DEVELOPMENT AND EFFICACY OF AN INTRODUCTION TO ROCKETRY COURSE ON STUDENT KNOWLEDGE AND INTEREST IN AEROSPACE
FOR
EXPANDING THE PIPELINE AND ENHANCING EDUCATION OF STUDENTS PURSUING CAREERS IN SPACE

BY

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THESIS

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ABSTRACT

As part of the Department of Defense's initiative to increase the number of students interested in pursuing careers in the space and defense industry several courses and challenge projects were developed by SpaceLab Illinois. These projects are meant to increase awareness of career opportunities in the space and defense industry. The flagship course is the Introduction to Rocketry course which is intended for high school and early college students. The course is a combination of the Massive Open Online Course (MOOC) and hands on model rocket building. Often referred to as a Bended MOOC, this course is intended to be as accessible as possible for students and teachers so that it can be accessed, understood, and completed by almost anyone in the target audience.

Not much is known about the development and effectiveness of blended MOOCs, likely because of the difficulty to implement such a course. The move to an online focused classroom in recent years has made educators more open to implementing online courses. This allows students access to up to date and expertly taught content that might not be possible in a traditional classroom. Still, it is important not to lose sight of the benefits of students experimenting and learning in the classroom with their teacher.

The studies presented in this paper attempt to provide insight into the efficacy of the introduction to rocketry course developed. Specifically, does the course increase students' technical knowledge and interest in aerospace? Along the journey of the development of this course and the research into its effectiveness, many challenges were encountered. This paper will also present qualitative findings from this journey to assist future educators and researchers if they should choose to develop a similar course.

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CHAPTER 1: INTRODUCTION

An introduction to rocketry course at the University of Illinois was developed through funding from the Department of Defense (DoD) and the National Defense Education Program (NDEP) for Science, Technology, Engineering, and Mathematics' (STEM) Education, Outreach, and Workforce Initiative Programs. The goal of this program is to inspire and prepare a new generation of engineers and scientists to participate in the new space and defense industry. The growth of the space industry has driven a need for a new, bigger, and more diverse generation of young people. Students who take the rocketry course will learn not only the basics of rockery, but also gain insight into what aerospace engineers work on and the goals of space companies.

The space industry has grown significantly over the past five years and there are more roles in space than people to fill them. A report from the Space Foundation found that the American space workforce saw a five-year growth of eighteen percent, while at the same time colleges in the United States saw a five-year decline in students pursuing engineering degrees [1]. A shortage of qualified engineers is not the only issue in the industry. In 2019 and 2020, fifty-six percent of the U.S. Citizens who graduated with a bachelor's degree in aerospace engineering were white males and fourteen percent were female, according to National Center for Education Statistics [2], [3]. Research has shown the positive impacts of diversity and performance in other workplaces [4] and there is no reason to think it wouldn't benefit the aerospace industry. Providing high school and college students the confidence to pursue a career in aerospace, especially those who would not typically pursue this type of career is our attempt to solve these issues. Development and operations of aerospace technologies, particularly space and defense, are by nature large and expensive. Understanding where they fit in can often be hard for students looking for a career. The course discussed in this paper along with the outreach alongside it are aimed to get students excited about aerospace and give them an idea about what is involved in participating in aerospace projects like rocketry.

The goals of this project were to inspire students to pursue a career in aerospace engineering, especially those who might not otherwise have considered it and increase the rocketry knowledge of all students taking the course. To achieve these goals, we had three objectives. First, create online rocketry courses with a hands-on component. Second, get this content into the hands of teachers and students at the high school and college levels. Three, assist future educators in the development and implementation of this course and similar courses. This paper will present the findings from carrying out these objectives. During the development and implementation of our course we deemed it necessary to assess its effectiveness. Along with a qualitative analysis of course development quantitative results will be presented from a pilot course at the University of Illinois Urbana-Champaign.

CHAPTER 2: A QUALITATIVE EXPERIENCE WITH THE DEVELOPMENT AND IMPLEMENTATION OF ONLINE AND HANDS-ON ROCKETRY EDUCATION AND OUTREACH

2.1 INTRODUCTION

As discussed in chapter one, the space industry has been growing and a diverse group of young people pursuing space related careers would be of great benefit to most aerospace companies. The coursework presented in this chapter is aimed at providing students with knowledge and efficacy in space related topics, particularly rocketry. SpaceLab Illinois [5] (SLI) is a team of aerospace and educational students and professionals created to address these issues. By creating an accessible and interesting rocketry course, SLI hopes to increase the understanding of what a career in the space industry is like and inspire some students to join the industry.

Creating accessible coursework that can be inserted into a variety of classrooms is clearly a challenging feat. Luckily the advances in online learning have provided an easy way to provide educators with ready to use coursework. The massive open online course (MOOC) was created in part to address this. Websites like Coursera, EdX, Canvas, and others have been successful in providing students and teachers with exceptional coursework that depends only on the mostly of the experts who designed the course. According to the National Center for Education Statistics [6], 44 percent of public schools in the U.S. reported having a teaching vacancy. This has without a doubt created more work for each teacher and less time to focus on learning and presenting students with the most modern set of courses. This is why we chose to create a MOOC style course. Without the stress of learning and creating course material and delivering lectures on the material, the classroom is flipped. Teachers can spend more time with students during the day while students watch lectures for homework. The MOOC structure alone as described here works great for many topics, but engineering and science often require experimentation and experiential learning. Because of this, it was decided that a hands-on component of the course would be added. Although the course is designed to be inserted into a classroom all of the material is publicly available like any MOOC on the SLI website [5] and does not necessarily needed to be completed in the classroom.

Hands-on projects in the classroom have been shown to enhance student knowledge, their interest in the subject, and confidence in themselves to participate in simper projects in the future. Integrating hands-on activities into MOOCs could provide the benefits of project-based learning (PBL) and hands-on learning while being more accessible to teachers. With these ideas in mind the SLI team decided to develop a hands-on rocketry course that gives lectures in an entirely online format. Along the journey of the development of this MOOC with hands-on activities and the research into its effectiveness, many challenges were encountered. Countless iterations were made based on discussions with educators and students. This chapter reports on the experiences while developing and implementing both the online and hands-on part of the introductory rocketry course and the outreach in high school and college classrooms. The benefit to educators is to understand how and why they might want to implement this or a similar course into their own classroom. If you are an educational researcher or looking to develop a new course with similarities to ours this chapter will give guidance based on lessons learned from our successes and failures in development.

The course developed is Introduction to Rocketry, which combines two types of educational resources: A web based MOOC style rocket science course and a hand-on model rocketry project. Insights into how these were created and experiences on implanted, and outreach are described in detail. Specifically, we hope to answer the following,

- 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?

Much of the content in this chapter was a collaboration between me and multiple authors and will be published in the Conference Proceedings of the American Society of Engineering

2.3 INTRODUCTION TO ROCKETRY BLENDED MOOC

Before diving into the lessons learned from our course development and implementation an overview of what the final course consists of will be discussed. This section will cover the entirety of the course as well as were and how it was implemented in classrooms.

2.3.1 Course structure

As mentioned in the introduction, this Introduction to Rocketry course is broken down into two parts. The first is an online course that mimics the style of most MOOCs seen on platforms like Coursera, EdX and others. The online content is broken down into five sections that gives students the basics of model rocketry and all the tools they need to participate in the hands-on project in the second part of the course. This second part is the hands-on project which is broken up into four sections. The first section is the rocket build. The second section is what we call the apogee activity. Students will use what they have learned to make predictions about their rocket and adjust their payload to achieve a desired apogee. After they have built their rocket and made their models, they will launch their rocket. Finally, the students use their data along with what was learned in the course to analyze their results and report on their findings.

