Experience with the Development and Implementation of Online and Hands-on Rocketry Education and Outreach

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Abstract

Space is increasingly becoming globally competitive, and both U.S. civilian and government agencies continue to increase and grow their activities in space. There is also a dearth in the workforce of highly trained and skilled space scientists and engineers. The overall goal of the program guiding this study is to enhance knowledge and expand the pipeline of students pursuing careers in space. Online learning platforms have gained in popularity due to their accessibility to broader audiences which the pandemic has further fostered. Furthermore, research suggests that incorporating hands-on activities in classrooms enhances student foundational knowledge, hands-on capabilities, and overall engineering design aptitude. Integrating hands-on activities into massive open online courses (MOOCs) could increase student access to more real-life learning opportunities. This paper reports on instructor(s) experiences while developing and implementing an introductory rocketry course with both online and hands-on components intended for high school and early collegiate students.

Introduction

From 2016 to 2021, the space industry grew by an estimated 18.4% [1] with nearly half of the growth occurring in 2021. The demand for work in the space and defense industry is high. Yet, many young students still do not see a place for themselves in the industry, especially minority and female students. According to National Center for Education Statistics [2], [3] of the share of US Citizens who graduated with a bachelor's degree in aerospace engineering in 2019 and 2020, 56% were white males and only 14% were female. There is a need for more diversity in the space industry and overall, more degrees in aerospace and related fields. SpaceLab* (SLI) was created to address these issues. The hope is that by creating accessible and interesting coursework, students who would not otherwise be interested, learn about the opportunities and benefits that exist in space-related careers. Literature suggests that engaging students in design-based science learning activities can help them develop problem-solving and science inquiry skills [4]. Therefore, these engaging, accessible, and affordable courses and challenge problems have been and will continue to be developed to reach more students throughout the state, and in the future, the country.

SLI's goal is to increase the number of students and enhance the education of students pursuing careers in space. The objective is to create an integrated set of educational resources, implement them strategically in undergraduate classrooms, K-12 classrooms, outreach events, and workshops, and assess their efficacy in achieving our goal. The public benefit of the project is expanded opportunities, materials, and resources for enhancing K-12, undergraduate, teacher/professor, and public knowledge and understanding of space science and engineering.

There are three main types of educational resources created as part of this project: (1) a web-based self-study platform that is a rocket science massive open online course (MOOC); (2) a

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*https://spacelab.web.illinois.edu/

hands-on activity and kit on model rocketry; and (3) an undergraduate student design challenge focused on vertically landing a model rocket. The focus of this paper is to provide insight into developing the first two of these three types of educational contexts and adapting them for delivery to high school students, college students, and instructors.

Specifically, we report on our experiences creating and implementing a rocketry MOOC with a hands-on component and the associated lessons learned. We describe the basis, structure, and content of online material, as well as the rocket kit for teachers and students. The efficacy and impact of the rocketry MOOC with hands-on kit are currently being systematically investigated in another research study; however, for this pilot study, we describe here our initial exploration towards gaging and understanding instructors' challenges in supporting participation and learning successes associated with adopting and implementing a rocketry MOOC with a hands-on kit.

Questions we hope to answer are as follows:

- What are important considerations when developing a MOOC with a hands-on project?
- What challenges and limitations are added when implementing a MOOC in high schools and colleges?
- What are the benefits of delivering a hands-on experience with a MOOC?
- Does this course encourage students to consider space-related careers?

Literature Review

Massive Open Online Courses (MOOCs) are models for delivering learning material via open online access. MOOCs introduce a completely new method of learning compared to traditional approaches. Students from around the world can effectively engage in a learning experience that involves the viewing of well-structured course material, participation in online discussions, and completion of assignments and exams [5]. Successful completion of MOOCs necessitates self-organized, goal-oriented, and actively engaged learners [6]. The rapid growth of MOOCs has garnered significant attention for their ability to revolutionize traditional education through increased access and delivery of cost-effective content to a large number of learners globally [7]. However, MOOCs often lag in terms of design quality, effective instructional delivery, and adequate resources necessary for most learners to attain the intended course outcomes [8]. The difficulties associated with online learning have been widely researched and discussed, encompassing the perspectives of students, instructors, and administrators [9]. Due to the large scale and open nature of MOOCs, these challenges are often exacerbated, requiring a distinct set of considerations to ensure course success. For instance, the massive scale of the course limits instructor interaction with students, due to the restrictions of time and energy [10].

The instructor's implementation of MOOCs is an important consideration in the overall learning experience. The teacher is portrayed as possessing expert knowledge but without the ability to widely impart it. The issue of effectively transmitting expert knowledge by teachers is a common topic in educational research and practice. Despite the portrayal of teachers as knowledgeable, they often face challenges in imparting their knowledge to students. This depiction oversimplifies the complexity of educational issues, such as power, pedagogy, assessment, feedback, and the nature of knowledge. Researchers and educators have long studied these issues and explored their practical applications. Furthermore, there are ongoing efforts to examine the complexities of education, particularly in relation to digital practices and technologies [11]. The teacher's role in a MOOC differs significantly from that of a traditional educational setting, where the teacher can interact with students through selecting, tutoring, and assessing individual work. In MOOCs, with their large enrollment and limited instructor presence, the teacher's role is primarily focused on designing and organizing the course, offering general guidance and support, and facilitating peer-to-peer interactions [12]. Online educators face the challenge of determining the most efficient course designs and teaching methods that can engage students in meaningful, stimulating, and productive learning experiences [13].

