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Establishing a Virtual Makerspace for an Online Graduate Course: A Design Case

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ESTABLISHING A VIRTUAL MAKERSPACE FOR AN ONLINE GRADUATE COURSE: A DESIGN CASE

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This design case discusses key steps taken to establish a virtual makerspace for students enrolled in an online graduate course on informal learning. Two key design decisions are elaborated around (a) the selection of appropriate projects and packaged materials that distance education students can receive by mail to participate in making, and (b) the choice of an online platform for distance education students to document their design processes for assessment purposes and peer interaction and learning. This design case is relevant to a variety of online communities who may wish to engage in maker activities as well as isolated face-to-face communities or individuals who may not have local mentors to support informal making and could, therefore, benefit from online connectivity to an expert or peer support. To promote replication of the design, materials and community tools to support making among geographically dispersed makers are detailed.

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INTRODUCTION

In the spring and fall of 2016, two sections of a new online course titled "Technology and Informal Learning Environments" were taught to graduate students in our College of Education's program in Learning Design and Technology. Students who plan to serve in technology leadership roles in varied settings--schools, non-profits, higher education, and business--enroll in this program and take this course. The course provides an introduction to a range of informal learning programs that heavily leverage technology (e.g., robotics clubs, computer clubhouses, coding camps), and includes several projects related to one specific type of informal learning program in makerspaces.

Makerspaces are learning environments in which students pursue projects of personal interest at the intersection of craft and technology, utilize shared materials and equipment, and collaborate with peers in a community of makers (Oliver, 2016). While making has traditionally been carried out as an informal activity in museums, private facilities, or school libraries, it can increasingly be found in formal academic classrooms as teachers learn effective ways to support curricular-focused instruction with maker technologies and practices. Makerspaces serve different audiences across the life span and vary quite widely in terms of media/project emphasis areas, the length of time a maker will work on a given project, and the structure of the community (Sheridan et al., 2014). Makers engage with varied media and technologies to create different products such as programmed e-textiles (Kafai et al., 2014), programmed robots (Fitton, Read, & Dempsey, 2015), 3D-printed or laser-cut building models (McKay, Banks, & Wallace, 2016), multimodal compositions and stories (McGrath & Guglielmo, 2015), and more.

In planning this course, it was decided that the distance education students should have the opportunity to participate in a makerspace and making activities to fully understand the community culture and design processes associated with the maker movement. The challenge for course designers, then, was how to establish a virtual makerspace when these spaces and their supports are typically physically sited. Educators are beginning to ask how we can support makers

in sharing their work and giving or receiving feedback in online spaces (Litts et al., 2016), and this design case introduces one approach to support making at a distance.

This design case discusses two primary design decisions that were made to establish a virtual makerspace for an online course on informal technology environments. The first design decision involved selecting workable maker projects and materials that could introduce the distance education students to common makerspace programming. The second design decision involved selecting strategies to elicit and document students' design processes as they worked on these maker projects while providing support for a community of online makers to share and learn from one another. A third decision is briefly described that does not directly relate to the establishment of a virtual makerspace, but rather to preparing future informal learning leaders by supporting discussions of important makerspace topics in the course (e.g., outfitting spaces, facilitating making).

COURSE COVERAGE AND MATERIALS

The first major design decision involved selecting an appropriate set of projects and sequence to introduce enrolled students to activities commonly conducted in after-school makerspaces. This coverage decision was necessarily made in parallel with a materials decision in regards to items that could be easily packaged and mailed to distance education students.

Six projects were selected for students in the course, in three core areas of circuitry, robotics and physical computing, and fabrication. The decision to engage students in these project categories was not random but rather informed by the course instructor participating in a variety of makerspace-related workshops over 18 months that provided the opportunity to try out different projects, work with materials, and come to an understanding of common makerspace project areas to reintroduce in the course. The instructor's first exposure to any making was also virtual/distant, as sponsored by The Exploratorium (San Francisco) in their massively open online course on *Tinkering Fundamentals: A*

Constructionist Approach to STEM Learning. This free course with a low-cost kit of parts introduced common circuitry projects with conductive copper foil and thread, as well as low-tech/approachable robotics in the form of a simple scribbling machine/spinbot. The instructor attended additional making workshops in his own campus library's makerspace and a makerspace in a nearby college of education, including sessions on conductive thread/sewing, TinkerCad design, 3D printing, and coding with Scratch. The instructor was also able to attend a free EdCamp at a nearby college where making was a focused topic of discussion. The availability of free instruction to inform this course was plentiful from national/local and online/face-to-face sources. Further, these courses and workshops commonly referenced or used third-party lesson plans and step-by-step guides that were repurposed to support the informal learning course. A summary of each project is now presented with a description of materials and activity guides provided.

The first project students complete in the course is a simple circuit drawn on paper using conductive ink. A "conductive poetry" activity was identified from the community-based Instructables website where members share projects with one another (see http://www.instructables.com/id/Conductive-Poetry/). The activity involves sketching a short poem with conductive ink, and breaking the circuit in one or more sections of the poem where a small paper cup with an image on top is inserted to replace a word or words, and a LED is inserted under the cup to light up the image. Materials for this activity include (a) construction paper; (b) a tube of conductive ink; (c) three or four LEDs; (d) regular office paper, glue, and markers to make a paper cup with image; and (e) a power supply such as a AA battery pack and batteries connected to the poem with alligator clips, or a coin cell battery holder and battery. Materials and sample conductive poems created by students in the course are shown in Figure 1.