Figure 1 displays the flow of the course. We have done our best to make the hands-on project as simple and affordable as possible, but it is understandable that not everyone will be able to participate in it. Because of this fact it is possible to participate in the course without the rocket build and launch. In this case you would create your model and be given sample data to compare with. In Figure 1 this version of the course would follow the top arrows through "Online Content", "Make Predictions", and "Reflect" using the sample data. Teachers may also want to reuse rockets skipping the build but collecting data through a rocket launch. We recommend following the entire course in Figure 1 building a rocket and collecting data through the launch due to the great benefits hands-on learning has for students.

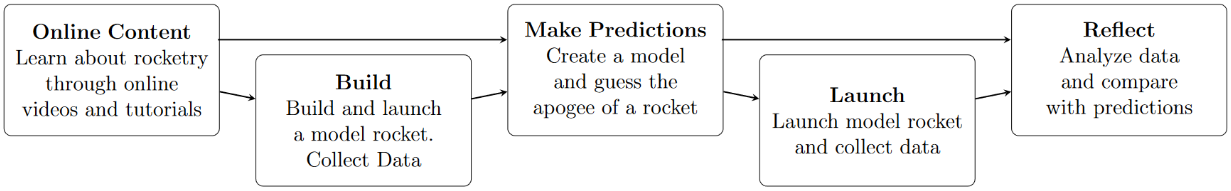


Figure 1: Possibilities for course structure

Like many online courses checkpoints and quizzes are given along the way to help students retain their knowledge and let them know if they are catching everything in the videos. The SLI team has developed four quizzes that go along with the online videos. We like to give them to students before and after learning so students know what to look for and so that we can track their improvement.

2.3.2 Online Content

The online content consists of thirty lecture videos, shown in Table 1, which in total last about two hours and fifty minutes. All the videos were developed and presented by undergraduate students pursuing a variety of STEM majors at the University of Illinois Urbana-Champaign (UIUC) and supervised by myself and another graduate student. Figure 2 shows a screenshot of one of our students presenting the phases of flight from the Introduction unit of the course. The course objectives and video topics were created by the entire SLI team and were iterated numerous times based on implementation and feedback that will be discussed in detail later in this chapter.

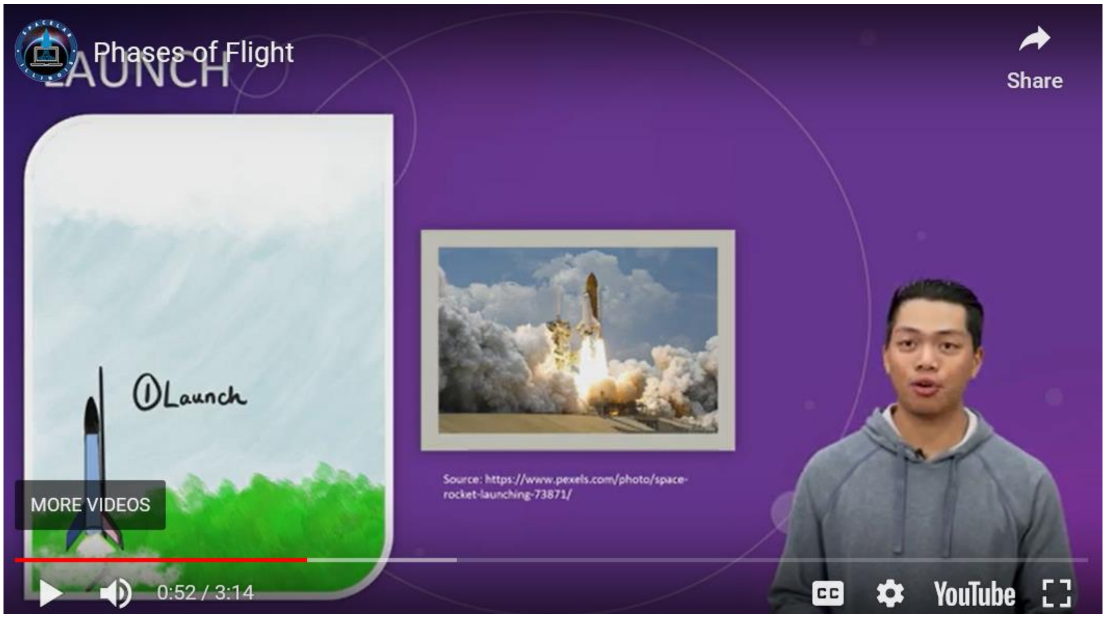


Figure 2: Video on the phases of a rockets flight presented by a UIUC engineering student.

The final course consists of five units, displayed in Table 1. The introduction section discusses the importance of space exploration and gives a brief overview of model rocketry and how it relates to full scale rockets. The goal of this unit is to get students excited about completing the course and feel like by participating they will receive valuable expertise. The next unit, Rocket Hardware, is exactly what it sounds like. Seven videos talk in detail about each part of a model rocket and why it is important. Along the way examples are given for the similarities and differences between the hardware on a model rocket a real space launch vehicle. These first two sections are combined into a single quiz since they are relatively short compared with the last three sections.

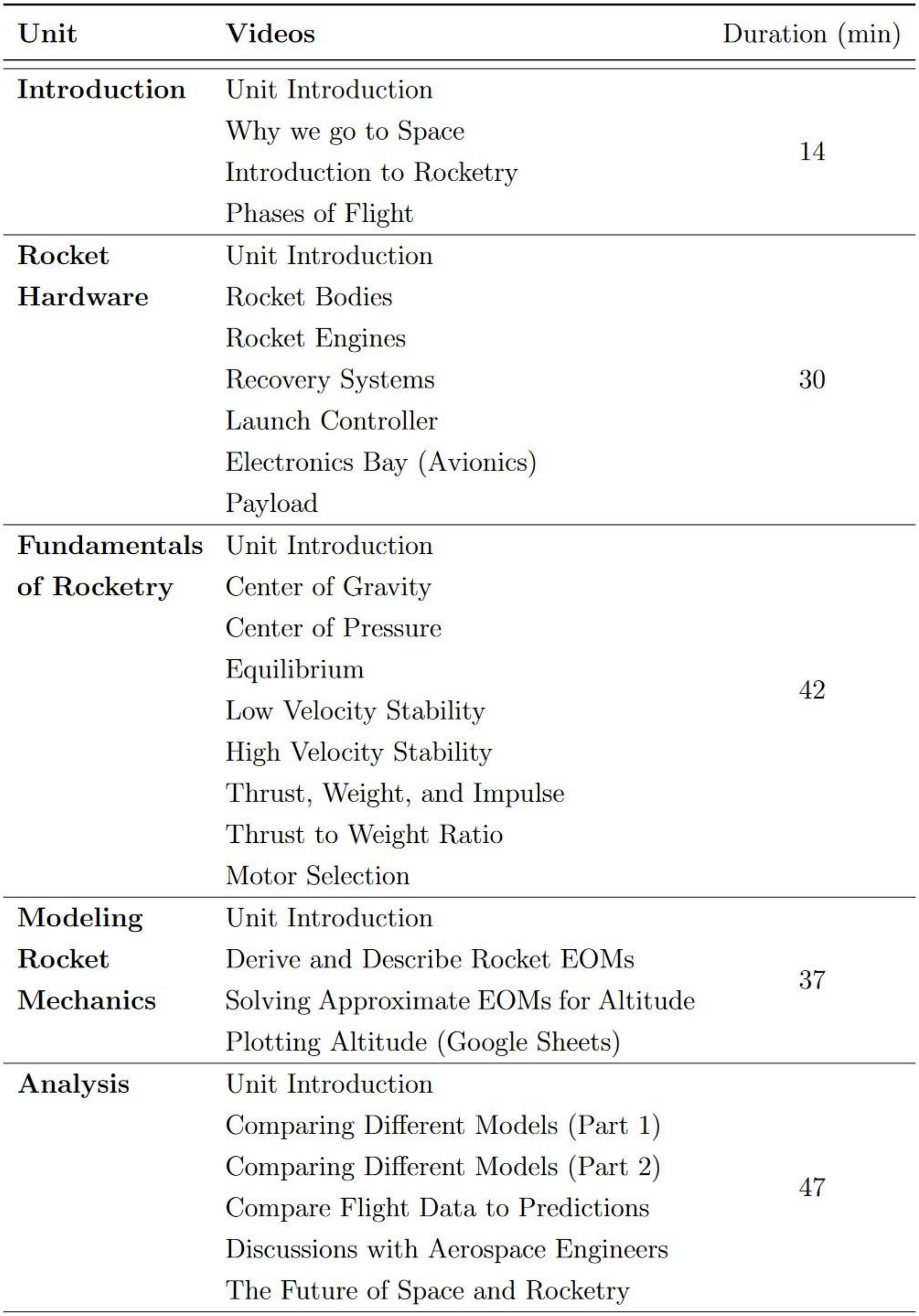
The next unit covers basics physics concepts that are necessary to understand how any rocket works. Topics in this section are relevant to many physics' courses, not just rocketry, but as the title suggests they are fundamental to understanding rocketry. Equilibrium and stability are critical to building a safe rocket that flies the way you want it to. Almost every video in this section somehow relates to ensuring students understand these two concepts and why they are important. For example, the center of gravity must be behind the center of pressure and the thrust to weight ration should be high enough to allow for rocket stability off the rail.

