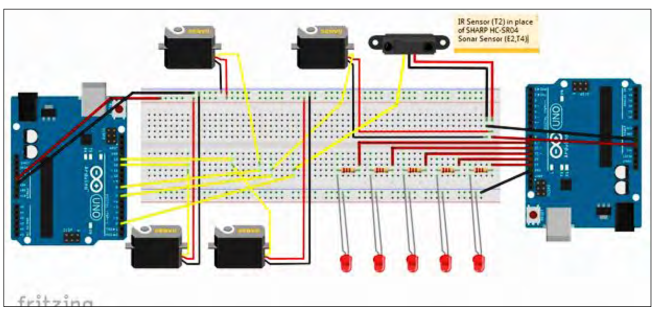


FIGURE 15. Wiring schematic of the product.

Fourth, students collaborate in writing a series of coding for each part of the product (see Figure 16).

During the first four steps, engineering students take a lead in discussion of the overall design process while the arts student informs the team when the visual design needs to be considered and how it can be improved. Students discuss design issues until agreement can be reached.

Fifth, students design a model and render it using Autodesk Maya (see Figure 17).

```
#define ECHOPIN 2                          //digital pin 7 is echo pin
#define TRIGPIN 4                          //digital pin 8 is trigger pin
#include <Servo.h>
void setup()
{
 Serial.begin(9600);                    //setting baud rate
 sensor.attach(7);                      //digital pin 9 is sensor servo
 head1servo.attach(8);                  //digital pin 10 is head1 servo
 head2servo.attach(12);                 //digital pin 11 is head2 servo
 head3servo.attach(13);                 //digital pin 12 is head3 servo

 pinMode(ECHOPIN, INPUT);               //designating echopin as an input
 pinMode(TRIGPIN, OUTPUT);              //designating trigpin as an output
}

 void loop() {
   digitalWrite(13, HIGH);   // start to turn the LEDs on
   delay(100);
   digitalWrite(12, HIGH);
   delay(100);
   digitalWrite(11, HIGH);
   delay(100);
   digitalWrite(10, HIGH);
   delay(100);
   digitalWrite(9, HIGH);
   delay(100);
   digitalWrite(13, LOW);    // start to turn the LEDs off
   delay(100);
   digitalWrite(12, LOW);
   delay(100);
   digitalWrite(11, LOW);
   delay(100);
   digitalWrite(10, LOW);
   delay(100);
   digitalWrite(9, LOW);
   delay(100);
 }
```

FIGURE 16. Multiple coding lines for the product.

Sixth, students follow the painting process using small brushes and sandpaper for the details and adjustments (see Figure 18).

During the fifth and sixth steps, art students lead the design process including the design concept, color theme, shape and size of the items, and the overall attractiveness of the product as well as the possible aesthetic-usability issues.

Seventh, students assemble parts and power supplies (see Figure 19).

Finally, students install Electronics Cradle into the product and complete the project (see Figure 20).

Once the final project is completed, each team is required to create a YouTube video highlighting the entire design process (see Figure 21). It helps them recapture their previous discussions and decision-making.

CHALLENGES OF THE MAKECOURSE-ART

The Makecourse-Art has been offered for three years since the Spring 2015 semester. When the first Makecourse-Art was implemented, one of the obstacles we noticed was a decline in student attendance for in-class help sessions. The instructors noticed that the quality of the deliverables declined as a result. Based on students' comments posted on the course learning management system and the end-of-semester evaluation form, we found several reasons. One main

