Bringing Physical Construction and Real-World Data Collection into a Massively Open Online Course (MOOC)

Julia S. Mullen, Lauren Milechin**, Michael Houle,
Patrick Bell, Alan Fenn, Kenneth E. Kolodziej, John Meklenburg,
Janet Nguyen, Bradley Perry and Albert Reuther
MIT Lincoln Laboratory, Lexington, MA 02420
**Massachusetts Institute of Technology, Cambridge, MA
Email: jsm@ll.mit.edu

***Abstract*—This Work-In-Progress paper details the process and lessons learned when converting a hands-on engineering mini-course to a scalable, self-paced Massively Open Online Course (MOOC). Online courseware has been part of academic and industry training and learning for decades. Learning activities in online courses strive to mimic in-person delivery by including lectures, homework assignments, software exercises and exams. While these instructional activities provide "theory and practice" for many disciplines, engineering courses often require hands-on activities with physical tools, devices and equipment. To accommodate the need for this type of learning, MIT Lincoln Laboratory's "Build A Small Radar" (BSR) course was used to explore teaching and learning strategies that support the inclusion of physical construction and real world data collection in a MOOC. These tasks are encountered across a range of engineering disciplines and the methods illustrated here are easily generalized to the learning experiences in engineering and science disciplines.**

I. Introduction

Despite decades of educational software and games, online courses and the recent advances in mastery education at scale, the element of practice continues to be primarily through simulation, discussion boards and written assignments that resemble homework in traditional courses. In contrast, the rise of the "Maker Movement" has created a vast market for building and science kits that offer a way to develop construction skills ranging from fiber art crafts to engineering Do-It-Yourself (DIY) 3D printers. However, these packaged kits, like the Heathkits® [1] before them, support a constructionist model of learning without a connection to the underlying theory or support for the development of troubleshooting techniques.

Recently small and large companies have begun expanding their science kits and curricula from the K-12 to higher education market. In 2013, Missouri University of Science and Technology's "Delivering Experiential Labs To All" (DELTA) program began the work of re-defining science and engineering laboratories to provide equivalent experiences in blended and online courses [2]. As part of the pilot they evaluated two of the primary players, eScience Labs [3] and Hands-On Labs [4] and to date have four science and three engineering courses using the kitted products from these companies. Further expansion of packaged higher education laboratories and curricula is happening at Pearson as part of the HoloLens project where they use augmented reality to provide a tactile sense for nursing education, archeology and improved understanding of multi-dimensional mathematical models [5]. Each of these technologies is designed to enhance instructor supported cohorts, but MOOCs require hands-on activities with physical components that can be built, tested, tuned and deployed with little or no supervision. To date, the only courses successfully integrating physical construction into a MOOC are the UTAustinX "Embedded Systems—Shape the World" series offered through edX [6]–[8].

The hands-on MIT Lincoln Laboratoy (MIT LL) "Build A Small Radar" course [9], regularly taught to a diverse range of students, served as the testbed for exploring the process of converting an in-person workshop to a self-paced MOOC. The primary educational components—lecture content, physical construction and the collection, processing and interpretation of real world data—cover the breadth of learning activities encountered in engineering courses making this a generalizable case study for other institutions and disciplines. This paper begins with an overview of the initial course, followed by a brief description of the Open edX pedagogy and the unique conversion elements required for a hands-on MOOC course. Section III presents the results from two sections of the blended version of the course. The paper closes with a discussion of the lessons learned and a summary of future work.

II. Design

A. Overview of the Short Course

Radar systems are designed and built by large teams spanning many engineering, physics and mathematical domains.

*This material is based upon work supported by the Assistant Secretary of Defense for Research and Engineering under Air Force Contract No. FA8721-05-C-0002 and/or FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Assistant Secretary of Defense for Research and Engineering.

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Understanding hardware design requires knowledge of radar, antennas and RF design. Once designed and built, radars are capable of operating in several modes, e.g. Doppler, range and Synthetic Aperture Radar (SAR), each of which require knowledge of signal processing.

To help students better understand radar design and processing from a system perspective, MIT LL staff have taught a short course, "Build A Small Radar" (BSR) to professional staff at MIT LL, undergraduate and graduate students in MIT's winter intersession and professional engineers from around the world through the MIT Professional Education program. In addition, a slightly modified version, "Lincoln Laboratory Radar Introduction for Student Engineers", is offered every summer for high school students and teachers (LLRISE) [10].

The original in-person BSR course included a lecture component to build student familiarity with the theory, design, and signal processing of radar data collections. However, the primary component of the course involved student teams physically constructing, testing, and tuning a small radar and using it to collect data in the Doppler, range and SAR radar modes. This construction component gave students the opportunity to create a physical system for use when applying, refining and demonstrating their understanding of concepts presented in the lectures.