The Modeling Rocket Mechanics unit was developed to assist with the make predictions part of the course (Figure 1). After attempting to implement the course it was evident that students and teachers struggle with these modeling techniques and more guidance was needed. This section discusses newtons second law of motion and derives and describes, without Drag, the kinematics equations. Then these equations are used to calculate an approximate apogee given constant mass and thrust for your rocket. Finally, students learn how to use spreadsheet software to do these calculations over and over at different times, creating a plot of the approximate rocket trajectory.

The last unit in the online course covers how to analyze the rocket trajectory data. Why does the plot look the way that is does and what does it mean? Students learn the answers in this section. Students will also learn how to compare their model to experimental data and determine why they might be different. Another important part of the section are the "Comparing Different

Models” videos. Since most students will not be able to use drag in their models, an online calculator was developed that includes drag. These videos compare the online calculator to what students created in google sheets and discuss how accurate each of them is and where the shortcomings of each arise. The end of this section talks less about analysis and more about what it looks like to have a career in aerospace. Interviews were conducted with students and aerospace professionals about their career path and current roles. The last video discusses what the future of the industry holds.

Table 1: Video lectures in the Introduction to Rocketry course



Unit	Videos	Duration (min)
Introduction	Unit Introduction	14
	Why we go to Space	
	Introduction to Rocketry	
	Phases of Flight	
Rocket Hardware	Unit Introduction	30
	Rocket Bodies	
	Rocket Engines	
	Recovery Systems	
	Launch Controller	
	Electronics Bay (Avionics)	
	Payload	
Fundamentals of Rocketry	Unit Introduction	42
	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	Unit Introduction	37
	Derive and Describe Rocket EOMs	
	Solving Approximate EOMs for Altitude	
	Plotting Altitude (Google Sheets)	
Analysis	Unit Introduction	47
	Comparing Different Models (Part 1)	
	Comparing Different Models (Part 2)	
	Compare Flight Data to Predictions	
	Discussions with Aerospace Engineers	
	The Future of Space and Rocketry	

2.3.3 Apogee Activity

After students learn how rockets work and how they might model them they will go on to create their own model using plotting software of their choice. It was decided due to accessibility reasons that google sheets would be supported in the videos, but if students are comfortable using excel, python, or anything else they are not prohibited from doing so. Students start by using Newtons second law and come up with equations 1 and 2, displayed below, that describing the rockets flight. Equation 1 describes the boost phase when the motor is burning. Here the mass of the system is decreasing since the motor is throwing propellent out of the rocket, the thrust is variable as will be discussed later in this section, and the drag is dependent on velocity (Equation 3) which is also changing. Since many students will not be well versed in numerical integration or calculus, they will drop the drag term and assume that the mass and thrust are constant to get an approximation for the trajectory. During the coast phase the mass of the rocket is constant since the motor is no longer burning, but the drag still changes with the velocity.

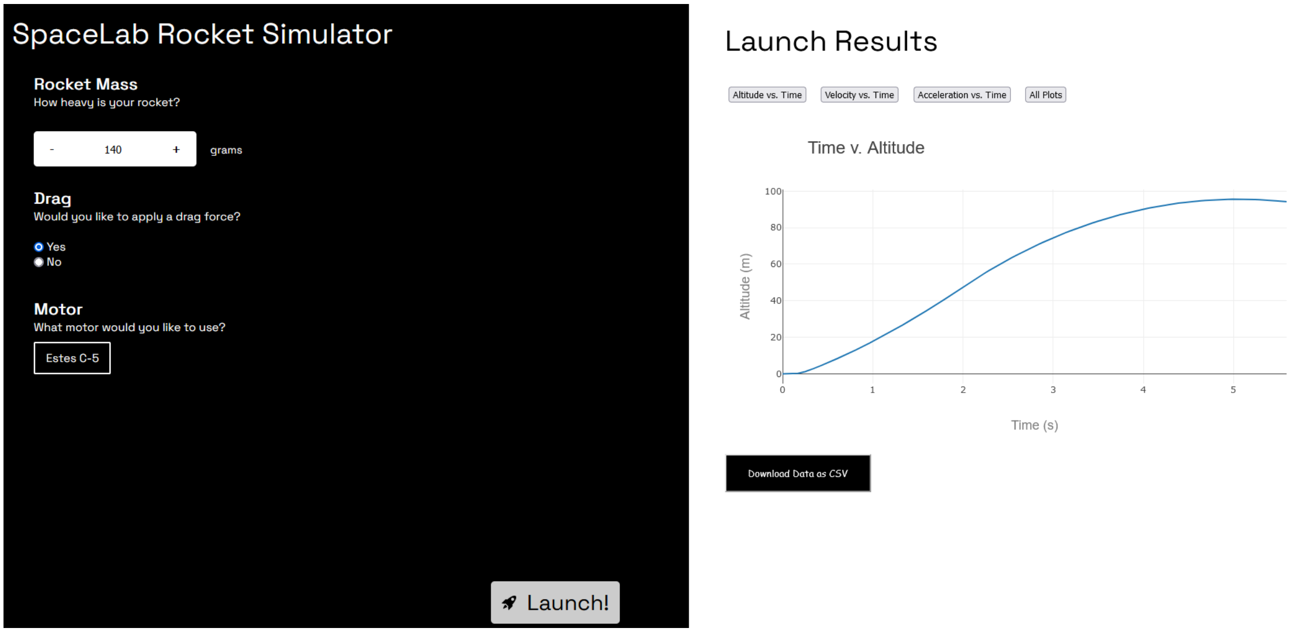
$$F_{boost} = -\,Weight + Thrust - Drag \tag{1}$$

$$F_{coast} = -\,Weight - Drag \tag{2}$$

$$Drag = (Drag\ Coefficent) \cdot \tfrac{1}{2} \cdot (Air\ Density) \cdot velocity^2 \cdot Area \tag{3}$$

Obviously removing the drag term will give them an incorrect estimation for the rocket’s trajectory. The SLI team also created an online applet that helps students see what the rockets flight would look like with drag using more methods likely too advanced for a high school or college student [7] . The applet allows them to adjust the mass and motor and see how it impacts the rocket’s flight. A screenshot of the website is shown in Figure 3. The simulator uses motor files from thrustcurve.org which include variable mass and variable thrust over the motor's burn time. Drag parameters were calculated by creating a model of our rocket in a software like OpenRocket [8]. With all these values known the equations above the equations were integrated using the fourth order Runge-Kutta method [9]. The simulator allows students to see acceleration, velocity, and altitude plots and download the data as a comma separated values file. The output has been fairly consistent with experimental results.