This study uses a blended MOOC, combining online classes with face-to-face instructor guidance. In this paper, this is referred to as a blended MOOC or hybrid MOOC. When MOOCs are offered using hybrid formats, it can improve student outcomes and reduce costs [14]–[16]. Results also show the impact of incorporating MOOCs in traditional classroom settings is almost equal or slightly better than face-to-face teaching environments [15]–[17].

The key assumptions when designing a blended learning course are: Thoughtfully integrating face-to-face and online learning, fundamentally restructuring and replacing the course design, and class hours for effective student engagement [18]. Curriculum designers must explore opportunities for blended MOOCs research on how factors like early support, high degree of structured content and assignments, and use of learning analytics help to guide early interventions to improve engagement, persistence, and outcomes of students [14]. Overall, MOOC providers should make their courseware more modular and must consider the intellectual property and licensing implications of making their content available for different contexts. They must also develop tools and content that are easier to implement and repurpose and provide assurance of online content available for use in the future [19]. Adding for those who wish to implement a blended MOOC, institutions adopting MOOCs should have overarching strategic frameworks for course redesigns and implementation to have significant impacts on enhancing students' outcomes and reducing costs [16].

One key aspect to enhancing the Intro to Rocketry blended MOOC developed here is that it requires students to create a mathematical model predicting a model rocket's apogee at various payload masses and then compare it to actual flight data. The data is collected during the flight of a rocket that the students build and launch themselves. This type of experience is commonly referred to as project-based learning (PBL). When a project is designed correctly, the benefits of PBL are known to be significant and positive for students' academic achievement [20]. However, although there is a clear benefit to PBL, Baron et al. [21] warns that project-based learning can fall into the trap of "doing for the sake of doing" rather than for the sake of learning, which can happen especially if students and teachers are not given the required support to implement the material [22]. Therefore, it is necessary to provide students a clear learning outcome for the project as well as support to teachers during implementation [20], [23].

Although implementing PBL courses can be beneficial to students, developing a course for modern classrooms has become more difficult. One reason has been the increase in online learning. Large numbers of students participated in hybrid or completely online learning during the pandemic, and some argue that, at least in some capacity, online learning is here to stay [24]. This is further complicated by a shortage of teachers in K-12 classrooms. According to the National Center for Education Statistics [25], 44 percent of public schools in the US reported having a teaching vacancy. This means more students per teacher and more work for each teacher. Because of this, proper scaffolding in PBL courses is critical to allowing teachers to be good facilitators in a classroom of many students without having to invest substantial amounts of time into preparation.

The combination of a MOOC with hands-on PBL opens many options for students and teachers and adds the scaffolding needed for teachers overextended due to the current schooling culture. Courses can be taught in a traditional classroom where students watch lectures in class or at home in hybrid or completely remote learning with the option of taking part in the hands-on section. Additionally, the creation of a MOOC-style course allows for a larger audience of students who are not participating as a part of their curriculum. There has been some promise in the implementation of courses like this, but more research needs to be done.

Introduction to Rocketry MOOC

Course Structure

The MOOC with hands-on activity discussed here has a structure as shown in Figure 1. The first part is the online content that includes videos on rocketry and pre- and post-unit quizzes to assess student understanding of the material and concepts. Videos cover rocket hardware and design fundamentals and provide demonstrations on rocket trajectory modeling, construction, launch preparation, and analysis. The online content also includes a web-based applet for simulating and predicting rocket trajectories. All videos were written, presented, and produced by undergraduate and graduate engineering students with aid from professionals in education and video editing.

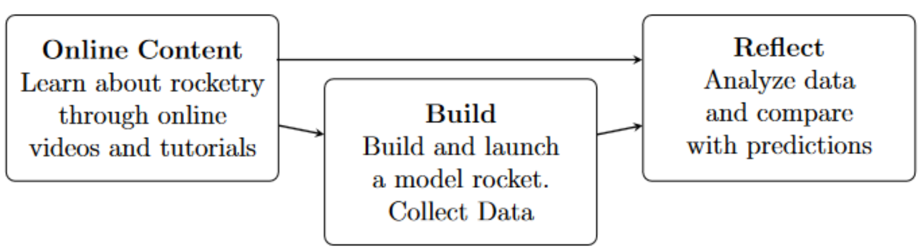

Figure 1: Course Structure

The second part of the course is the hands-on component where students build and launch a model rocket applying knowledge learned from the online content. Students use the data collected during their model rocket launch along with what they learned and modeled in the MOOC to analyze the flight and compare the collected data to their predictions. The course is developed so that these three parts can be taught as discussed or broken up and used in the way that is best for students and educators.