The second project students complete is a greeting card with an internal copper foil circuit that lights up one or more LEDs. An activity guide created at The Exploratorium
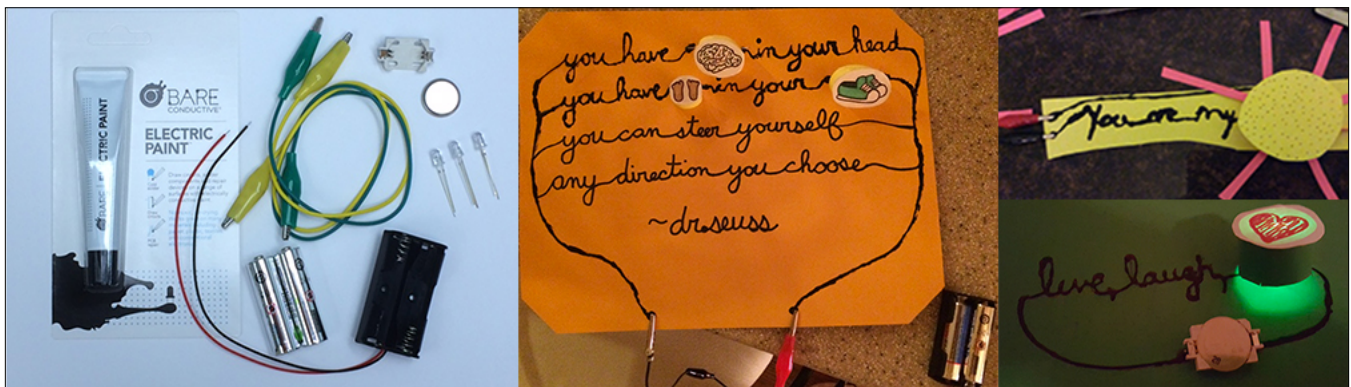

FIGURE 1. Conductive poetry project: materials used and project examples.
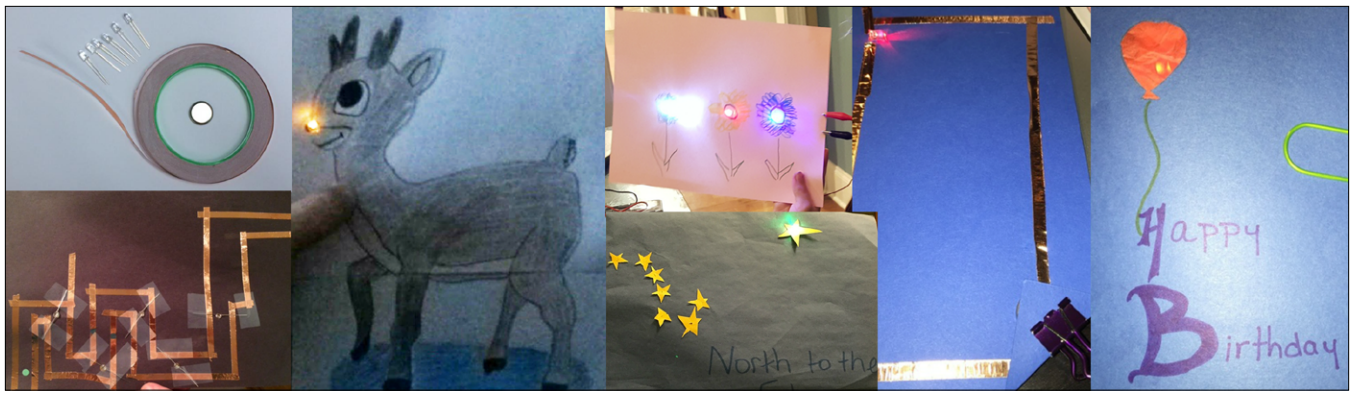
FIGURE 2. Copper foil circuit greeting card project: materials used and project examples.

FIGURE 3. Soft circuit brooches project: materials used and project examples.

supports students working on this project (see http://tinkering.exploratorium.edu/paper-circuits). Students begin by creating a switch that folds over each side of a coin cell battery, and then constructing a copper foil circuit that extends in two directions from this switch. Students must complete some calculations to ensure whatever design they wish to light up on the front of their card is properly aligned with the circuit structure and LED in the back of the card. Materials for this activity include (a) conductive copper foil tape, ideally with conductive adhesive; (b) three or four LEDs; (c) card stock or construction paper; and (d) a power supply such as a coin cell battery. Materials and sample greeting cards created by students in the course are shown in Figure 2.

The third project students complete is a soft circuit or a conductive wearable brooch. A soft circuits facilitator guide created by Lovell (2016) supports students working on this project. In this project, students use conductive thread to sew a LED to a battery pack. Materials for this activity include (a) conductive thread and a sewing needle; (b) two or three LEDs, preferably sewable LEDs that come with positive/negative holes to loop thread around; (c) felt, to cut into a brooch pattern or pre-cut felt pieces; (d) a smaller power supply such as a coin cell battery holder and coin cell battery, preferably a sewable coin cell battery holder with positive/negative holes to loop thread around; (e) a brooch pin back;

and (f) hot glue to fasten felt pieces together and felt pieces to battery pack. Materials and sample soft circuit brooches created by students in the course are shown in Figure 3.

Moving to the second project area of robotics and physical computing, the fourth project students complete is a simple spinbot or scribbling machine. This project was inspired by an activity promoted in the aforementioned Exploratorium MOOC on tinkering. Students attach markers to a container of their choice, then attach a powered rotor with some type of propeller to the top of the container, and study the resulting spinning motion and scribbling that vary depending on many design variables that can be discussed. Materials used in this project include (a) some type of container such as a plastic cup that the student provides; (b) a rotor with positive/negative leads that are attached to a AA battery with a wide rubber band; (c) several markers; and (d) something to use as a propeller on the rotor such as a glue stick. Materials and sample spinbots created by students in the course are shown in Figure 4.