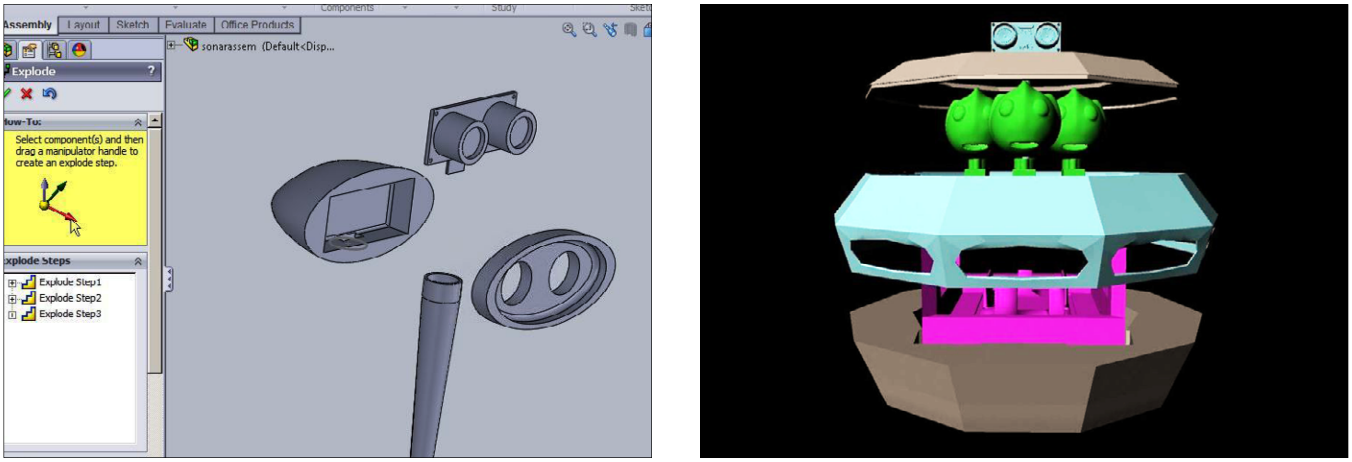


FIGURE 17. Modeling of the product.

FIGURE 18. Painting process.

FIGURE 19. Assembling process.

reason reported was that instructors were unable to address the specific problem areas for individual students. Also, after speaking with some students, we learned that students considered viewing the lecture videos as a replacement of in-class attendance. As there were no follow up activities designed, students were not given the opportunity to reinforce their knowledge and skills after viewing the lecture/tutorial videos.

To address these problems, we considered several instructional design models. We chose to incorporate the four components of the 4C/ID model (Van Merriënboer, & Kester, 2014) including learning tasks, supportive information, just-in-time information, and part-task practice. The 4C/ID model was selected because it emphasizes the part-task practice with just-in-time information to promote procedural knowledge acquisition. Using the supportive information provided through the video lectures/tutorials, students were able to learn the scope of the learning tasks to complete. However, they were not given a chance to practice recurring tasks.

To solve this problem, we designed weekly, small-size home activities that needed to be completed by the end of in-class sessions. We provided in-class help for each team to discuss and solve challenges and issues with the weekly homework. As part of the homework, students were required to demonstrate their completed assignment in person while meeting in the classroom. The instructors created additional videos that demonstrate the necessary learning tasks and components to help students complete the assignments. The videos were provided online as well. Implementing the homework components proved beneficial as the instructors observed an increase in student attendance in the classroom sessions. This led to instructor interventions in the classroom and further improved the quality of the project deliverables.

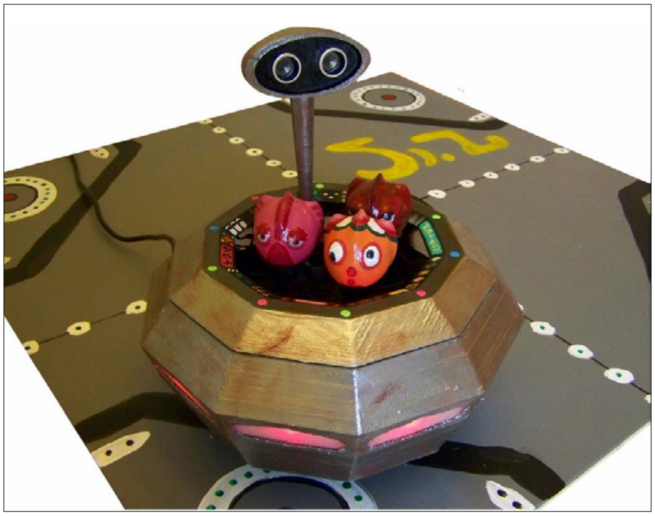


FIGURE 20. Final engineering project completed.

At the end of the fall semester, 2016, we conducted our first formative evaluation of the Makecourse-Art focusing on students' motivational experiences. Students had been reporting their overall course satisfaction and knowledge/skill gains through the course evaluation and course deliverables/projects. Yet, there had been no data gathered to understand students' perceived motivational experiences while progressing in the Makecourse-Art. In the learning context, motivation helps people choose goals to pursue and actively, intensively engages them as they persevere. Since motivation plays the key role in the Makecourse-Art, we were interested in identifying students' motivational drives, motivational challenges, and how they attempted to resolve the perceived challenges. We selected Keller's ARCS motivational theory as a framework because, according to Keller (2010), the concept of motivation is defined in four categories: Attention, Relevance, Confidence, and

