Work in Progress: Teaching MATLAB through Authentic Data Collection and Analysis Experiences using self-contained, guided experimental setups with a range of disciplinary themes.

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Introduction

This work-in-progress focuses on utilizing simplified versions of the experimental setups found in their upper level courses to introduce a more situated learning approach to a first-year engineering program's MATLAB curriculum. Engineers primarily use MATLAB to support their research and lab-course experimentation in their undergraduate curriculum and careers. It is simply what the platform was designed for; an experimental support tool for collecting, analyzing, and visualizing data. That is the platform's primary use in upper-level courses at Northeastern University. Although those lab courses provide some support and education for more advanced usage, those courses rely heavily on the first-year engineering curriculum to handle that initial introduction of MATLAB and instruction in its general use. This is sufficient for some students but very challenging for others. This project hopes to provide some relief by introducing a more situated learning experience in their initial MATLAB instruction.

Typical MATLAB curriculum at the introductory level focuses on simple exercises on the programming concepts with simple concepts or using randomly generated information. Even though MathWorks' various promotional materials focus on its use as a support tool in control systems, robotics, deep-learning, and more, their help documentation typically showcases commands and concepts in isolation. Their instructional paradigm uses randomized, command-generated inputs or idealized data without a direct connection to a real-world context. In attempting to teach MATLAB in isolation, the typical use context is not factored in that initial experience. As a result, there is little opportunity to develop a familiarity with MATLAB as more than just a collection of programming commands rather than to know it as a practical engineering tool for assessment through the collection and analysis of data.

On top of that, there are some inherent pitfalls to overcome in teaching any design application. Be it MATLAB or SOLIDWORKS; these tools are large and complex with thousands of commands. Even though we ask students to engage with just a tiny portion of it, the available scope can be overwhelming and leave them unsure of what to do. The more advanced and interesting use of these tools require some understanding of the various low-level tasks and how to usefully combine them, necessitating some menial and tedious study of low-level commands to gain some mastery of the tool [1]. Many approaches try to alleviate the tedium and immensity by utilizing simple games as the context for developing and implementing algorithms while trying to include an entertaining and relatable aspect. These show significant success, but there are also pitfalls. Not everybody likes games or is familiar with the games implemented. The use of games in an engineering context is also not always seen as serious, well-used time by other faculty or administration [2]. That experience may not always transfer well to the more common academic and professional use cases in engineering. The algorithms and techniques for implementing a digital board game will not always be the same as those necessary for collecting and analyzing experimental data.

Just utilizing a more situated learning approach is by no means novel for the acquisition of programming skills. It has been successful and recommended in many contexts [3-6]. Many science and math courses, disciplines closely associated with MATLAB's purposes, have shown success in trying to integrate real-world scenarios into their lessons and assignments [7, 8]. Real-world examples and challenges are commonplace in first-year engineering courses as part of their design education [9-11] and even positively influences retention and identification[12, 13]. As part of a programming curriculum, real-world datasets and challenges have helped internalize the concepts and mastery of the tools [14, 15]. MATLAB specifically has been co-taught within other disciplinary contexts like robotics and controls with some success, providing a contextual understanding of MATLAB for those disciplinary topics and practices [16, 17]. Where most of these utilize just provided data, are isolated to a specific use case, or the hardware being of primary concern with MATLAB being the secondary learning objective, our approach combines that use of real-world data and experimental setups, actively collected by the students through their interactions with the provided hardware to create a personal connection to their MATLAB curricular experience.

Pedagogical Considerations

In many cases, the situated learning scenario applies to that specific course and discipline, relating it to real-world use cases. Even in the examples where understanding MATLAB was the learning goal, it intertwines with learning the disciplinary topics. They use MATLAB to enable engagement with that specialty with students majoring within those subject areas, not just to learn the language. At Northeastern University, the first-year engineering courses are made up of a mix of students from all engineering disciplines. Our learning goals are explicitly preparing them for the use of MATLAB in future courses, which will take place across a range of all engineering majors since all. Although it serves as a minor design tool within the design projects, the primary purpose of our curriculum is to support those upper-level classes. Much of our MATLAB curriculum will inherently not bear fruit until much later in their undergraduate career. The overall goal of this project is to create a curriculum and resources that create enough of a situated learning scenario that familiarity with those future use cases is achieved and transferable experiences with this design tool. These tools and curricula look to establish an applicable programming muscle memory for when they enter those more advanced lab courses and are expected to use MATLAB and professional equipment to complete their experimental tasks. By establishing a memorable proto-lab experience that directly emulates those future use cases, we hope to better prepare students to face the anxiety brought on by those more advanced [1].