Many teachers want to skip the student model in google sheets since it consistently gives an altitude ten to twenty meters over the online simulator. We believe that the students working it out themselves first is extremely important. It makes the simulator less of a black box by giving them an understanding of how it works. They see the drag equation and the issues that arise if they were to try to use themselves. Then the makes calculations without it but can try to make out how they might incorporate it once they move on in their mathematics courses.



SpaceLab Rocket Simulator

Rocket Mass
How heavy is your rocket?
140 grams

Drag
Would you like to apply a drag force?
● Yes
○ No

Motor
What motor would you like to use?
Estes C-5

Launch Results

Figure 3: Online Rocket Simulator

Once students have created their models and compared them to the online simulator, they are given a target apogee. This is to represent a real space mission. No rocket is just shot in the air for fun, they deliver payloads to a certain place in space. Students can decide what payload they want to add to achieve a mission of their choice. The use the simulators to determine how much of this payload is to be added in order to make the rocket peak at their mission's target apogee.

2.3.4 Assessment Development

Like the popular MOOC platforms online, we created checkpoint quizzes for students. This was decided not based on what these other platforms have done, but that the research suggests that 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 [10].In addition to these quizzes a baseline quiz was created to help determine how much student actually had improved after taking the course. Some students will come in knowing some of this material and maybe the questions are too easy for others. Quizzing students before helps us get a better understanding of the effectiveness of the course material.

Questions were created based on important concepts taught throughout the videos. Quiz questions were initially open-ended and free response. These turned out to be too challenging and hard to assess. The team decided to switch to multiple-choice questions for a more realistic difficulty for an intro course and grading efficiency.

As discussed previously the course structure was broken down into four sections. Students first build their rocket, then make predictions, then launch their rocket, and finally analyze the data. In some cases, teachers or students are not interested in putting in the extra time, effort, and money to use the hands-on part of the course. If this is the case, it is possible to use only this course up to this point and then analyze sample data. We have found through both qualitative and quantitative studies that students get the most out of the course when they use the hands-on project. When building and launching the rocket, students get excited and curious about engineering. In chapter 3 it will be shown quantitatively that student’s interest and self-efficacy in rocketry also increase. Because of these findings we recommend the hands-on sections presented not be skipped over.

2.3.5 The Hands-on Project Tutorials

This part of the course does contain online video tutorials to assist teachers and students with the build and launch of their rockets. As shown in Table 2, there are a total of twelve videos lasting about an hour and ten minutes total. The build videos are not required to complete the course. These tutorials are accompanied by a set of instructions that students may use if they prefer them to the videos. The benefit of the videos is the students reiterate the importance of each component of the rocket and explain why it is there along with showing how to actually build this courses model rocket.

The launch videos also come with a set of written documentation for teachers and students may not need to know all the details, but it is recommended that these videos are still watched by students since they include important safety information. For example, teachers will likely enforce launch procedures, but it will be much easier if students learn them ahead of time and understand why they are done. There may be misfires while launching, these videos will give students information on what may have gone wrong and how it can be fixed for a successful future launch.

There are videos in the Launch unit that describe the launch site selection and environment. Students will likely not need to select the launch site, but we decided to include this information in case they wanted to try model rocketry as a hobby. Also, although the course was initially intended to be inserted into a classroom all of the material is publicly available like any MOOC on the SLI website [5] and can be completed in other settings like after school clubs. As mentioned in videos and course documentation, if completing the hands-on part of the course it is important to contact your local National Association of Rocketry (NAR) club for information on safe launch sites and procedures in your area.

Table 2: Hands-on tutorial videos

Unit	Videos	Duration (min)
Build	Build Introduction Motor Assembly Fins and Launch Lug Nose Cone Cut Recovery System	46
Launch	Launch Introduction Launch Environment Launch Site Selection Prepare Recovery System and Motor Prepare Payload and Avionics Launch Pad Set-up Launch Procedure	24

2.3.6 Model Rocket Kit

Over the past two years of development the model rocket kit has gone through the most iterations. Complete explanations for the selection of the materials outlined in this section will be described in the lessons learned section. This section focuses on what the current hands-on kit looks like and gives a brief overview of why it was selected. As you will discover, most of the iterations stemmed off the fact that achieving the goals of this course meant the kit needed to be accessible and cost effective, but still exciting so that students are interested in the project.

The Quest Courier model rocket was selected as the model rocket, displayed in Figure 4. This rocket has plenty of room for payload and an altimeter in the nose cone and can be built in only two to four hours. The rocket is simple, it includes few parts, all of which arrive in the kit when purchased, and requires only glue and a box cutter to complete. Through rigorous testing the SLI team considers this this kit to be reliable and of good quality, making it perfect for a classroom.

Figure 4: Quest Courier Model Rocket

The size of the rocket was an important consideration. Larger models necessitate more powerful motors which require larger areas for launch. To create an accessible course for high school and college classrooms we determined that the launch area could be no larger than a baseball or football field. This amounts to roughly a 400 foot launch diameter which meant we were limited to A, B, and C class motors. Motor lettering signifies the total impulse of the motor, A being the smallest. The NAR uses these impulse values to recommend how large your launch radius should be. It would seem like a small motor would be better for this situation, but we had a few other things to consider. First, we wanted students to be able to add significant payload mass to their nose cone for the apogee activity. Second, if the rocket barely flies students are going to be less interested and excited about the project. Fortunately, the Estes C5-3 motor was the perfect motor to achieve all our goals. We had some reliability issues with the motor, but proper storage and launch procedures have resolved these issues.

The last part of the kit is the altimeter. This records the maximum height, or apogee, that the rocket achieves during flight. This is a critical part of the rocket kit since students are required to compare their predictions to the actual flight data. Many different altimeters were analyzed and the Jolly Logic AltimeterOne (Figure 5) was found to be the best combination of ease, reliability, and cost effectiveness. The altimeter can save multiple flights and has a long battery life so that a classroom can save money by reusing a few rather than buying one for every rocket.

Figure 5: Jolly Logic AltimeterOne

Recording the apogee is a good start for the intro course, but more advanced courses will want to compare their entire launch trajectory to their predictive model. There are options for this on the market, for example the Pnut Altimeter from PerfectFlite (Figure 6). This is only slightly more expensive than the AltimeterOne, but it beeps out only the most recent flights apogee rather than having a display of multiple flights. The upside is it stores the entire flight log of altitude and velocity onboard. The reason we decided not to use it for the novice course was that it requires software to be downloaded on a MAC or PC which is often not possible at the high school setting. At a more expensive price the team has developed an Arduino option that requires only and type of computer, including a Chromebook which is often used in high schools, and the entire altitude flight log is provided.