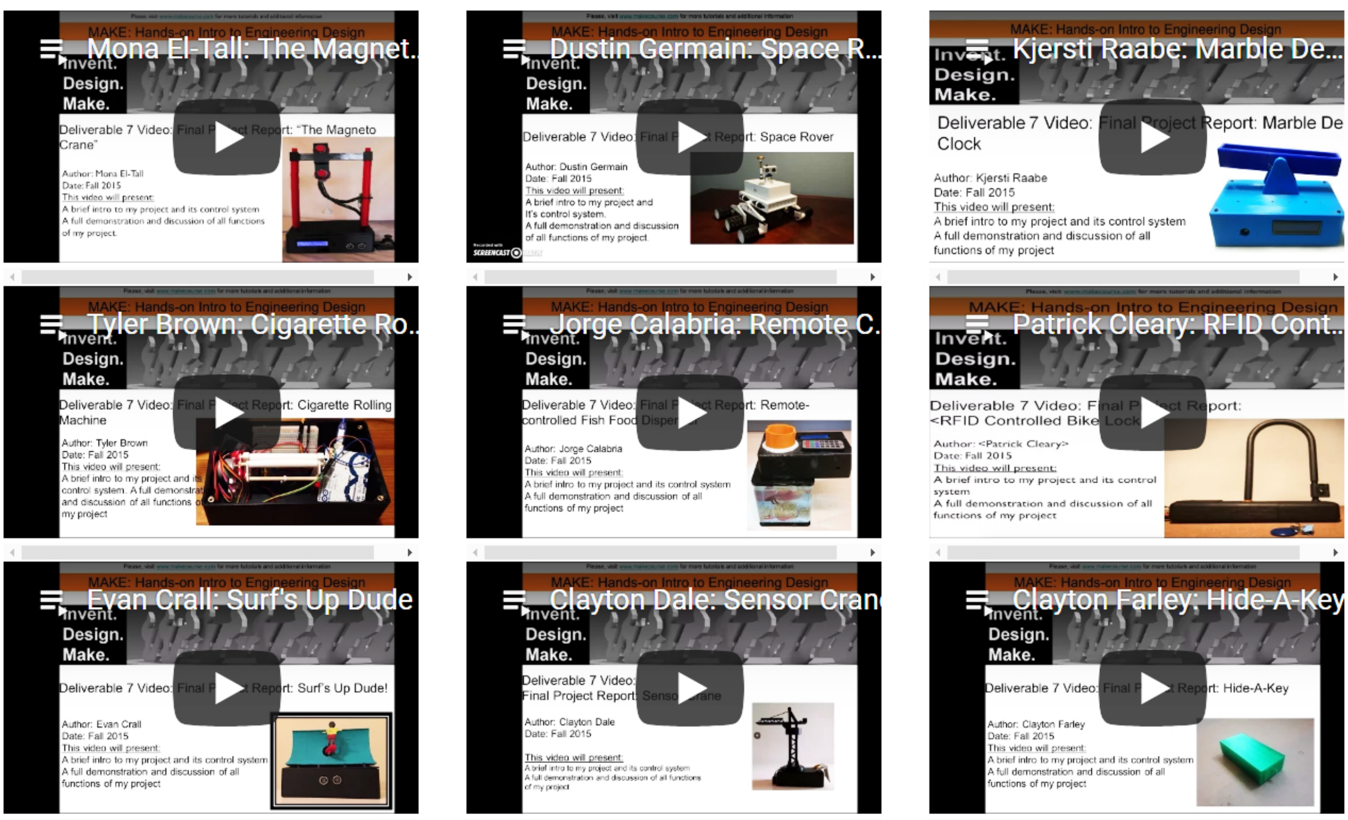


FIGURE 21. Collection of student project samples with video presentations

CATEGORY	DEFINITION
Attention	Capturing the interest of learners; stimulating the curiosity to learn
Relevance	Meeting the personal needs/goals of the learner to affect a positive attitude
Confidence	Helping learners believe/feel that they will succeed and can control their success
Satisfaction	Reinforcing accomplishments with internal and external rewards

TABLE 2. ARCS model categories and definitions (Keller, 2010).

Satisfaction (Table 2). Attention refers to stimulating and sustaining a learner's curiosity and interest while participating in the learning process. Relevance, the second motivational component, helps students meet their personal goals so that a positive attitude can be developed. Confidence is the third motivational component, and it influences students' beliefs regarding their control over their own academic success. Lastly, satisfaction reinforces students' accomplishments with rewards so motivation can be continued in future lessons.

We used the course interest survey (CIS) developed based on the ARCS model (Keller, 2010). The survey responses range from one to five on a Likert scale for eight attention component items, nine relevance component items, eight confidence component items, and nine satisfaction component items.