An examination of the typical use cases for upper-level students, through informal inquires of past students, revealed a wide range of possible scenarios and experiences to serve as inspiration. Our institution utilizes it in various courses, but all in different disciplines. Even though the lab topics vary greatly, many utilize MATLAB in similar ways for controlling data collection from some hardware as part of an established experimental setup than for the analysis and visualization of the collected data. Therefore, our focus became the emulation of that experience by factoring in that data collection aspect as part of the learning experience and nest the actual MATLAB instruction and exercise in the analysis of that data. Admitting an inability to develop a single scientific theme, we drew inspiration from several disciplines and experiments used in upper-level labs to develop proto-versions of those experimental setups. We had to concede that,

although each takes inspiration from those future labs and situates itself within them, it will never be directly applicable for all students across all lessons as they start to diverge into different disciplines. For that reason, the curriculum itself focuses on establishing the transferable skills of each to those lab situations, leaning on that "wax on, wax off" paradigm.

Several other pedagogical considerations factored into the design, but all secondary to their use in a MATLAB curriculum. The cost was one of the primary considerations so that other institutions could implement designs with relative ease. A specific goal of a $25 maximum cost per unit per student was set and met, accounting for pairing and usage grouping. The

Figure 1. UV Module

cost concern drives the use of many readily available COTS parts and components manufactured from common makerspace resources like 3d-printers and laser cutters. That unintentionally served a secondary purpose of showcasing best design practices for those resources since the First-year engineering courses also include a design project that utilizes that equipment. Other indirect concerns include storage, repair/replacement/ and support. Currently these are not fully addressed; currently just being used and managed by their developer, supported by them and their teaching assistant, and maintained by the remaining initial grant funding. If successful and deemed viable for broader use, these concerns will need to be addressed in full.
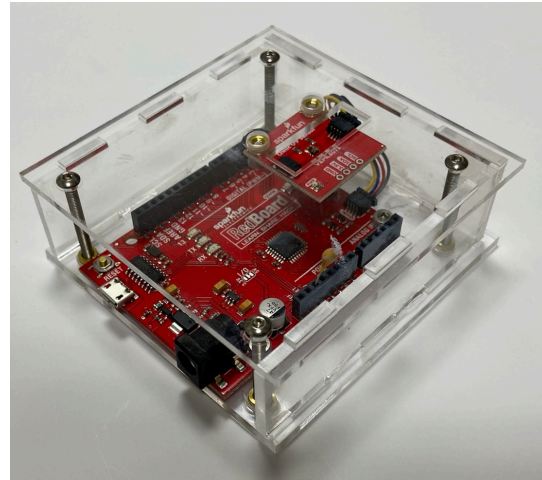
Curriculum Technology

As part of a MathWorks® funded MATLAB Curriculum Development grant, we developed four experimental setups as the central element for student assignments[18]. They enable students to interact with data-collection hardware as part of their lesson and use real-world data in their learning activities. Each focus on a different discipline.

- GPS enabled environmental data collection as an environmental engineering experience (See Figure 1)
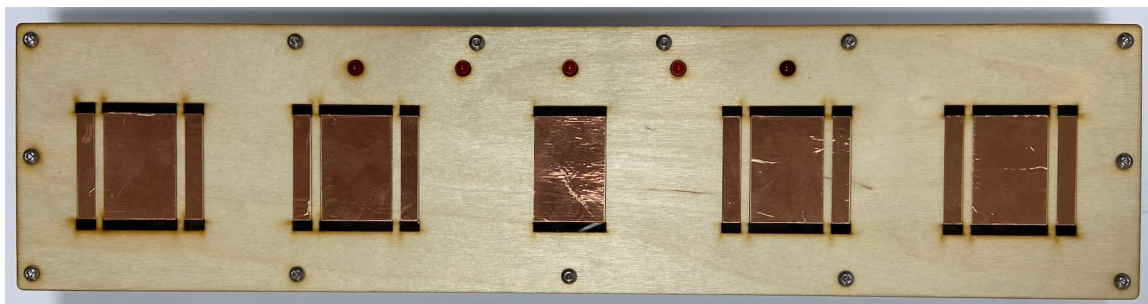- Human reaction time experiment as part of bio-engineering (See Figure 2)

Figure 2. Reaction Time Module

- Signal analysis and decryption for signal/electrical engineering (See Figure 4 on the following page)
- A 3-point bend test setup for mechanical/industrial engineering (See Figure 3 on the following page)

Figure 4. Signal Processing & Decryption Module

Each involves an Arduino-based hardware component that enables the student to collect data. The hardware uses open-source sensors and readily available commercial-off-the-shelf parts, as well as rapid prototyping typically available in academic settings to achieve a reasonable cost. We ruggedized the design and kept it compact to provide them with their assignments as take-home components. The compactness also helps with storage of the current 40 unit set in under 9 cubic feet in space (less than an average school locker). A provided MATLAB class definition allows students to construct an object in their program for each experiment. This allows for single command interactions with the hardware rather than copy-pasting large portions of example code, allowing students to focus on the MATLAB lesson elements rather than debugging advanced examples. In addition, the class provides methods to handle hardware communication, data collection, and database connection. Finally, the centralized database provides students a resource for larger datasets, compiled from the experimental runs of all students in the course in their data analysis.