Figure 6: Pnut Altimeter from PerfectFlite

2.3.7 Implementation

Over the past two years different versions of this course have been implemented into high school and college classrooms. We have also presented the course at teacher professional development workshops to see what teachers though of the course and if they would think of implementing it into their classroom. A summary of the implementation type and audience is shown in Table 3. The collegiate implementations have taken place at UIUC and Southern Illinois University Edwardsville (SIUE). My work has been only at UIUC so that is the implementation that will be discussed throughout this manuscript. The course was run three times as an eight week elective. It was first offered only to aerospace students, then to anyone, and finally to all students outside of those pursuing aerospace majors. This third time will be discussed in detail in Chapter 3. Most of the students who have taken the course have been first and second year students in engineering. All course materials were provided to students for free and were taught by my teammates at SLI and myself.

The high school implementation has occurred only once in the past two years but will be picking up soon. A group of six local high school teachers decided to implement the course at varying levels of difficulty to students from the freshman to honors senior level. In all cases the course was a part of physics classes.

Table 3: Summary of how the course has been implemented and presented.

Type	Audience		Location
Teacher PD Workshops	Middle school and high school STEM teachers	>60	Throughout the Midwest and NM
Pilot Courses	Undergraduate students (Mostly majoring in STEM fields)	90	UIUC and SIUE
High School Implementation	High school (Freshmen - Senior) students	345	Local High School

2.4 LESSONS LEARNED

The course described in section 2.3 is the result of many iterations. As shown in Table 3 the SLI team worked hard to get our work in the hands of users and receive feedback from them. The initial course looked very different that the current state. Course development began during the COVID-19 pandemic making it hard to reach out to stakeholders at PDs and high schools in the beginning. It might not be much of a surprise that when a group of aerospace engineers got together to create an introductory level course the result was complex, difficult, and expensive. The rocket build looked like something out of a collegiate senior design course and the videos were too long and numerous. This section discusses how we solved these problems after discussing with the teachers and students of the target audience.

2.4.1 Development of Course Material and Structure

So far, the benefits of MOOCs have been presented like they are inherent to any online course. Now that nearly every student and teacher has participated in some online instruction it is obvious that this is certainly not the case. One issue that we had at the beginning was with video retention. Studies have shown that lecture videos should be no more than six minutes long or significant decline in engagement will occur [11]. Most of the videos in this course have been reduced to around five minutes in length. The exceptions are in a few tutorial videos that we were unable to cut down on since they contained necessary information. One example of this is “Plotting Altitude (Google Sheets),” where it is assumed that students have never used spreadsheet software. This video teaches both about plotting data and using google sheets and is difficult to go through in five minutes. This is not uncommon in these types of videos and is not necessarily an issue [12]. This video did in fact see a fewer watch time per viewer but had many more views than other videos. Students watched this video many times when they were completing their apogee activity.

As is clear from this discussion, video analytics are critical to understanding how students are engaging with your material. In the first pilot course conducted we attempted to survey students on each video, and this was overwhelming and did not yield good results. Especially when implementing to large groups having a way to track viewership automatically is important. Early on, little research was done on the impact of video length. All of this course’s videos are posted on YouTube which provides video analytics for free.

2.4.2 Apogee Activity

Many of the issues the initial course possessed were solved by the development of this activity. Our initial course contained most of the complexity in the challenge in following the build and launch instructions. There was little room for students to test hypotheses. After implementing the course into the early college classroom, students asked for more engagement and knowledge about making calculations. These were of course engineering students, but after presenting the course at teacher PDs we heard the same arguments. Students needed to be able to manipulate variables and be creative. It turns our that building and launching rockets is difficult and making the hands-on part of the course simpler is better. The complexity should come elsewhere, in places were students are free to make mistakes. This place is the apogee activity and data analysis. The rocket, as will be discussed in more detail in a future section, was simplified greatly after the inception of this and students still find the build and launch exciting.

Our initial course contained difficult hands-on learning but did not have the benefits of project-based learning (PBL). This is particularly important for the Next Generation Science Standards NGSS. If you are going to replace coursework in high school science classrooms, you have to follow NGSS. What the apogee allows students to do is create a model, use this model to make predictions, test their hypothesis, and finally analyze the data and discuss why their launch data did not match their predictions perfectly. This connection between what is learned in the classroom and what is done through experiments is what excites the teacher about this course the most.

Even after the activity was developed it needed many updates to become accessible to most high school and college students. Most people are not well versed in coding or spreadsheet software. In the beginning, too much of a burned was on students to learn this themselves. Since testing and receiving feedback, the course has been adjusted to support google sheets plotting which was deemed to be the easiest to learn. This is used alongside the online applet that was discussed in section 2.3.3.

2.4.3 Assessments

When using the initial assessments during course piloting were completely free response. The questions also were often open ended and did not have direct answers in the videos. This clearly makes grading the students more difficult and the questions more difficult. This was understood at the time and all quizzes were graded on timely completion rather than correctness. The reason for creating quizzes like this was to get a better understanding of what information were getting from the videos as well as what their previous biases were, without being swayed by the multiple choice's answers. Eventually all assessments were changed to multiple choice, but this initial set of quizzes helped greatly. We used free response answers to educate us on what material needed to be fixed and added, and their answers helped develop multiple choice selections.

2.4.4 Model Rocket Kit

The model rocket kit went through the most changes of any part of the course. As mentioned previously the initial rocket was a better fit for a collegiate senior design course than an intro course. The original kit was designed around a central microelectronics system. The original thought was to work with a microelectronics device that can be used on all space engineering related kits including rockets, rovers, and landers and building a course around it. The goal was to have many different project-based courses and that students and teachers could easily participate in all of them. This introductory rocketry course was the first course developed using this concept. I will briefly describe what the initial avionics and rocket system looked like and then explain how and why changes were made to the current kit.

The microelectronics system that was chosen had to satisfy many criteria for not only working with rockets but also drones and landers. Therefore, the inaugurate choice of microelectronics had to be a complex system with multiple sensors onboard and provide real-time data. The Raspberry Pi/Navio2 Figure 7 seemed like a solid choice because of its versatility. The Raspberry Pi4 system is a microcomputer and the Navio2 is an autopilot HAT for the RPi4 that comes with preconfigured software and documentation. The Navio2 contains multiple sensors onboard including GNSS receiver for GPS tracking, Dual IMU with accelerometer, gyroscopes, and magnetometers for orientation and motion sensing, and a high-resolution barometer for accurate altitude measurement. The developers realized this may be overkill for a rocket since the only requirement for the rocket flight was to collect data and many other microelectronics systems have been created to accomplish the same task in cheaper, lightweight versions. However, the idea at the time was this complex microelectronics system could be then used again and again in different projects and it had a seemingly amount of endless data for students to analyze.

Figure 7: Navio2 Mounted on a Raspberry Pi

With the centralized microelectronics system, the goal was to search for off-the-shelf model rockets that the RPi4/Navio2 can fit into and motors that produce enough thrust for launching the heavy equipment. With these limitations in mind, many model rockets were researched and tested. As a result, the Super Big Bertha was chosen due to its spacious room for carrying the avionics system and its corresponding design of motor E and F class.

Figure 8: Estes Super Big Bertha Model Rocket

The avionics, including the battery, microcontroller (Figure 7), telemetry antenna, and GPS antenna were stored in a well-designed, 3D printed avionics bay (Figure 9) that fit into the top of the rocket (Figure 8).