The fifth project involves students in physical computing. Students recreate several simple computer programs in Scratch, connect their computers to an external PicoBoard, and then use different sensors on the PicoBoard (e.g., light, sound, button push) to make their computer programs react in different ways to external inputs. While numerous
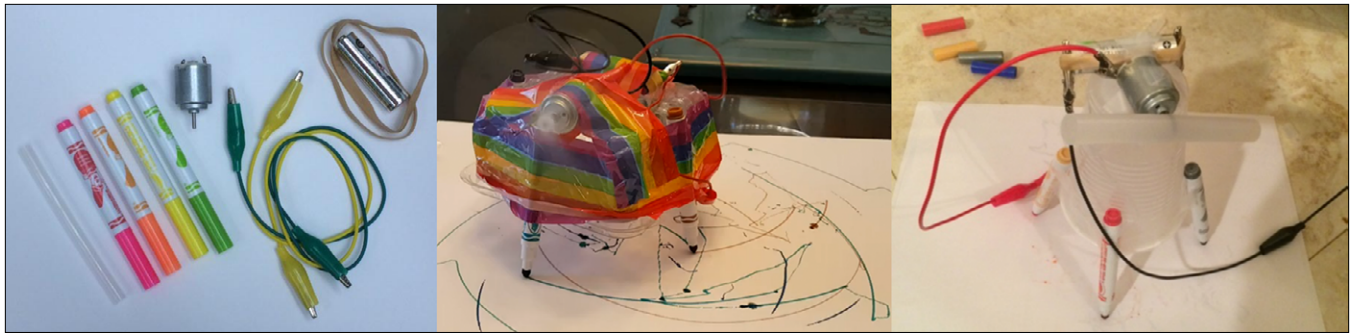
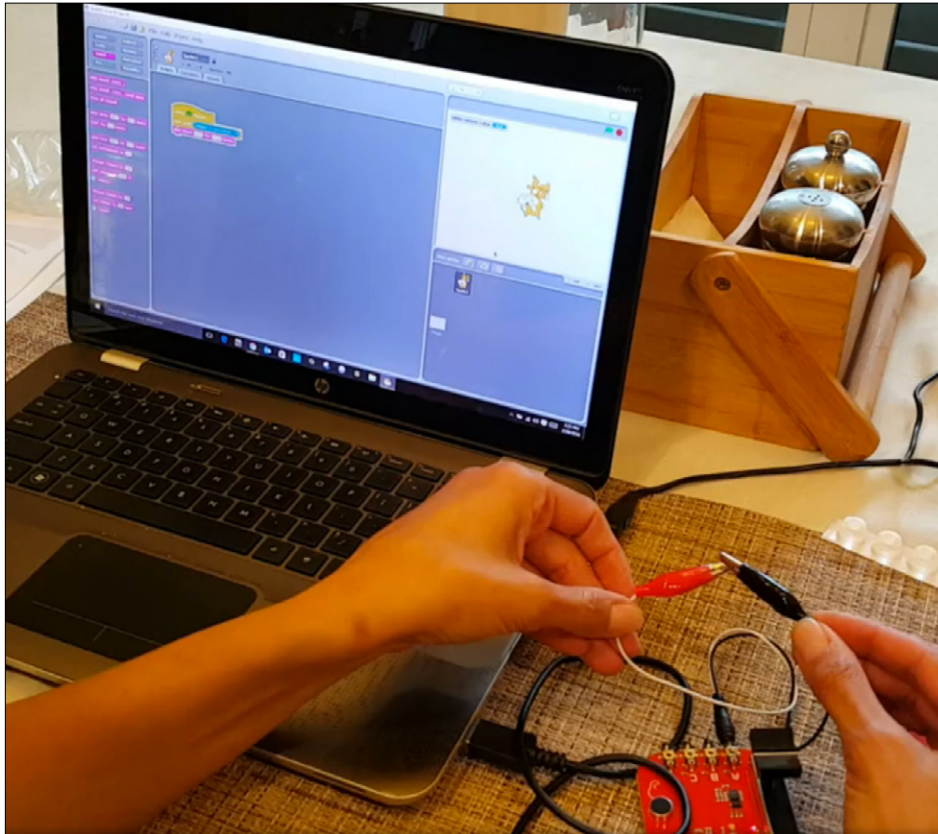**FIGURE 4.** Spinbot project: materials used and project examples.

FIGURE 5. Scratch program interfacing with PicoBoard.

guides and sample projects for the PicoBoard are available, an activity guide with six projects that made use of different sensors supported our students (Playful Invention, 2010). Materials used in this project include (a) a PicoBoard and (b) a mini-USB cable. Figure 5 illustrates one of our students' Scratch programs interfacing with a PicoBoard.

The sixth and final course project moves into the category of fabrication, with students using the TinkerCad program to create their own 3D designs and .stl files for 3D printing. To guide students in using TinkerCad, we leverage the AutoDesk's Project Ignite website that provides step-by-step guides for creating different 3D models in TinkerCad (see https://projectignite.autodesk.com/app/browse/). Students

choose two design projects from this website to recreate in TinkerCad. Materials used in this project include a two-button, scroll-wheel mouse for more easily manipulating objects in TinkerCad. In the spring 2016 iteration of this course, the instructor used a mini-grant to purchase a 3D printer with the intent of printing students' .stl files and mailing them a physical copy of their designed objects. Unfortunately, the first two 3D printers purchased were low quality and difficult to operate--both were returned to the manufacturers. The instructor received a recommendation for a reliable 3D printer from his campus library's makerspace (i.e., the LulzBot Mini), and subsequently purchased this item in May 2016. The printer worked very well as advertised, but unfortunately too late for students in the spring 2016 section of the course. In future sections of the course, the instructor will offer to print objects for enrolled students who do not have access to their own 3D printer. The instructor has also purchased a mini-tripod to capture time-lapse video so that students can view a video of their object being printed. Figure 6 illustrates some of the TinkerCad designs recreated by students in the course.