Online Content

The online content is broken up into the 5 units displayed in Table 1. These units cover the essentials for model rocketry, but also bridge the gap between model rocketry and full-scale commercial rockets.

Unit	**Videos**
Introduction	Why we go to Space
	Introductions to Rocketry
	Phases of Flight
Rocket Hardware	Rocket Bodies
	Rocket Engines
	Recovery Systems
	Launch Controller
	Electronics Bay (Avionics)
	Payload
Fundamentals of Rocketry	Center of Gravity
	Center of Pressure
	Equilibrium
	Low Velocity Stability
	High Velocity Stability
	Thrust, Weight, and Impulse
	Thrust to Weight Ratio
	Motor Selection
Modeling Rocket Mechanics	Derive and Describe Rocket EOMs
	Solving Approximate EOMs for Altitude
	Plotting Altitude (Google Sheets)
Analysis	Comparing Different Models (Part 1)
	Comparing Different Models (Part 2)
	Compare Flight Data to Predictions

Table 1: Video Lectures by Unit

The introductory unit explains why rockets are used and why the demand for space travel is increasing. Technical information about the stages of a rocket's flight is also provided and supplies the necessary context and terminology for the following sections. The rocket hardware unit provides foundational knowledge about critical rocket components. The section presents each part of a model rocket, explains its utility, and then gives details about how it compares to a full-scale rocket. Fundamentals of rocketry delves deeper into the fundamentals of rocket design and components' impact on the rocket's flight. This unit teaches the criticality of stability through the center of gravity and center of pressure and ends with an introduction to rocket performance parameters. Rocket mechanics is the heart of the course, with learning how to formulate a predictive model of the rocket's flight. The unit introduces the equations of motion and analyzes forces on the rocket allowing students to calculate the simulation of the rocket's flight. The course concludes with a comparison of predictive and experimental rocket flight. The analysis section enables students to develop data literacy skills by evaluating the strengths and shortcomings of their predictions as compared to the actual flight data.

Apogee Activity

The hands-on project involves using the models and data interpretation learned in units four and five. In this activity students are given a target apogee that they attempt to achieve by adjusting payload mass using multiple trajectory models. Students use Newton's Second Law of Motion and other fundamental physics equations to calculate the theoretical apogee of a rocket and then compare their data to the actual flight data collected from the launch. We also developed and provide access to an online applet that uses more advanced methods than are typical of high school and early college students. This applet allows students to adjust the mass and motor of their rocket to see how their model differs from ones that include drag or the variable thrust of a motor. These data are downloadable as a comma-separated values file, and students can compare these more complicated predictions with their simple prediction and then again to the actual flight of the rocket.

Assessment Development

Most online course platforms (Coursera, EdX, etc.) have quizzes that act as checkpoints after each section. Current literature suggests that frequent low-stakes quizzing is beneficial to students learning, so a similar format is used in this course with the addition of a baseline quiz [26]. The baseline quiz was created to determine what students know before starting the unit and is the same as the post-unit quiz. The difference in these two quizzes allows instructors to quantify students' progress throughout the course. The quiz questions were created by our team of rocketry and education professionals. We created questions from important concepts taught throughout the videos. Initially, the quiz questions were designed as open-ended questions. However, due to the challenging and intricate nature of these questions, it was decided to switch to multiple-choice questions for ease and efficiency.

Hands-on and Project Based Learning Content

We found that some students and teachers are either not interested or unable to participate in hands-on sections of the course, and in this case, the first five sections described above can be used independently as a MOOC. Current and past implementations of the course indicate that students gain the most from the course when they engage in both the MOOC and the hands-on build and launch section, but still gain a great deal of understanding and self-efficacy from the online course alone. When taking part in the hands-on portion, students become more curious and ask insightful questions they had not thought of during the earlier sections, indicating qualitatively an increase in student interest in further pursuing rocketry. These results are currently being studied more quantitatively in implementation of the course at the university level.

The instructional design is structured as first learning the theoretical concepts via video lessons, and then applying the hands-on kits to build and launch while making connections with the theoretical concepts. The hands-on kits allow students to learn by doing, while acquiring novel experiences with a rocket launch.

Once the analysis video lectures are complete (Table 1), the hands-on kit is introduced. The build video lessons provide not only a walkthrough of model rocket build instructions, but also connect the rocket build with earlier foundational and theoretical units and explain why each part of the rocket is being used. Table 2 shows the videos presented in this section. The build unit is designed to allow students to make connections between what is learned and how it can be applied in the real world. After building their rocket, students develop a model to estimate and predict the vertical flight and apogee using the rocket mass and average motor thrust. They use this model to determine the payload mass they need in the nose cone to achieve a desired apogee.

Unit	**Videos**
Build	Motor Assembly
	Fins and Launch Lug
	Nose Cone Cut
	Recovery System
Launch	Launch Environment
	Launch Site Selection
	Prepare Recovery System and Motor
	Prepare Payload and Avionics
	Launch Pad Set-up
	Launch Procedure

Table 2: Hands-on Course Video Content

Finally, the launch unit provides information and descriptions on how to launch a rocket, and the safety and logistical measures that must be considered. In-depth launch procedures are covered here to ensure the safe completion of the launch. After launch, students compare their rocket trajectory and apogee predictions to the recorded flight data and discuss any differences and what they would do differently next time.