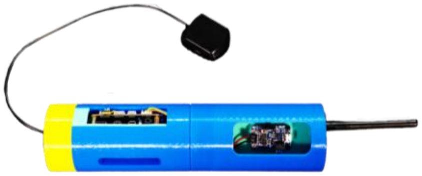


Figure 9: 3D Printed Avionics Bay

With the additional masses, the developers searched for a motor that allows this heavy rocket to be launched. From performing experiments both computationally via OpenRocket and experimentally, the selected motor for the final rocket was chosen to be the Aerotech F67 motor shown in Figure 10. The motor matched dimensions of the SBB’s motor mount and produced a large thrust to ensure a successful rocket flight.

Figure 10: Aerotech F67-4W Motors

The entire kit completed and expanded for view is displayed in Figure 11. This kit certainly followed the initial model we hoped to achieve. It was an exciting project for students and once in the classroom the electronics could be used for new projects that continued to get students excited about aerospace. And the avionics system looked a lot more like a real system would and collected enough data for students to understand the full trajectory of the rocket and more.

Figure 11: Initial model rocket kit built and ready for assembly.

Unfortunately, issues arose that forced the team to pivot. After first implanting into a freshman college course at UIUC students reported that the rocket build was difficult and potentially unsafe. As an instructor I saw that the setup and use of the electronics required way too much assistance. Students were unable to complete the project on their own without help from someone who had done hours of troubleshooting with these specific avionics system. Once the course was presented to teachers at PD events, many more issues came up. The kit was well out of the price range of most school budgets, and it was extremely difficult to find a launch site for an F class motor. Accessibility issues with the avionics were also a huge problem. Most teachers had never used a Raspberry Pi before and were overwhelmed by the setup process. Also, the setup required a Windows or MAC computer while many school systems use only Chromebooks.

If the goal is to engage more students in the industry who were not already interested, and in the case of high school might not even be considering a STEM career, the barrier of entry needs to be low. At the same time students need to be challenged with something new and complex to garner interest in a topic. This tug of war turned out to be the main theme of this project. How do you create a challenging and interesting course that motivates students to enjoy learning about space but make it simple enough that they will not get lost. Even more important is ensuring that a high school physics teacher feels comfortable teaching the material.

When designing the new rocket system, we made sure not to make the same mistakes. But we still learned a lot from creating the simpler rocket kit described in section 2.3.6. Early on we wanted to use an even smaller and simpler rocket but ran into issues with the payload addition in the apogee activity. In this activity students add additional weight to the rocket to achieve a desired apogee, but this reduced the off rail velocity making the rocket launch less safe. One solution was to reduce the range for apogee and thus mass addition, but when trying this it was clear that it was less interesting for students. In these cases, since the rocket masses are so similar it is also more likely that students will come to incorrect conclusions.

The C5-3 motor, and Courier rocket were the perfect solution. There is plenty of room in the rocket for a wide variety of payload and its mass. As seen in Figure 12, the C5-3 motor produces a large amount of thrust off the rail making the launch safer for larger payloads, but then the thrust dips drastically so that the launch radius can be reduced, and launches can be done on a baseball or football field.

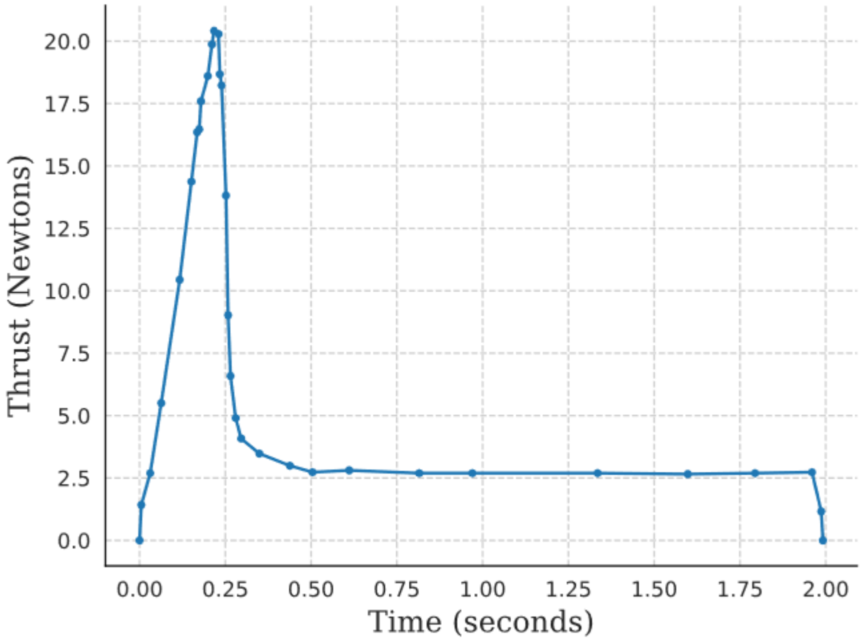


Figure 12: Estes C5-3 Thrust Curve

2.4.5 Launch Troubleshooting

The launch is the scariest part for teachers wanting to implement the course into their classroom. Educators' issues with safety were expected, but what was not was their hesitation to implement due to reliability. After working hard to learn and build the rocket would it launch consistently and reliably? If something did not work, how might you trouble shoot it? These concerns are justifiable as are safety concerns since this project involves projectiles moving very fast, but the SLI team has worked very hard to ensure that proper scaffolding is in place to keep the launch day safe and successful.

We have found that making a reliable system is really the hardest part. Model rocket motors need to be stored in warm places or they are likely to misfire. Also installing motor ignitors and using launch controllers can be difficult with one minor error keeping your rocket on the ground rather than being thrust into the air. Current solutions have the SLI team meeting with teachers and discussing and reiterating launch procedures in detail. Although these messages do not have to be delivered live it seems to make new launchers feel better about it and it gives them an ability to ask questions.

2.4.6 High School Classroom Implementation

As discussed throughout this chapter, getting the course into high schools and presenting the course to high school teachers at PDs has provided us with significant feedback that was necessary to creating something worthwhile. We found that teachers were eager to add courses like this too their curriculum if they were easy to adopt and fulfilled their physics requirements. Making the course easy for teachers to insert into any classroom meant a course that did not require more than a Chromebook and basic algebra and physics knowledge. Our team consisted of engineers that likely had more resources than these teachers and students during our time in school which made us vastly overestimate the abilities of students' math, science, and computer skills. Additionally, most students have not done much hands-on work even by senior year of high school and struggle with using power tools which our initial rocket build required.

When the course was implemented into the classroom, we tried to use google classroom since it is used in the majority of high school classrooms. This turned out to be an issue since Classroom restrict who has access to the classroom to those within a school. It was very difficult to distribute the course and then monitor student progress without access. We have since moved to our own website [5] which allows us more flexibility. This flexibility is now key to our implementation. Again, we want to get the course in as many students' hands as possible and that means that some teachers want to select material that fits into their classroom. This flexibility has allowed us to implement into freshman through senior classrooms in high schools. These challenges along with the others discussed in this chapter make it clear that a better understanding of what the modern high school classroom looks like is necessary, before starting to develop a course of this scale.

Students and teachers that have used the course have said good things and plan on participating again. 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."

2.4.7 College Implementation

Since this courses development worked out of UIUC, knowledge of the college classroom was much better, and many successful pilots were run with both the original course and new course. We believe that there is room for the complex material presented as our original course at the college level, but it does not reflect the goals of SLI which include getting new students who would not otherwise be interested in rocketry to become interested. This is why we have used the new simpler course during the most recent test run of the course. Although students enjoyed the course there was feedback for a bit more complexity. This feedback has led us to begin additional material for a more advanced version of our course. This would include a python model that includes a numerical integration of drag. We still believe that a simple hands-on rocket build and launch is sufficient for that advanced course.