A materials list was created for the aforementioned projects to bulk order parts for students enrolling in the course. The first four projects required simple materials, while students were asked to purchase their own physical computing PicoBoard for project five (which costs around $45.00) and the free online TinkerCad program was used for project six. At our university, students pay an Educational Technology Fee (ETF) each semester, and the instructor applied for and

FIGURE 6. Example TinkerCad designs.

received associated funds to cover the materials costs for projects one through four, along with packaging materials for mailing (i.e., boxes, bubble wrap, plastic zip-top bags). The materials for each of four projects were placed in plastic zip-top bags of different sizes, so students could easily identify which materials went with which project. Creating a kit of parts for each student is beneficial for three reasons: (a) the instructor as a single purchaser can take advantage of bulk buy options, then divide materials, for significantly reduced costs; (b) the instructor as a single purchaser can pay multiple vendors for shipping once instead of requiring each student to pay multiple shipping fees; and (c) a common kit of parts ensures each student is working with the same quality materials that will likely respond similarly to manipulation and stress, and students can discuss materials usage knowing their peers are working with the same items. The total per person cost of this bulk buy was a reasonable $45.22 per student, less than each student pays in technology fees to take a three-credit hour course.

After learning about some of the common makerspace project areas in circuitry, programmed robotics and physical computing, and fabrication, the choice of projects to include in the course was made by the instructor. The choice of projects also received some validation from the local college of education computing and technology committee who approved the request for educational technology fee funding to purchase materials kits for enrolled students. The rationale for including these projects in the course was based on the understanding that general circuitry is an underlying concept in robotics and programmed physical computing boards with supplemental sensors, and programming and 3D designing are technical skills that graduates of our program need to know about to lead their own after-school technology environments. Projects were sequenced in this order, as some simple circuitry concepts are applied when wiring spinbots and physical computing boards, while some knowledge of robotics can be put to use in fabrication design programs if students opt to create and 3D print new parts to modify their robots.

Another criterion for selecting this particular mix of projects was customizability. As illustrated in Figures 1 to 6, students had the flexibility to customize particular projects to suit their personal interests--and they did. Makerspaces commonly encourage students to pursue projects of personal interest, and these projects illustrate how personalization can be supported. In the conductive ink project, students could select a quote or lyric from a favorite author, historical figure, or musical artist. One student chose a beloved Dr. Seuss phrase, and another student chose a quote from a favorite football coach. In the copper foil project, one student chose to represent the North Star on a greeting card she created with her daughter, drawing on a book her daughter was reading in school about fugitive slaves who relied on the North Star for navigation. In the soft circuit project that guided students to make a flower brooch, student designs reflected considerable differences from one that was sewn into a piece of fabric to display a stem for the flower, to two designs that incorporated clips to be worn in the hair rather than on clothing. Allowing students to choose a container for the base of their spinbot led to considerable variability in that particular project. A range of plastic cups and storage containers were integrated into designs, along with wooden and metal boxes that students quickly found out were too heavy to allow spinning motion. The least variable project was student programming of the PicoBoard, but only because students worked through a series of common, scripted projects. In documenting their projects with the tool VoiceThread, students did discuss options for modifying their programs, so the opportunity to customize this project is present if the assignment pushes students to create an original program. Finally, students were able to select 3D design projects of interest from the Project Ignite website,

and these choices varied widely from jewelry and customized key chains to scientific objects like planets, seashells, and computing boards.

The decision to engage with these particular projects was judged to be successful by student thinking elicited and anecdotal evidence of materials usage by different audiences. In this course, the instructor is interested in projects that are not too easy, but rather require students to solve problems when materials do not behave as anticipated. Troubleshooting is an important skill for future facilitators who will be helping students work in these project areas in makerspaces where trial and error and retrial is an accepted part of the culture.

To determine if these projects did indeed stump students and prompted some problem solving, the instructor and teaching assistant completed a critical incident analysis of student design documentation in spring 2016 (n=6 students) to identify scenarios where a problem was encountered and had to be resolved (e.g., the LED would not light, the spinbot would not spin, the elements in a 3D design would not align). The critical incident technique dates to World War II and observing pilot behavior to better understand errors and generate a statement as to "the requirements of the activity" (Flanagan, 1954). Critical incidents can be routine or commonplace, but they become "critical" when they "cause us to think and reflect, which leads to learning about ourselves or others... or about processes…." (Crisp, Green-Lister, & Dutton, 2005, p. 14).

Our critical incident analysis started by creating two identical Google Spreadsheets where each column represented the Voicethread documentation created by one student for a given project (i.e., six columns per student, pertaining to the six projects completed), and where each row represented a given slide in a student's Voicethread documentation. The first and second authors each took one of these identical spreadsheets and analyzed each Voicethread documentation slide from each project independently, filling in cells of the spreadsheet with notes as to the critical incidents a given project elicited (e.g., "neither of two LEDs lit up, so she went back over thin areas and filled them in, and made bigger circles where alligator clips connect to the circuit line"). After initial coding, a shared spreadsheet was created for each project with three columns--one for the first author's notes, one for the second author's notes, and one for discussion. When the notes of both coders concurred that an incident was present on a slide (n=102 across six projects), the adjacent third column was shaded green. When only one coder identified an incident, the third column was shaded red, and the item was discussed to reach consensus as to whether the slide represented an incident or not (n=101 across six projects). Only a few items were discarded after discussion as not representing critical incidents.

In the process of comparing notes, we expanded our definition of critical incident beyond just problems encountered that require a response/decision (e.g., "thread unravels, uses lip balm as a waxy substance to hold ends together;" n=137), to also include events that lead to a general realization about a pattern or rule (e.g., "realizes rotor won't generate motion without glue stick attached;" n=46), and events that verify one's thinking is correct/on target (e.g., "expresses excitement when slider sensor on PicoBoard causes spite to move;" n=16). Just as an error can provide a student with valuable information, so too can a moment of inspiration or evidence of success.

When looking at the n=137 problem incidents generated across projects (see Table 1), it is noteworthy that almost all projects did elicit some problem solving from students. The fifth PicoBoard project, although seemingly more technical, was found to be less problematic overall with fewer design variables at play (i.e., re-create this computer program in Scratch to interact with your PicoBoard sensors). Likewise, the computer-based design of 3D objects in TinkerCad following well-outlined tutorials (project six), led to fewer problem incidents than the hands-on making of ink, foil, and conductive thread circuits, and spinbots (projects 1 to 4). This is an interesting result because one might assume the "arts and crafts" nature of circuit projects (create a light-up greeting card) is less cognitively taxing than programming or drafting 3D models, but if the latter are well-structured with step-by-step instructions, that may not be the case.