Model Rocket Kit

The model rocket kit underwent many iterations with the goal of delivering a product to students and teachers that was straightforward and accessible yet was still complex and challenging enough to capture their interest. To achieve accessibility goals, the model rocket and its motor had to be small, cost-effective, and reliable, while still meeting the goal of the project (i.e., payload). Supplying a reliable system was essential to ensure students and teachers had a quality project. The current rocket and motor have been tested extensively through building and launching. We believe this is one of the most reliable rocket kits available, although we do find that model rocket motors and igniters have misfires due to incorrect ignitor or launch controller setup. Cold weather can also make it more difficult for the motors to ignite. However, these misfires are often easily fixed with a new igniter or adjusting the launch controller setup. In rare circumstances, the motor ignites incorrectly or not at all.

The size of the rocket was important because larger rockets require a larger motor, and correspondingly a larger launch radius. A typical high school baseball field provides about a 400 ft. launch diameter, therefore C-class motors or smaller were considered. Additionally, the rocket was required to have storage space for the payload and avionics. As a result, the Aerotech Quest Courier (Figure 2) rocket was chosen as the model rocket. The Estes C5-3 motor was selected as the recommended rocket motor for both safety and performance reasons that will be discussed in the lessons learned section below.

Figure 2: Quest Courier Model Rocket

For students to record flight data, they need an avionics system to collect data. There are countless options on the market that can collect a variety of data. Cost-effective options often only collect the apogee of the rocket. However, these simple avionics are still sufficient to compare to an apogee calculation and are recommended as an option for teachers and students, especially since they display data immediately post-flight. The recommended altimeter is the AltimeterOne from Jolly Logic (Figure 3) due to its reliability and accuracy. If there is a desire to collect more flight data, there are great options from PerfectFlite, but these cost slightly more and require data to be extracted on a MAC or PC. Development is currently underway for an option using a small Arduino that is compatible with Chromebooks.

Figure 3: JollyLogic Altimeter One with Quarter for Comparison

Implementation

The Introduction to Rocketry course was implemented in a high school class and as a college course. For the high school implementation, a condensed professional development event was conducted for physics teachers of varying class levels. The event covered all units, from rocket hardware to launch. Teachers built their own rocket and launched it in preparation for their own classroom implementations during which model rockets were launched. The classes ranged from physical science freshmen-level classes to honors physics senior-level classes. The presentation of the same course material to different class levels allowed us to visualize the challenges for all levels of high school classes.

The collegiate track was implemented through an 8-week university course for students of varying majors. The target audience was first- and second-year students, but some third and fourth years were enrolled in the course. The course material was provided online through the MOOC with the in-person build and launch sessions managed by instructors.

Lessons Learned

Course development of a particular subject like rocketry is often conceptualized by subject matter experts. It is critical to remember that it is not just knowledge that goes into developing a course. This was the most important lesson we learned in development for the course. The importance of receiving feedback from experienced educators, teachers, and students from day one was key. Since much of the course development occurred during the COVID-19 pandemic, receiving this feedback was more difficult. Teachers were overwhelmed and not interested in implementing new courses even if they included an online or hybrid learning method. Still, some iterations of this course could have been avoided had this principle been implemented from the start.

Development of Course Material and Structure

It has been known since the inception of the MOOC that student engagement drops significantly as the course progresses. Feedback from teachers indicated that they only assigned videos they deemed most important because they knew assigning too many would result in students losing interest. YouTube analytics suggested that on average students will not watch more than five minutes of a video. This agrees with the literature that recommends making MOOC video lectures a maximum of 6 minutes [27]. Multiple videos are around 10 minutes in length and were not shortened despite knowing this data. This decision was made because these videos are critical tutorials that guide students through problem solving. Even with the high dropout rate, these videos are high in viewership. This could mean that students come back to watch parts of the videos later, which is common in tutorial videos [28]. In the future, these tutorials may be re-structured to reduce the length and hopefully reduce the dropout rate.

Apogee Activity

It was not until after the course was developed that the team realized that learning about rocketry in tandem with assembling and launching a rocket was not yet a complete course. Students needed to be challenged to problem solve using what they have learned. Early pilot studies without the apogee activity showed that students sought more engaging material. To satisfy the need for more engagement, the payload and apogee activity was introduced. This activity opened many new doors for the course. We introduced students to different models that estimated the apogee of their rocket given a payload mass, then showed them how to plot and interpret these models while discussing their shortcomings. Finally, they compare their predictions to the real-world data collected during flight.

This activity meets the necessary Next Generation Science Standards (NGSS), which high school curricula follow as guidance, requiring manipulating data and using scientific methods. Knowing the importance of fulfilling these standards is a perfect example of the importance of having educational personal help in the creation of a course. Feedback from teachers shows that the benefits of this course go beyond the necessary high school standards because of the uncertainty in rocket flight. Because their predictions will disagree with flight data, students are challenged to think critically about the uncertainty in engineering, assumptions in their model, and how real rockets and rocket scientists might address these issues.