2.4.8 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/.

2.5 CONCLUSION

At the beginning of this chapter four questions were asked about the development of this blended rocketry MOOC. First, what are important considerations when developing a MOOC with a hands-on project? As will be discussed further in chapter 3, hands-on courses are of great benefit to students and if they can be combined with online MOOC content teachers’ jobs can be made much easier. Some of the findings from the development of this course are not much different than any course. For example, understanding the stakeholders, in this case teachers and students is critical to ensure appropriate learning material. This means that early piloting and discussion with teachers goes a long way. There are other findings that are more unique to this style of course. MOOC videos need to be concise, or students will not maintain interest. The hands-on project must be simple and cost effective yet interesting enough to make it worthwhile for the users.

The second question asked was, what challenges and limitations are added when implementing a MOOC in high schools and colleges? Creating an accessible course in rocketry is not easy. Most courses on the market involve using software that cannot be used on Chromebooks and rockets that are big and expensive. It turns out the biggest limitations are cost and ease of implementation. Of course, schools only have so much money and if we want these courses in the hands of students who would not otherwise launch rockets users cannot be from the richest schools. Throughout this chapter we have outlined ways to make the course easier for teachers to implement into the course that require less and less investment of their time and effort. It should be noted that these teachers were not in any way unwilling to put in the effort needed to use a rocketry course, but our content was just way too difficult, and the logistics were impossible for our initial launch. When teachers calculated their opportunity cost, they realized they could find other content to get their students almost as excited about science that required very little effort in comparison. This is why we decided to simply the course in the way that we did.

The last two questions posed were, what are the benefits of delivering a hands-on experience with a MOOC? And does this course encourage students to consider space-related careers? These are impossible to answer precisely from the qualitative analysis done in this chapter. The next chapter will dive into an educational study that gives quantitative results. There is anecdotal evidence that the course has benefited students. Although there did seem a slight reduction of engagement from watching weeks of videos, it was clear during the build and launch sessions that students immediately regained their interest and curiosity about rocketry to the end of the course. Many students asked about future courses they might take related to what they learned, and a notable amount claimed that they had joined because they heard good things from friends who had taken it previously.

CHAPTER 3: QUANTITATIVE ANALYSIS OF STUDENT KNOWLEDGE AND INTEREST IN ROCKETRY AFTER PARTICIPATION IN SPACELABS INTRODUCTION TO ROCKETRY COURSE

3.1 INTRODUCTION

To better understand how well the course described in chapter 2 has done in achieving our goals, a study was conducted at UIUC implanting the course and testing its efficacy. The goal of the study was to understand how our blended MOOC impacted students in three ways. First, did they learn the material? Second, were students who took the course more interested in pursuing a career in rocketry or space engineering? Lastly, did aspects of students' personal background impact students learning experience in the course? Additionally, we hoped to determine what impact the hands-on kit had on the participants. The study was done on undergraduate students not pursuing an aerospace engineering major. As will be described in detail throughout the chapter quizzes and surveys were administered throughout the course that hope to give insights into the questions posed.

This study was approved by the Institutional Review Board (IRB) at UIUC and by our funder the Department of Defense. Details and approval letter are located in Appendix A.

3.2 LITERATURE REVIEW

3.2.1 Online Coursework in the Classroom

The course utilized in this study has all its lecture material online structured similar to a massive open online course (MOOC) seen on websites like Coursera, EdX, and others. MOOCs, as their name suggests, deliver content to students through online access and are open to anyone, but are not necessarily free. The benefits of this model are that students learn by viewing a well-structured course material, sometimes participating in online discussions, and completing assignments and exams [13] without the need of an expert educator in the room. This is a huge benefit to teachers who are increasingly overworked due to shortages. According to the National Center for Education Statistics [6], 44 percent of public schools in the US reported having a teaching vacancy. Providing K-12 teachers with well-structured courses created by experts frees them up to focus more on individual students. MOOCs are far from perfect though. Current research suggests that in order successful completion of MOOCs necessitates self-organized, goal-oriented, and actively engaged learners [14]. Since students do much of the learning at home in their own time, keeping them engaged is difficult, especially with longer videos.

3.2.2 Hands-on and Project Based Learning

Project-based learning (PBL) separates itself from traditional instructional by assigning students complex tasks based on challenging questions or problems that involve students in design, problem-solving, decision-making, or investigative activities [15]. Although PBL has likely been researched in some capacity for over a century, possibly as early as the 1890s [16], it is only recently that sufficient research has been conducted to demonstrate its benefits. A review of the literature by Thomas in 2000 [15] indicated that there is some evidence that PBL is more popular among students and teachers and has positive benefits, for example, increased attendance, self-reliance, and improved attitudes towards learning. However, the research on learning and achievement was sparse, often not relevant to what teachers were implementing in the class according to Thomas. In 2019 Cheng-Huan and Yong-Chi reviewed the literature from

1998 to 2017 [17]. Their findings show that there is a clear positive effect on academic achievement with the inclusion of PBL when compared to traditional instruction alone. They attribute this improvement to increased research and teachers having an easier time accessing and implementing findings from this research. This seems to indicate that the disconnect between PBL research and the classroom Thomas discusses is no longer present or at least has decreased.

In this course, students build and launch a model rocket but notice that the participation in a hands-on activity does not necessarily classify it as PBL although they often occur together. Constraining students to a predetermined outcome, building and launching a rocket from instructions, leaves them with little room to investigate and develop their own approaches to answering the challenging questions posed in the course [18]. This, process according to Blumenfeld et. al. [18] is where students construct their knowledge and is therefore critical. Baron et al. [13] 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 [18]. With these challenges in mind, our hands-on activity was developed to follow the PBL model by requiring students to create a mathematical model of predicting a model rocket's apogee at various payload masses by calculating what amount of payload mass they should use to achieve a particular apogee. They then compare their predictions to actual flight data.

It is clear that a well-developed PBL course has the potential to increase student learning and achievement. So why include the rocket build and launch at all? Teaching students about rocketry is not the sole purpose of this course. We want students to get more students interested in the topics discussed in the course and leave them with the confidence that they can excel in similar courses and projects. Although building and launching the rocket may not directly increase students' learning it may help increase their interest and self-efficacy. There has been some evidence that hands-on experiences, particularly in engineering, have these types of positive benefits for students. Aglan and Ali [19] provided engineering students with hands-on projects and saw that their motivation to pursue a career in engineering increased. Similar findings came from a study by Knight et. al [20]. The research followed undergraduate students from freshman year to graduation and saw that freshman that took an optional hands-on project course were more likely to still by enrolled in an engineering major than their counterparts who did not take the course.

Because this course is highly structured and mostly online, it is not obvious that it possesses the same types of benefits as other hands-on and PBL courses. The study in this paper will attempt to determine if this rocketry course is well designed to take advantage of hands-on and project-based learning discussed in current literature. There has been some research on these types of courses, often called Blended MOOCs.

3.2.3 Blended Learning

Blended learning is a learning method for combining face-to-face classroom instruction with online classes and has been recognized as a valuable approach in education. Blended MOOCs, particularly when incorporating hands-on activities, have the potential to optimize the educational process by leveraging the strengths of synchronous and asynchronous learning [21]. Research indicates that combining online and face-to-face instruction leads to enhanced learning outcomes. Further explaining, blended learning also offers flexibility and personalized learning experiences, allowing students to progress at their own pace and cater to their individual learning styles [22]. This integration addresses the limitations of traditional MOOCs by providing students with practical application and opportunities for experimentation. Engagement is a key challenge in online learning but adding project-based and team-based learning in MOOCs can foster interaction, success, and higher completion rates [23]. In the context of aerospace engineering, previous studies have found that blended MOOCs had a strong positive impact on participation and satisfaction for both students and teachers [24].