	Pr. 1	Pr. 2	Pr. 3	Pr. 4	Pr. 5	Pr. 6
St. A	5	2	6	6	1	7
St. B	8	2	5	6	3	5
St. C	2	2	4	5	3	1
St. D	8	5	5	2	3	1
St. E	6	4	2	4	0	3
St. F	2	6	4	7	0	2
Totals	**31**	**21**	**26**	**30**	**10**	**19**

TABLE 1. Critical problem incidents discussed by Students A to F in Projects 1 to 6.

Some of the more common problem incidents we coded for each project included the following. In project one (conductive ink), students expressed difficulties in (a) constructing appropriately-sized paper cups to place over their LEDs; (b) correctly aligning positive/negative ends of LED with positive/negative ends of battery pack; and (c) getting ink to conduct electricity because it was not dry, not thick enough, or the circuit was too long. In project two (copper foil circuit), students expressed difficulties in (a) aligning visible elements on the front of a greeting card (message, LED) with the copper foil circuit hidden underneath; (b) getting multiple LEDs to light up when copper foil circuit was pieced together with cut/torn strips leading to conductivity issues; and (c) applying the proper power/voltage to the card so as to avoid burning out the LEDs. In project three (soft circuit), students

expressed difficulties in (a) threading thick conductive thread through small needle holes and sewable battery packs, and (b) getting LEDs to light due to crossed threads and short circuits or improper alignment of positive/negative ends of LEDs and battery packs. In project four (spinbot), students expressed difficulties in (a) designing the spinbot to secure and/or hide multiple elements (rotor, battery pack, alligator clips) without pieces coming loose or getting in the way of propeller; (b) jutting the rotor and propeller far enough away from the base to avoid collisions; and (c) getting the spinbot to move and/or spin in a circle due to weight issues or improper propeller placement. In project five (PicoBoard programming), students expressed difficulties in (a) interfacing issues between the physical computing board and the Scratch interface; and (b) modifying programs when the Scratch sprite did not react as anticipated (e.g., doesn't spin or move as expected in response to physical inputs). In project six (TinkerCad 3D design), students expressed difficulties in (a) following tutorials that left out some steps or made assumptions about what students would know (e.g., how to group/align objects); and (b) modifying objects in the interface (e.g., sizing, combining).

That the selected projects were generating problem incidents, and that students were able to resolve those incidents, provided a good indicator that projects were posing an appropriate level of challenge. Further anecdotal evidence of project effectiveness was derived from student C who appreciated the projects enough to request a copy of the associated materials and vendor lists to help set up a summer maker camp at a K-12 school. Also, students A, E, and F, all attempted to make projects with their own children, as the instructor encouraged them to do. Student A attempted four projects with children, student E five projects, and student F one project. While there were problem incidents, all of these young children were able to complete the projects with the aid of their adult/parent facilitator. This result provided further evidence that projects were manageable across age ranges, and that graduate students enrolled in the online course were capable of project facilitation.

A few changes were made to the original decisions noted earlier for the second section of the course. In the first section, students were shipped complete spools of copper foil tape and conductive thread, while only a small amount of each was used for course projects. In the second section, students were only given strips of tape and thread to help limited supplies go farther as more students hear about the course and enrollment increases (up from six to eleven enrollees in the second section). In the second section, it was also noted that students do not need a separate power supply for every project. Rather, they can re-use the same power supplies/batteries across multiple projects (e.g., a dual AA battery holder and two AA batteries, a sewable coin cell battery holder, and a coin cell battery).

Also important to note are the changes we did not make between teaching the first and second sections of the course. For example, we still do not include common household items such as glue and tape in the mailed kits. The assumption that students would have access to these items was found to be true. Interestingly, it was also found that students had access to unique items in their homes that gave their peers ideas for creative resourcing and helped with troubleshooting common problems. For example, in creating small paper cups for project one, a student made the simple suggestion to wrap paper strips around a marker to form a perfect circle. Also, in troubleshooting project two, one student had access to a multi-meter that was useful to determine where her copper foil circuit was losing conductivity. This student was able to inform her peers that conductivity tends to be lost at the connection points where the tape is torn and overlapped.

Another change we did not make in the second section of the course was our presentation of projects to the students. Even though we discovered from the aforementioned critical incident analysis what is likely to go wrong as students work on this set of projects, and warning students about these common errors could have saved them some time and frustration, it also would have "given away the answers" so to speak, instead of allowing students to tinker and discover best approaches on their own. Students commonly run into small problems while working on these projects (e.g., it takes a long time for conductive ink to dry before it conducts electricity, the connection points on torn copper foil tape are usually where the circuit loses current, the propeller on the spinbot creates more motion/spinning if it is offset). Allowing students to discover solutions to these issues gives them practice in troubleshooting as well as a sense of pride in sharing their solutions with the maker community, while over-explaining what could go wrong would undermine these positive outcomes.

CAPTURING THE DESIGN PROCESS ONLINE

The second major design decision for this course involved identifying strategies that would allow online students to document and share their design processes as they worked on a series of maker projects. While a face-to-face instructor can observe students, make assessments of success, and promote student-student interaction as they work on maker projects in a physical makerspace, an online instructor must rely on digital documentation and interaction.