To provide students with the appropriate background to build and operate the radar as well as process the data they collect, course topics include radar fundamentals, antenna and RF design, Doppler, range and SAR processing. For the radar build, student teams were given a kit of parts, tools and instructions. The instructors assisted with the build, tuning, testing and troubleshooting, where necessary. The final small radar is shown in Figure 1. Once constructed, the students

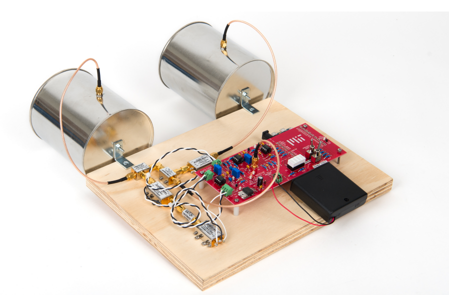

Fig. 1. MIT Lincoln Laboratory Small Radar

operate their radar in the Industrial Scientific and Medical (ISM) frequency band to collect data in the three modes: Doppler, ranging and SAR and present their results during the last class meeting.

These courses are highly successful and popular with long wait lists and requests to expand the course to other sites. However, as staff members at a Federally Funded Research and Development Center (FFRDC), the authors are primarily researchers with mission driven programmatic work and expanding the offerings is not feasible. To satisfy demands for additional course offerings, while simultaneously reducing the staff's time and resource commitments, we began exploring the use of MOOCs to scale the BSR course while maintaining the educational quality.

B. MOOC Pedagogy

Online courses and programs have existed for decades, but recently MOOCs have demonstrated the ability to scale education to hundreds of thousands of students. Among the leading MOOC consortia, only edX [8] has open sourced their learning platform. The platform used by edX, and adopted by hundreds of businesses and academic institutions around the world, is available through Open edX [11]. The edX platform builds on pedagogical research demonstrating the value of segmenting content and providing frequent assessments to build mastery learning [12]. edX courses include assessment questions that are auto-graded and interspersed between units of video content. A full list of assessment options can be found in the Open edX documentation [13].

In designing the MOOC courseware, we used Grant Wiggins' instructional design framework, "Understanding by Design" [14] or "Backward Design." The framework focuses on using the content you want the students to learn and the evidence that demonstrates student understanding to guide content selection and the design of assessments necessary to support student attainment of the learning goals. We note that this framework is applicable to each of the individual modules or sections of a course as well as the overall integrated course.

C. Build A Small Radar MOOC Conversion

Converting the in-person course into digital courseware follows standard practices, e.g., the creation of targeted concept videos and developing auto-graded review questions and exercises that reinforce the theory. The real conversion challenge lies in the fact that static photos and video instructions are typically insufficient to ensure that novices are able to build a functional small radar without help developing the troubleshooting mindset that is typically learned through real-time, in-person interactions with an instructor. To address this challenge, the authors revisited the numerous technical and construction difficulties typically encountered by students during in-person courses. The list included:

- limited soldering experience
- confusion around debugging the radar build, i.e.
  - where to find test points for tuning
  - what values to expect at test points
  - uncertainty reading schematic and components
- misconceptions about data collection and processing, i.e.
  - poor scene selection
  - poor understanding of radar capabilities and limitations

As part of the conversion process, the printed circuit board (PCB) was redesigned with clearly defined test points for tuning and a toggle switch for setting the radar to run in the three operating modes mentioned previously. In addition, the new design used a micro-controller to simplify the data collection and provide for future real-time processing capability. Once redesigned a new suite of still photos was created to show each step of the radar build process and the "Radar Build" module was expanded to highlight how each step of the build process aligns with specific engineering disciplines, e.g. mechanical, antenna design, RF, and signal processing. To provide additional scaffolding for the students, detailed discussions of scene selection considerations were added. With respect to prerequisite skills such as soldering and MATLAB®, links to external educational material were provided with the expectation that students would follow through and learn the necessary skills.

III. Implementation

A. Case 1: Professional Engineers as Students

The conversion involved refactoring seven hour long PowerPoint® lectures into modularized single concept videos, creating questions for each unit (concept video) and capturing a set of photos to provide clear step-by-step instructions for configuring the micro-controller software, constructing and tuning the radar and collecting data. In the fall of 2016, the online version was offered through MIT Lincoln Laboratory's Technical Education program (MIT LL TechEd) and the student cohort included professional engineers and technicians from MIT LL. The course used a blended format where lectures and build instructions were provided via MIT Lincoln Laboratory's MOOC platform, LLx, and the tuning, troubleshooting and student presentations were held during in-class hours. This choice of format resulted in a 50% reduction in class lecture time versus the traditional BSR MIT LL TechEd course, providing additional in-class time for experimentation. One observation from the student presentations of the Doppler experiment results was the recognition that students were struggling with tuning and scene selection. Based on this observation, the team designed a controlled experiment and used class time to run the experiment with the students *en masse*. This use of lecture time allowed students to debug their radars, observe the instructor team's approach to troubleshooting radar settings and see the images that result from correct and incorrect tuning. The controlled experiment was so successful that it was incorporated in the second blended offering.