Early plans for this activity shifted too much responsibility onto students and teachers to learn new material. The first iteration had little scaffolding and only a short video that presented the activity. There were plans to have options for both python and spreadsheet plotting, but at high school PD events teachers explained that they, as well as the students, need more practice and experience in both software. Even with limited experience in spreadsheet software, teachers expressed excitement during the demonstration of the plotting in Google Sheets activity. Since receiving this feedback, the course was adjusted to include extra tutorial videos for the Google Sheets activities. Not surprisingly, this model is limited since it assumes that high school students are not exposed to calculus or numerical integration. This sparked the development of the online rocket trajectory calculator. The current model hosted on the SLI website calculates the trajectory using variable mass, thrust, and drag. Implementation into high school classrooms shows that some teachers skip the Google Sheets plotting altogether in favor of the simple and more accurate online applet. The key takeaway for us was discovering how difficult it was to balance complexity and novelty with such a large target audience. Providing options for the stakeholders like the plotting example is one instance.

Assessments

As mentioned in the previous section, quizzes were developed along with each section. Early iterations of the quizzes were free response questions. These free response answers helped inform instructors of students' misconceptions before and after they engaged in course content. They also informed content developers where videos needed to be improved. Current assessments are all multiple-choice answers. One reason for the change was due to the difficulty of the questions and the rigorous time-consuming process for grading.

Quizzes were initially distributed through Google Forms. Although they are easy to make and convenient for students, many problems arose for the instructors that precipitated a change in approach. The main issue was having immediate feedback. It was found to be difficult when collecting many questions and trying to link them through many surveys.

Model Rocket Kit

Early versions of the model rocket kit had a larger and more complex rocket. We ran into similar issues as the apogee activity where we did succeed in creating an exciting and novel course, but found it was too complex and not accessible to most high school students and teachers. Aside from the difficulty, the cost was also a significant factor in whether teachers would be interested in implementation. Also, the launch could not be done on school grounds. Transportation requires additional costs and logistics that teachers often do not have the support and funds to make possible. Considering the facilities available at high schools, we decided to work around the typical 400 ft. dimension of high school football/soccer practice fields. This feedback forced the rocket to be scaled down in size to meet these requirements.

The purpose of the rocket launch is to test various payloads to visualize the difference in apogee. Because we are adding extra mass to the payload, the motor was required to produce a large thrust force in the beginning for a safe takeoff, but a small enough thrust so that the rocket landed within the desired launch radius. Commercial rocket motors have specification values showing the full thrust curve as well as the average thrust, maximum thrust, and thrust duration. Solid rocket motors use lettering to display the impulse classification, A being the smallest. Using the constraints discussed above, a selection of B, C, and D motors were tested as possible candidates. After testing in the field, the Estes C5 motor was determined to be the best fit for the course. This was mainly due to its unique thrust curve (Figure 4).

The thrust curve in Figure 4 displays a graph of thrust vs time. To overcome the limitations of a heavy rocket takeoff, we looked for engines with a high thrust in the beginning that would ensure a safe takeoff (if the rocket comes off the rail slowly, it is unstable). What also needs to be considered is the delay charge (time between thrust and parachute deployment). After considering the range of payload mass for the rocket, the optimal delay charge for all rockets was the best at around 3 seconds, therefore we use the motor C5-3.

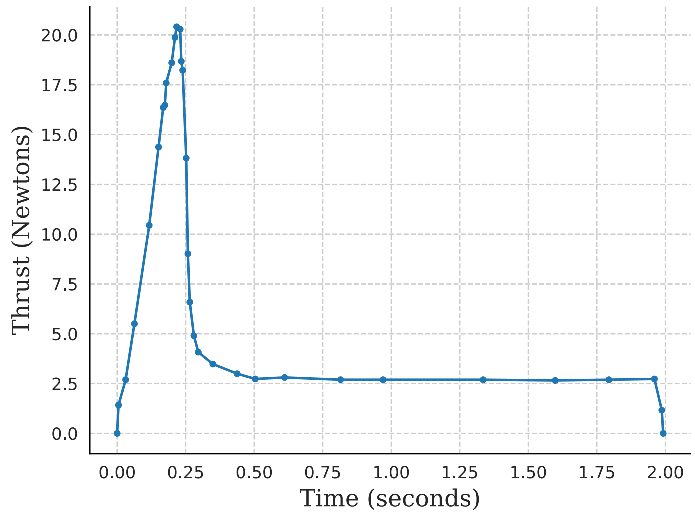

Figure 4: Estes C5 Thrust Curve

Launch Troubleshooting

The high school implementation informed us that the teachers were unfamiliar with how to address rocket launch failures. Nine teachers conducted this course totaling the participating students to about 350 students. Each class consisted of around thirty students with some teachers instructing multiple classes. The teachers dedicated a launch day where all classes staggered throughout the day to perform launches. Each class period was managed by different teachers, all of whom attended the professional development sessions. Because the teachers had to supervise so many students, they reached out to us for launch assistance. On the launch day, we helped prepare rockets for the launch by helping with technical procedures including parachute packing, motor and igniter installation, and payload and avionics setup. During the launch, many model rockets experienced failures, due to several reasons including motor failure, improper build, and misuse of the launch controller. The teachers were undertrained for these situations involving launch failures and had to rely on us to address the problems. We realized that more detailed professional development sessions are needed to train implementors of the course to ensure the safety and success of rocket launches.