To support digital documentation and interaction, a decision was made to use the online tool VoiceThread (http://VoiceThread.com). This tool allows students to share photos or videos of their design process from beginning to end, and annotate each of these artifacts using their voice or typed comments. In the learning management system utilized for the online course, a wiki was set up for each maker project
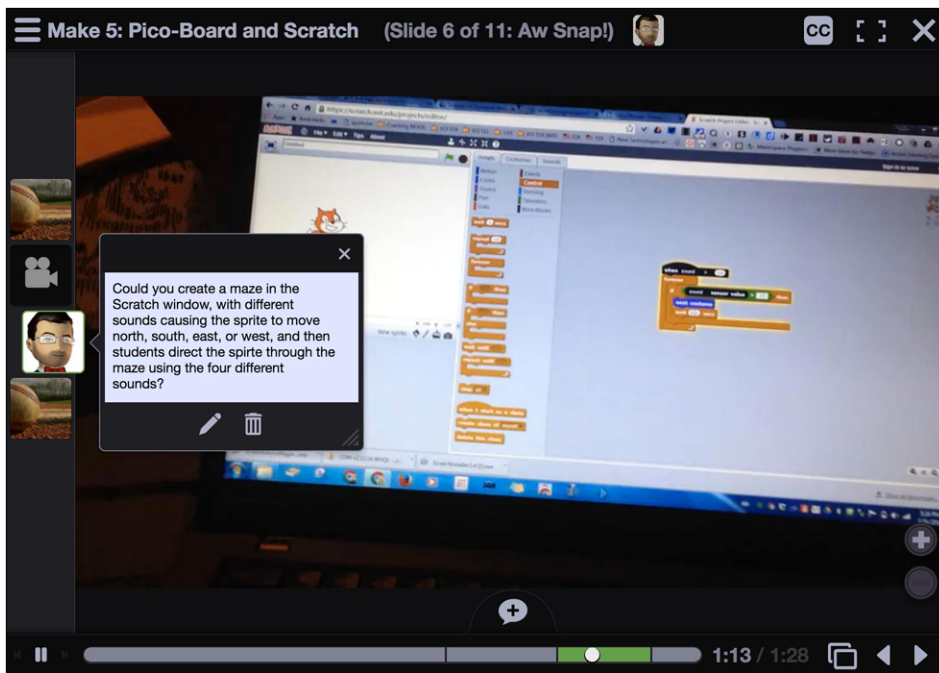
FIGURE 7. Maker project documentation in VoiceThread.

In the course syllabus, students are given guidelines for documenting their design process in VoiceThread. They are asked to take photos or videos as appropriate throughout their design from beginning to end. The instructor recommended that students capture more media than actually would be used and select a set of critical images to tell their story after their project work is completed. If students opt to engage children in project work (an option in this course), it is suggested they ask questions of those young makers and capture their thoughts on the design process as videos. Since learning to reflect on physical designs can be a challenge for those unfamiliar with it, students were given a set of questions to guide their oral reflections (see Table 2). They were not expected to answer all of these questions, but the questions provided a scaffold as to the type of information they should look to share. A further scaffold was provided for each project in the form of an instructor VoiceThread, where the instructor's design process was shared before students started working on a project as a model for students to follow.

where students could share the link to their VoiceThread for a given project. Students clicked these links to review their peers' projects, and using VoiceThread features for commenting orally or in text, left comments on peer work. The instructor recommended that students look for steps in a design process in which a peer struggled and offer guidance or alternative strategies. Figure 7 depicts one of eleven slides from one student's VoiceThread documentation of their PicoBoard project. The figure shows one image this student imported into VoiceThread as a point of discussion, and a peer comment.

- What did you find particularly challenging?
- How would you modify the process the next time around?
- Were there any "teachable" or "aha" moments for you, when you figured out how something worked/could work/should work, or how it could be expanded/modified?
- If you were to do this project with a student, were there particular moments you noted when you might engage them in conversations about the process to reveal key concepts or ideas?
- How could the project tie-into different parts of a school curriculum (e.g., math, science, technology, business, English, art, social studies)?
- What tips would you give another educator or parent trying out this project?

TABLE 2. Oral reflection prompts.

The decision to use VoiceThread in this course was made during the instructor's participation in an instructional innovation program sponsored by the state university system's distance education office. This two-week summer program provided instructors developing new online courses an opportunity to work with instructional designers and online learning experts as they outlined and began to develop their new courses and embedded strategies. During this program, the instructor met a colleague from another institution who had worked with physical makerspaces. In brainstorming tools that might support online design documentation, VoiceThread was suggested as one promising option. Ultimately, the instructor tested VoiceThread and created a model documentation for each project in the course--noting that the tool did indeed work well--to share and walk peers through a step-by-step process.

The rationale for using an asynchronous tool like VoiceThread instead of another option was justified by several criteria. We also considered synchronous tools like Google Hangouts that would allow a small group to log in at the same time to work on the same maker project in a virtual lab session. The synchronous option would allow students to ask questions of one another as problems were encountered and discuss/

compare design processes, but so too would VoiceThread where advice and feedback could be received after students shared their process. The synchronous option would allow the instructor to see and visually assess the students' success with a given project (e.g., the LED is lighting up), but so too would VoiceThread where students can share and "turn in" both still images and time-dependent videos to document their work (e.g., here you can see my spinbot is spinning and drawing circles). Asynchronous documentation in VoiceThread was viewed as a superior option in allowing students to practice independent troubleshooting and problem solving, practice documentation and intentional reflection, practice facilitation if they opted to work with children on their make projects, all while supporting the often-preferred option by busy graduate students to work on their own schedule and at their own pace. In addition, VoiceThread provided an easy way for students to view each other's work products and give feedback and suggestions. A host of asynchronous tools are available for students to share images and annotations, potentially as part of maker project documentation (e.g., Padlet, Lino), but these typically do not allow peer commenting on shared images, so VoiceThread was deemed the best option for supporting an online maker community.