Each module pairs with an associated lesson that includes a MATLAB live script that walks them through the data collection process, utilizing the built-in class to enable single command interaction with the modules and database. As part of their MATLAB lessons and assignments, student individually collect data, upload it to a database, then download the full class dataset. With that context of better understanding the data source, they practice their newly acquired MATLAB knowledge to analyze the dataset. The goal is that the students, having directly collected the data, have a greater connection to it and can better understand how they engage with that data through MATLAB. Using the contextual "why" around manipulating the data to reinforce the "how." For example, to learn about MATLAB visualization by representing UV light levels around campus in relation to time and location. After running experiments on human reaction time, they can then analyze the data set for trends and engage with filtering algorithms to eliminate bad data points, identifying unreasonable times based on their own experience with the data collection. The signal processing and decryption engage with sample times, determine a critical mass of data, and use signal filtering and offsetting algorithms to isolate the
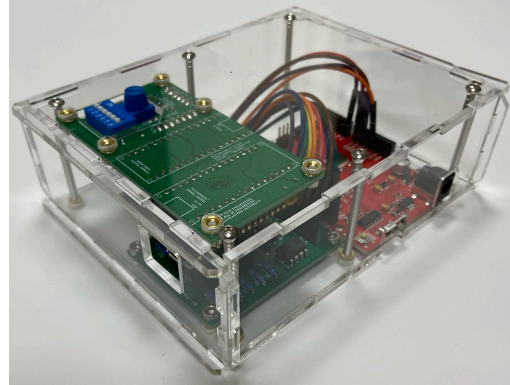

Figure 3. Mechanical Strength Testing Module

messages. They can even add their own messages for partners to try and decode to personalize the challenge. The final, a desktop 3-point bend test, allows for determining the mechanical properties of various materials, specifically those they used for some of their early design projects. Through this, they get to use a MATLAB analysis to inform their design decisions as part of their engineering design process.

Project Approach

This project began in late 2019 with the awarding of the grant but suffered several delays due to COVID restrictions and the continued disruption of the standard classroom environment. Development of the hardware and software did not occur until summer 2021. Delayed due to increased complications in rollout with hybrid learning and difficulty in accommodating quarantine needs, beta testing was further postponed to Fall 2022. Evaluation of the usability of the modules and efficacy of this pedagogical approach will take place over several phases.

The initial cohort of students to engage with the modules and associated curriculum will be part of the author's 32 student honors-level first-year engineering course, an 8-credit dual course introduction to the engineering design process which includes introduction to several engineering tools, MATLAB being one of them. In-class learning of MATLAB concepts is assessed as part of the course. However, there will be some voluntary non-course-related pre and post-testing for initial comparisons among that cohort aimed at assessing familiarity with the experimental context. This upcoming study recruits' students from this initial class to formally engage in a longevity study over the course of their next few following years. As they continue with their undergraduate courses, check-in surveys will be sent out at the end of the semester to determine their use of MATLAB in any regular and lab courses. In addition, follow-up interviews will be conducted when they have used it to determine if and how well familiarity and skill transfer occurs.

A direct comparison between this curriculum and the existing one will not be available due to the lack of feasibility of simultaneously assigning the new and old curriculum. In an attempt to overcome that void, students in other sections will be recruited, specifically, those who use the same or similar curriculum the author previously used. Past courses will provide some historical comparisons. Past students will also be contacted and recruited to pilot interview/survey protocols and develop some baseline understanding of MATLAB use and capability among upper-level students.

The hardware and support software will also be under examination. A variety of metrics will be tracked to assess the quality of the module design. These include error reporting, troubleshooting requests during office hours and with our first-year tutors, pre and post-damage assessments to the various modules, and replacement rate to name a few. In addition, database quality and completeness will be a factor in the support scripts assessment, error handling, and edge case analysis.

Discussion

Currently, the primary achievement is the development of the initial hardware, database, and example scripts. Delays due to COVID restrictions and hybrid learning forcing significant

adaptations and restrictions to the curriculum have put off any ability to pilot and analyze these modules at scale. In conjunction with other planned longevity studies, we seek to follow a cohort of students from their first-year engineering experience through graduation. One of the topics of interest is their MATLAB usage, and, as part of that, the efficacy of this approach will be a significant subject of interest. In addition to this, there will be some continued development of the system. Other grants are being pursued to develop more modules drawn from other disciplines. A stretch goal is to have enough variety that there are multiple disciplinary versions for every lesson, allowing students to select their preferred situated MATLAB learning experience.

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