Despite launch difficulties, students responded positively to the experience. Feedback from undergraduate pilot studies and high school teachers say that the hands-on experience makes students more engaged and excited to learn. This was true across all levels of students taking the course. Seeing what they built launched three hundred feet into the air made the course worth it even for the students that had struggled during the online section. Students were often competitive when trying to match their rocket’s flight to their model and they were always excited for opportunities to do additional launches.

High School Classroom Implementation

Due to restrictions within high schools to ensure safety of students, the biggest roadblocks to high school implementation are accessibility issues. Issues arose from launches, as mentioned above, the use of Google Chromebooks within classrooms and language barriers. During our implementation attempts at high schools, we realized many high school students do not have computer labs available and are restricted to using Google Chromebooks. In addition, Chromebooks used in high schools have a firewall installed that restricts the use of external websites and software. This limited the use of any downloadable software. We initially planned to use the OpenRocket software for rocket modeling and other software for collecting, analyzing, and interpreting avionics data. Since this clearly was not accessible to most high schools we developed instead an entirely web-based, open-access, publicly available course.

The first online classroom platform we chose was Google Classroom due to its easy access to Chromebooks, which was a viable choice for both instructors and students. However, Classroom required the usage of Gmail, which for some schools, instructors were restricted to using school-linked accounts that limited access to the class from any external accounts. Instructors and students limited to using school-linked Google accounts could receive the online classroom material from us only if everyone made a personal Gmail account. This was often restricted within schools and was not allowed for usage. The efforts of sharing the online classroom material were restricted and had to rely on high school IT departments to alleviate firewall restrictions. Also, Google Classroom could only be accessed by sending invites through Gmail. There was no option for publishing Classroom publicly for everyone to view, defeating the purpose of the “open online class.” The instructors who wished to view our content had to be invited to sign up individually. With these restrictions in mind, we decided to develop an all-web-based public classroom platform addressing the above-mentioned challenges.

Initially, we designed the course activity around the OpenRocket software, a model rocket simulator. This activity was quickly changed to the current Apogee Activity using Google Sheets in accordance with Chromebook access. However, we still needed to provide an easy option to calculate the apogee, which was one of the options embedded within OpenRocket. Therefore, we developed a public online calculator, which allows users to input mass of the rocket and select motor type and then use the applet to calculate and output graphs showing the trajectory of the rocket and the apogee value.

Many high schools have English as a Second Language courses (ESL), which means videos in English may not work. Adding Spanish closed captioning has helped with this, and we hope to address more issues with language barriers in the future.

As the results from high school implementation and PD events showed, the need for scaffolded content was urgent. The teachers were mainly concerned about the length of the course and felt hesitant about incorporating the whole course. The four-to-six-week length of the course was a rigorous task for teachers to blend this MOOC into other ongoing class activities. Teachers are faced with fulfilling required topics throughout their classroom timeline with limited time for additional elective material. Although they worried about the time commitment, the teachers loved the apogee activity and comparing predicted data to experimental data. They noted that this is an activity that allows students to apply mathematics to science where they could visualize the data produced from their own experiment(s) (rocket launches) and compare it to calculated values (trajectory/apogee predictions).

A high school teacher quoted, "Our students, as most students, learn best when engaged with hands-on projects. We have incorporated as many real-world data collection opportunities as possible into our curriculum, and a rocketry project would take our data collection to a whole other level. We serve many bright students who lack the means to take part in engineering hobbies outside of the school setting such as model rockets, model cars, or even Legos. Being able to supply this type of engineering and science opportunity would help open the door to scientific curiosity for so many students who have had limited experiences in this area." A participant, a student in the classroom commented "I really enjoyed the rocketry course especially getting to build and launch the rocket. It really helped me to understand the rocket better. I even have the rocket hanging on my bedroom wall now."

This activity could be implemented in ongoing curriculums and would be of benefit to the students. Even though the content was lengthy, teachers wanted to use parts of the course, perhaps using a condensed list of videos covering just enough content to help understand rocketry and perform activities. The need for a condensed curriculum was repeated to us by teachers throughout all PD events and with the high school implementations.

College Course Implementation

The same version of the course was piloted as an introduction to rocketry course at the University of Illinois at Urbana-Champaign (UIUC). The course consisted of the same online videos and hands-on activity and was conducted by an instructor overseeing the self-guided online course. The 8-week course encompassed all online material within the first 5 weeks, then performing the in-person model rocketry activity for the last 3 weeks. Participants were recruited through advertising on various university platforms and were self-registered. Unlike the high school students who took the mandatory course, some of these college students had a pre-existing knowledge in rocketry. To better understand the participant demographics and prior experience, students were required to fill out an application form consisting of questions about their background and previous experience with online courses and model rocketry.