Among the eight teams enrolled in the Makecourse-Art in Fall 2016, six teams of twelve students (six engineering students and six art students) completed the survey. Figure 22 presents the results of the CIS. Both engineering and art students perceived similar levels of attention, confidence, and satisfaction despite art students' low prior knowledge/skills in engineering design. The relevance component showed the largest difference between the engineering students (4.19/5) and the art students (3.43/5) among the four motivational components. From the survey results, we learned that art students needed to be more informed about their roles in the engineering design projects to increase their perceived relevance while taking the Makecourse-Art.At the end of the survey, the students were invited to freely share any challenges they had perceived while taking the Makecourse-Art and how they overcame them. The most shared challenges were low level of knowledge/skills with the software and meeting the high standard of the required design activities. They also shared difficulties when collaborating with their team partners, particularly, about miscommunication issues. Interestingly, engineering students tended to report concerns regarding their skills in using software, time management, and meeting scheduling issues, whereas art students perceived challenges in making

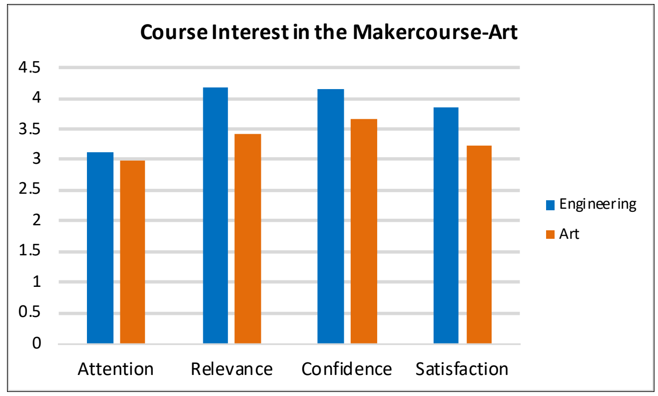


FIGURE 22. Course interest results in the Makecourse-Art.

connections between their art knowledge/skills to the engineering product and making valued contributions to the team.

To overcome the challenges, students stated that they tried to work with their teammates by sharing resources and keeping in communication about new terms and responsibilities. However, some art students stated that although they were expected to work in a team, they sometimes let their team partners lead the tasks while they provided as much effort as they were capable.

From the survey and the group interviews, we learned two lessons. First, from the CIS results and the interviews, it was clear that art students have trouble in understanding how the Makecourse-Art activities are related to what they do within their academic areas. In other words, art students were not able to see the usefulness of the course or how their needs match with the course activities. Their design skills were not used enough or considered as important as engineering skills because, due to the nature of the course, the activities were aimed at creating an engineering product. Although we emphasized both functional and aesthetically pleasing product, the students seemed focused more on the engineering design aspect.

Second, although art students expressed a lower level of perceived relevance than the engineering students, some of them still tried to communicate often with their team partner to understand the software and course requirements. Since one of the goals of the Makecourse-Art was to encourage team communications between engineering students and art students, we considered it positive but learned the need to encourage students to spend more time in and out of the classroom to maintain effective communication channels.

FUTURE DIRECTION

Based on the findings of the formative evaluation on motivational experiences of students in the Makecourse-Art, we are working on several motivational strategies to help improve art students perceived relevance. Keller (2010) suggested three concrete strategies to improve relevance in course design: goal orientation, motive matching, and familiarity. For goal orientation, we are adding motivational messages to help students understand how the course will help them in the future, such as finding a job or participating in an engineering project. The messages will be provided individually via emails or collectively via course announcement. For motive matching, each student's reason for taking the Makecourse-Art will be identified on the first day of the class, and guidance will be provided to match the course activities and the identified needs. Also, for familiarity, we will continue to provide individualized help sessions so students can learn from the experts who understand each student's unique challenges. At the end of Spring 2018, the second formative evaluation will be conducted to examine how students' motivation, especially art students' perceived level of relevance, has changed.

CONCLUSION

In this paper, we introduced a case of the Makecourse-Art in a higher education setting. We described how the Makecourse-Art has progressed from its earlier version of the Makecourse, and what design decisions have been made to overcome identified challenges. We also explained the pedagogical foundation of the Makecourse-Art, the structure and components of the course materials, and step-by-step description of students' engineering design experiences with visuals and rationales of the decisions.

For both engineering and art students, the Makecourse-Art has been a great approach to offer them a place to collaborate, communicate, and experiment on engineering projects. Although students reported several challenges while working in a team, they eventually showed an overall increase in their understanding of the aesthetic design of engineering products. We expect our design case will provide useful tips and strategies for administrators and scholars who want to initiate the interdisciplinary approach in designing a maker space. Our design decisions and concrete examples/directions will also help readers gain useful guidelines on how to design the maker space course and student design learning experiences. To further expand the Makecourse-Art model with a flipped learning approach to other engineering classrooms, the target course curriculum/practices and design goals need to be clearly defined and analyzed so that intended design activities can be seamlessly intertwined with learning goals.

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