B. Case 2: Undergraduate and Graduate Students

Based on the professional cohort experience the online content and troubleshooting tips were modified and extended in preparation for an offering on MIT campus during the winter intersession, Independent Activities Period (IAP), in January 2017. The IAP cohort included undergraduate and graduate students from electrical engineering, mechanical engineering and computer science. As with the professional cohort, the course did not have grades or award any academic credit. By using the blended format the instructors were able to significantly compress the course to three afternoons, one for introductions and handing out kits, one for debugging and the controlled experiment and the last for presentations of student work. The students worked in teams and despite the short cycle most teams were able to build functioning radars based solely on the material in the online course.

C. Evidence of Learning

The Open edX platform has been designed for academic use and provides a means of computing grades for students. Neither of the two blended courses was offered for academic credit, so evidence of learning could not be grade based. For this course, the ability to build a working radar, collect and analyze radar data and present the results to the instructors and student cohort, is evidence of learning using the definition in the "Understanding by Design" Framework (Section II-B). The completed radar is pictured in Figure 1 and an example student image from the controlled experiment is shown in Figures 2.

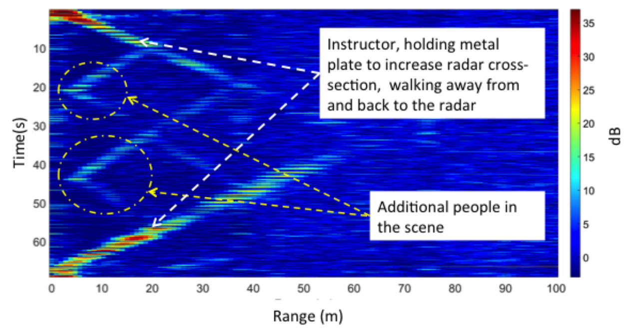

Fig. 2. Controlled Experiment Range Results

In addition to the completion of a working radar, the students were surveyed to capture their level of familiarity with the course material prior to the start of course and at the end of the course. The self-reported results are presented in Figure 3. As expected, the professional cohort arrives with a deeper background in most topic areas compared to the undergraduate and graduate cohort; however, both show deepening understanding of the topics by the end of the course.

IV. Lessons Learned and Future Work

Included in the end-of-course survey was the question "How easy would it be to complete this course if it were entirely online?" On a four point scale, with one being unfeasible, and four being feasible in the current form, the average of professional cohort ranking was 3.2 and the undergraduate-graduate cohort ranking was 2.9. These values correspond to self-paced, solo individuals being able to build a working radar and collect data using the current online materials with minor additions. Meanwhile, reflecting on the two blended course experiences, the course team refined the list of gaps to be filled and developed strategies for extending the current content.

The inclusion of test points as part of the radar build has simplified the tuning process but students still have difficulty determining whether or not additional tuning is necessary. One strategy to help students recognize what, if any, tuning is necessary, is to build questions that incorporate correct and incorrect oscilloscope readings. This strategy will help

(a) MIT Lincoln Laboratory Technical Education Cohort.

(b) MIT Independent Activities Period (IAP) Cohort.

Fig. 3. Self-reported understanding of Radar Topics before (upper half) and after the course (lower half). Darker colors indicate deeper understanding.

students develop the troubleshooting skills associated with working with real hardware. Additionally, self-paced online students need a "controlled experiment" that can be run in an unknown cluttered scene to confirm that the radar is operating correctly. One approach is using a flat plate or corner reflector to increase a test subject's radar cross-section so they stand out in the scene. The results of this approach are highlighted in Figure 2.

Finally, with respect to data collection and image processing, despite lectures and discussions about the small radar's capabilities, there are always a few students who try to capture scenes that are beyond the capability of the radar. Developing an intuitive sense and pre-collection expectation of what the radar image of a scene should look like takes time and experience. One approach to steer students in the right direction is a set of thought exercises, or questions, that provide the details and/or photos of a particular scene and ask the student to select the correct radar image from a set of images. Beyond simply being able to choose the correct image, the student should be able to articulate the reasoning behind the selection. While these exercises don't completely replace the in-person instructor guidance, they should be a first step in helping students recognize when an image indicates necessary scene refinement versus additional radar tuning.

More generally, the key elements for success in converting a hands-on workshop to a self-paced online course include

- starting with
  - a tried and true course
  - a clear understanding of the topics and tasks where students have the most difficulty
- designing
  - with modular blocks, breaking difficult topics into small manageable pieces
  - questions that encourage deeper reflection of the topic
  - your construction project to include
    - a series of simple steps
    - a clear set of annotated images, with tips
    - test points with references to troubleshooting techniques
    - controlled examples that test the system, with known results
  - experiments including good and bad results with explanations
- testing the course
  - as a blended course to identify gaps
  - to define the full set of online requirements

V. Summary

In summary, this work presented a process for converting a workshop designed to teach hands-on radar construction, data collection and processing to engineers and scientists to a MOOC. Included in the description of the process are the lessons learned with suggestions for the successful conversion of a learning experience that closely resembles the life-long active learning that engineers engage in throughout their careers. The process and suggestions are easily generalizable to other science and engineering disciplines.

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