Throughout the course, the students' progress was closely monitored, and multiple reminders were sent to ensure the completion of assignments. The unit videos were presented on a week-by-week basis, accompanied by pre- and post-unit quizzes that were graded upon completion. After the hands-on course was complete all the quizzes were then administered for a third time. Preliminary results for each of these quizzes are shown in Figure 5 outlining the trend for the technical assessment scores. On average, technical knowledge quiz scores increased after the online section and decreased after the hands-on section. It was clear from instructor observations that the majority of students were engaged and excited to take part in the hands-on section, which may suggest that the drop in scores may have to do with something other than interest in the material. The significance of these changes as well as further tests including student engagement and retention rate will be addressed in a future publication.

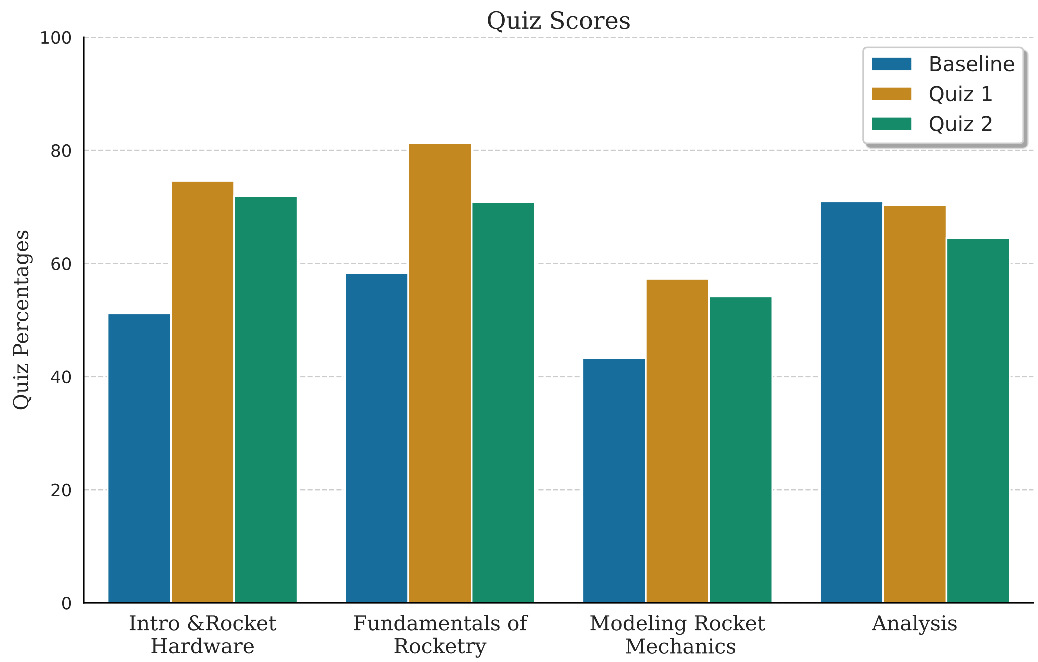

Figure 5: Average Quiz Scores for Each Unit of the Online Course

All students were able to complete the build and launch under instructor guidance. Both video and written launch procedures were provided, but it was clear that many of the students had not studied them because few students knew what to do on launch day. This is likely because they knew there would be assistance at the launch site and would be no written quiz. In the future, a written quiz outlining launch procedures should be administered to ensure a smooth and safe launch day.

The hands-on activity seemed very accessible to college students although students with stronger backgrounds in math and science might have benefited from a more advanced course. Most college students that took this course had previous experience in coding, and this allowed students to easily determine the necessary payload mass for a given target apogee. Some ways to improve the experience for college students would be introducing a more advanced avionics system and requiring students to predict the flight trajectory using a model that incorporates drag. In light of this information, the team is in development of an Arduino avionics system that requires some more work upfront to prepare but produces a full flight trajectory rather than just an apogee. Also being developed is a Python version of the course that would replace the Google Sheets requirements.

After delivering the course to a diverse group of students with varying academic backgrounds, it became apparent that there was a need for different versions of the course to cater to the students' different skill levels. Of course, it can never be perfectly calibrated for every skill level, but we feel that there are easy fixes that can make the material challenging and interesting for both college and high school students. This could be achieved by differentiating the types of computer software used, assumptions made within the rocket trajectory equation, and by using more advanced rocket and avionics systems. By doing so, the level of difficulty can be adjusted to better match the target group of students.

Current Course

The current iteration of the course is found at https://learnrockets.spacelab.web.illinois.edu/course-toc?course=6. A public version of the course is available with video content and information on how to implement the course. Links to federal grants are also available our website https://spacelab.web.illinois.edu/.

Conclusion

What are important considerations when developing a MOOC with a hands-on project and what challenges and limitations are added when implementing a MOOC in high schools and colleges?