The decision to use asynchronous VoiceThread for project documentation and sharing was judged to be successful by collected artifacts and student feedback. In analyzing student documentation, the instructor was able to identify prevalent critical incidents across projects as noted, providing asynchronous evidence of students engaging in troubleshooting and problem solving, as well as evidence of ultimate project success. In addition, spring 2016 students were invited to email the instructor feedback on VoiceThread as a tool to capture design thinking in makerspaces. All six students agreed they would consider using the tool if they were running an after-school makerspace of their own. Students noted many VoiceThread strengths: (a) supports step-by-step documenting across multiple slides which complement the iterative design process and phases; (b) supports oral and photographic documentation which younger students might prefer to writing; (c) integrates well with mobile devices to readily capture images while making; (d) supports video sharing which is useful to illustrate the results of a design (e.g., flashing LED, moving spinbot, physical computing sensor interfacing with a Scratch program); (e) supports drawing on slides to point out minute details on small parts when presenting a particular design decision; (f) supports the identification of similar issues/problems encountered and variations in designs in reviewing one another's work; (g) allows for peer/instructor questioning; and (h) allows for instructor modeling of process which can reinforce incomplete instructions downloaded from third party sources. Students did note that remembering to capture media throughout the design process took practice,

and that delayed mentoring/advice received only after a VoiceThread was posted could be problematic.

The decision to use VoiceThread for design documentation was well supported, and the tool continues to be used in subsequent iterations of this course. On the basis of feedback, the instructor did change how the tool and documentation were introduced to students. The ability to mark-up designs with VoiceThread's drawing tool to highlight parts or elements of designs, and the ability to share videos to highlight project successes/results, were features explicitly noted rather than assumed that all students would know to use in design documentation. On the basis of spring 2016 documentation of thinking, the instructor also changed how students were prompted to provide design reflections. In noting the prevalence of critical incidents across make projects, and more so what those incidents represented, it became clear that an opportunity exists to explicitly share thinking frameworks with students and have them identify exemplars from their design processes that align with said frameworks.

One potential framework worth consideration for making is engineering design thinking (Becker & Mentzer, 2015). With this framework in hand, students can note in their design documentation where they defined a problem and its constraints, considered alternatives, or modeled solutions. As they look across peers' VoiceThreads, they can also evaluate solutions and decide which best meet criteria as called for in design thinking. Another framework that could prompt reflection is computational thinking (Selby & Woollard, 2013). With this framework in hand, students can note in their design documentation where they broke down a problem into parts, where they abstracted a problem to focus on a key component, and where they identified a pattern or generalization. By providing students with thinking frameworks and guiding them to reflect on how their making and discussing elicited such thinking, students should come to a better understanding of how the elements in these frameworks are supported in makerspaces.

PREPARING FUTURE MAKER LEADERS

An informal learning course should focus on more than hands-on skills to adequately prepare future leaders of these technology spaces. A number of extended topics are included in our 15-session course, in between the sessions on different maker project areas as detailed previously. Some of the extended topics deemed important for this course include (a) the relative position of makerspaces in the informal learning hemisphere (Cavalcanti, 2013); (b) the rationale for making (Martinez, 2014); (c) space planning and outfitting (Cooper, 2013; Jarrett, 2015); (d) curricular connections (Gerstein, 2013; Hertz, 2013; Pang, 2013); (e) documentation and assessment (Gutwill, Hido, & Sindorf, 2015; Loertscher, Preddy, & Derry, 2013; Yokana, 2015); (f) facilitating learning
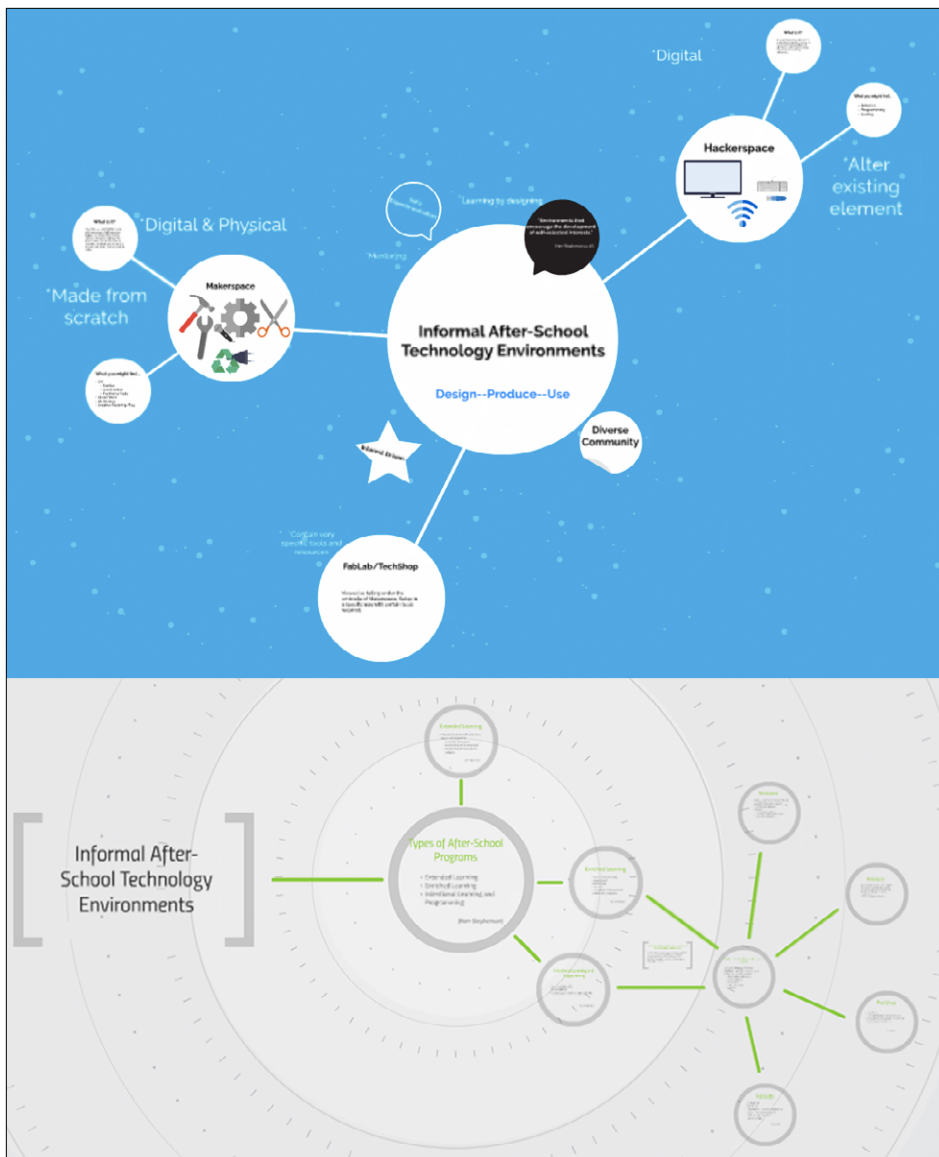
FIGURE 8. Sample Prezi presentations illustrating students' understandings of relationships between different informal learning environments.
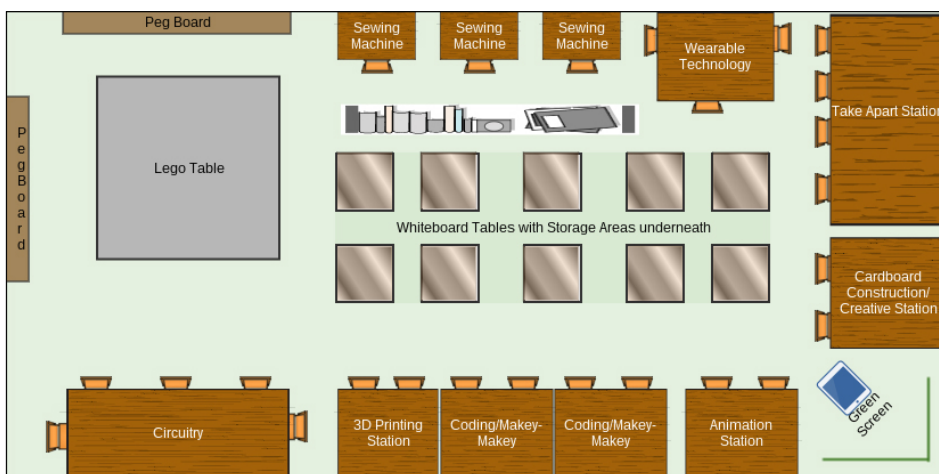

FIGURE 9. Makerspace space plan created in Gliffy.

(Long, 2011); (g) promoting collaboration (Bielaczyc & Collins, 1999); and (h) strategies for makerspace sustainability and community engagement (Garcia-Lopez, 2013; Kakli, Kreider, Little, Buck, & Coffey, 2006).

To engage our distance education students in conversations around these topics, a discussion forum was selected as a tool in which students could not only post ideas and comments, but also share artifacts as prompts for conversation. In several discussions, students are asked to create an item and share it in the forum, with discussions stemming from those peer ideas. For example, to discuss the relative position of makerspaces in the informal learning hemisphere, students peruse multiple readings and online videos on different types of informal learning programming. Students then create a summary presentation with the Prezi tool that explains their initial, week one understanding of connections between makerspaces and similar informal learning programs such as fab labs, tech shops, computer clubhouses, robotics teams, and more (see Figure 8). Students share the links to their Prezi presentations in the discussion forum, which allows them to see different views about how these learning environments overlap and differentiate. At the end of the course, students return to this forum, update their presentations, and further discuss how their understanding of the position of makerspaces in informal learning has matured.

In another discussion forum, students are asked to create a space plan for their ideal makerspace using the Gliffy tool, and engage in conversations about the range of different project areas that can be emphasized in makerspaces--as well as useful secondary areas

such as small group work tables and spaces for sharing or presenting project work (see Figure 9). In another forum, students are asked to source materials for a paper circuit activity and are given a mock $100 budget to shop. Students share spreadsheets in the forum with selected items, vendors, and prices and discuss best price options for products and different strategies to accomplish a similar goal. In another forum, students are asked to create and share asset maps that detail relevant human resources in their communities who might be tapped as part of a community engagement strategy. By looking across peers' asset maps in the forum, students can identify and synthesize categories of STEM and education experts who might be willing to help out a particular makerspace in a certain way.

IMPLICATIONS

The implications of a virtual/online makerspace design are considerable across education levels. As with our College of Education's master's program in Learning Design and Technology, many higher education programs in educational technology are online. The strategies and resources listed in this design case are replicable by faculty in other online programs who would like to incorporate a new course on informal learning with a focus on makerspaces. At the K-12 level, the considerable growth in virtual schools that sometimes serve non-traditional students who are not physically sited, suggests there may be an opportunity for these organizations to create virtual maker clubs and communities for students who cannot attend physical makerspaces. Likewise, for many students who are physically sited, but attending schools without a makerspace or a willing STEM mentor, there are opportunities to plan low-cost maker kits that can be distributed to these sites--to support students with online tools for project sharing and feedback from a virtual community of makers and mentors. Since a recurring goal of organizations such as the National Science Foundation (2015) is to reach and interest underserved students in STEM education, and underserved students are more likely to be in limited-resource schools without makerspaces and mentors, understanding strategies for virtual/online makerspaces that might better reach these learners is of critical importance.

Another implication of this design relates to the use of VoiceThread as a tool for sharing one's making and receiving feedback from a community of makers. At least 140 websites allow children to share projects online, but these sites rarely provide for community support outside of a common user forum (Litts et al., 2016). Maker community platforms "do not deliberately address the needs for connected making such as allowing members to build on other's work, share know how, and critique each other's design to foster new interactions" (Litts et al., 2016, p. 1044). Our success with VoiceThread in allowing students to thoroughly document a design process and directly receive ideas and clarifications from peers on their specific project, suggests the type of

features embedded in this tool may also be of interest to designers and developers of maker community platforms. Similar media sharing and commenting features could be repurposed to support communities of makers across physical and distance settings who can benefit from sharing their work online.

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