Despite the emergence of MOOC incorporating hands-on activities in the course, there is limited understanding on how these are adapted into hybrid learning environments. Because of this, testing the course and receiving student and teacher feedback helped immensely in making improvements. During initial development there was a sense that the expert knowledge of rocketry and engineering would be more than enough to produce an effective course. However, it was quickly realized that without educational expertise and stakeholder feedback a course like this cannot succeed. MOOCs are not like other courses, which is why it was necessary to involve UIUC's Center for Innovation in Teaching and Learning who had experiences with developing videos for courses like MOOCs and other online learning content.

Hands-on projects can greatly benefit students, but it is important to consider not only the skill level of the project, but also how accessible they are to your target audience. An important consideration was the tools required to build the rocket. Many high school and college students have not operated drills and saws before. Although the tutorial videos show techniques for safely using the tools, there are still safety concerns in a classroom of many students and one teacher. It is crucial that the project be safe, but also that there are some challenges and learning opportunities left for the students. In the end, we were able to provide safer opportunities for tool use by removing the drilling steps by simplifying the rocket. The students avoided the usage of power tools and were only required to cut through a part of the rocket's nose cone using a box cutter or saw. These steps were necessary for students to make space for their payload, one of our key learning opportunities.

Implementation is dependent on and should be tailored by the teacher to their students' needs. The iterations discussed in this paper were primarily aimed to facilitate teacher implementation rather than focusing on the inadequacy of the students. If we want this course to inspire students who are not already interested in rocketry, it must be put into classrooms and be straightforward for the teacher to understand and implement in these broad-reach learning environments such as science classrooms.

The most difficult part of implementing this MOOC course with hands-on model rocketry was developing the scaffolding that would allow the course to stand on its own. So far, the development team has had to assist during the hands-on section for the course to work. This is a huge limitation if we want the course to be used across the country.

What are the benefits of delivering a hands-on experience with a MOOC? Does this course encourage students to consider space related careers?

Student and teacher comments about the newest version of the course have been positive overall. In the first part of the course, MOOC attrition is still as high as in other courses, but the hands-on activity appears to reignite students' interest and encourages them to go back and watch videos a second time. Whether or not this interest is increased after the course is still undetermined and a current study is attempting to answer this as well as the quantitative impact of the hands-on part. Preliminary data shown in Figure 6 indicated that there is some increase. Whether this increase is significant will be discussed in a future publication.

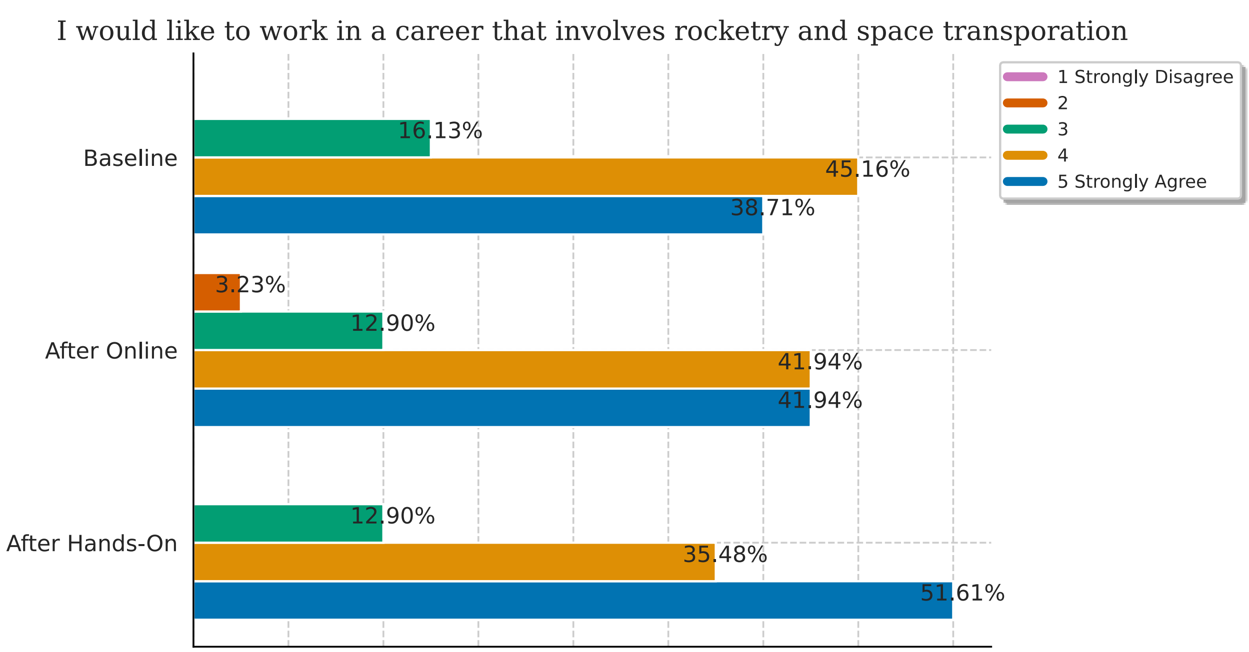

Figure 6: Students' Response to Career Interest Question in College Implementation

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