Building upon the positive effects observed in blended MOOCs, it is shown that incorporating a hands-on activity alongside online videos has the potential to overcome the limitations of traditional MOOCs. By integrating practical application and project-based learning, this study aims to enhance not only student engagement but also promote deeper understanding of the subject. Through this comprehensive approach, we aimed to create a course that maximizes the benefits of blended learning and minimize the challenges faced by traditional MOOCs, ultimately fostering an enhanced and interactive learning experience for students.

3.3 METHODOLOGY

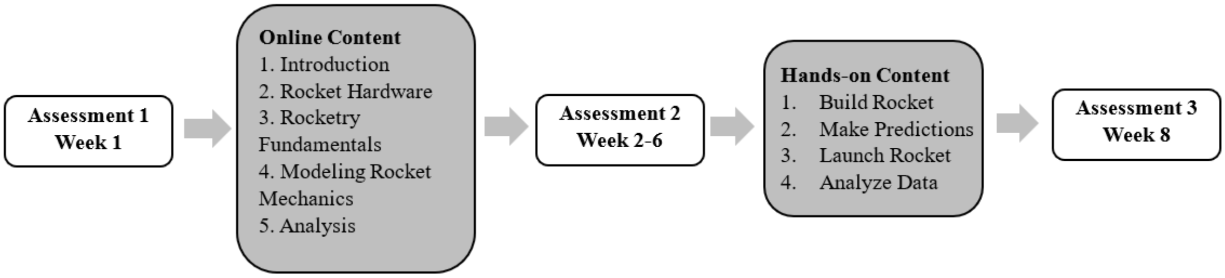


Figure 13: Structure of the educational study conducted

The course described in chapter 2 was run over eight weeks at UIUC. Freshman pursuing an aerospace engineering degree take an introductory course that is very similar to our course so only non-aerospace majors were allowed to participate in the course. Figure 13 outlines how the study was done. Before any part of the course took place, students were assessed through a variety of quizzes and surveys. Then after they learned the material, they took the same surveys and quizzes. Finally, after completing the entire course, they completed these assessments a third and final time. Initially we planned to test a fourth time on knowledge retention eight weeks after assessment three, but the response rate was abysmal, so the data was thrown out.

3.3.1 Assessments

Three different metrics were examined during this study. First was students' self-efficacy in engineering and rocketry content. This material is not described in this paper but will be published by the SLI team in the future. Second was the interest levels of students throughout the course. Lastly, we measured what students learned. Topic interest survey questions were derived from the 2006 Program for International Student Assessment's (PISA) periodic testing program on student performance [25]. At the time, PISA was interested in understanding students' interest in science since there was a decline in students studying STEM in college [26]. Questions from this interest assessment was well thought out and field tested to ensure they were appropriate and the applicable to understanding students interest [27]. The survey required minor adjustments to fit this course. All assessment material is located in Appendix B.

No special quizzes were made for the study since quizzes were already developed alongside the course. These four quizzes were used to determine if students had learned the material and when. Notice that there are five sections of content, but only four quizzes. The Introduction and the Rocket Hardware sections are the shortest and were combined into a single quiz. As indicated in Figure 13, there were quizzes given before and after the online content was learned. Unlike the interest and self-efficacy surveys the quizzes for assessment 1 and two were given the week before and the week after learning the material. For example, during week 1 the interest and self-efficacy questionnaire were assigned but only quiz 1, for Introduction and Rocket hardware was given. Then after learning rocket hardware the quiz was assigned again alongside the Fundamentals of rocketry quiz. This continued until after analysis during week 6, where the analysis quiz was assigned along with the interest and self-efficacy surveys. The reasoning for this was that we did not want the time elapsed since learning the material to impact the data. This source of error was unavoidable for assessment three since the course ended during the eighth week of the semester meaning we had to give the final assessments.

Before students began the course they were surveyed on their demographics, previous experience in rocketry, and were asked to take a quiz on their learning styles. This data allowed us to determine if students' background had an impact on their learning or interest in the course.

3.3.2 Data Analysis

After the data was collected means and standard deviations from each assessment were compared. This data was also broken up by students' previous experience in rocketry and their demographic data. To determine the significance of each of these changes, a paired t-test was performed. Since we hypothesize that the course provides a positive impact on students' performance and interest, the alternate hypothesis of the difference in the means greater than zero was used. If this value was less than 0.05 it was deemed a significant increase. This of course cannot be said for our entire target population. This group was a volunteer sample of mostly engineering students which is clearly not a probability sample of the audience we hope to reach. It does though provide a starting point and could motivate future more rigorous studies to verify the results.

3.4 RESULTS

3.4.1 Sample Group

Sample group data is displayed in Table 4. Thirty-two students who took the course decided to participate in the study. These students were mostly engineers and other STEM majors with one business major. 87.5 percent of the students were freshman and sophomores, which was closest to the target audience. Juniors and seniors were still allowed to take the course. Although the course might be easier for them with their mathematics background, they were not aerospace students, so there was still a chance that they could be captivated by new material. We would have liked to have more females take part in the course, but the numbers here do represent the demographics of STEM students. According to the National Center for Educational Statistics, 62 percent of bachelor’s degrees in engineering were given to males in the 2020-2021 [28]. With the STEMP umbrella there were a wide variety of majors. Students came from ten different colleges with one undeclared student. Table 4, displays only what college students came from, but within some of these colleges were multiple majors.

Students too the Felder-Silverman Index of Learning styles assessment to determine what group they fell under. The values in Table 4 only show the binary learning style selection for simplicity, but this assessment does give students a value from one to eleven indicating how much of that learning style they are determined to have through this assessment.

Throughout this section the legend in Figure 14 is used in all figures.

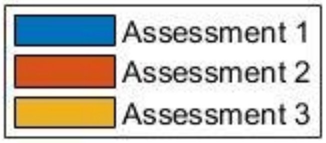


Figure 14: Legend for figures in results section

Table 4: Smaple group information and demographics

Categories	**n**	**%**
Total	32	100.0
Gender		
Female	11	34.4
Male	20	62.5
Prefer not to say	1	3.1
Ethnicity		
Do not wish to provide	1	3.1
Hispanic or Latina/o	6	18.8
Not-Hispanic or not-Latina/o	25	78.1
Race (*Multiple selections allowed*)		
American Indian or Alaska Native	1	3.12
Asian	19	59.38
Black or African American	2	6.25
White	12	37.50
Do not wish to provide	1	3.12
Year in College		
1	19	59.4
2	9	28.1
3	3	9.4
4	1	3.1
College		
Agricultural and Biological Engineering	1	3.1
Civil Engineering	1	3.1
Computer Science	1	3.1
Electrical & Computer Engineering	2	6.2
Industrial & Enterprise Systems Engineering	4	12.5
Materials Science and Engineering	2	6.2
Mathematics	2	6.2
Mechanical Engineering	9	28.1
Physics	8	25.0
Business	1	3.1
Engineering Undeclared	1	3.1
Learning Styles		
Active	18	56.2
Reflective	14	43.8
Sensing	20	62.5
Intuitive	12	37.5
Visual	31	96.9
Verbal	1	3.1
Sequential	19	59.4
Global	13	40.6

3.4.2 Technical Knowledge Results

Table 5, Table 6, Table 7, and Table 8 include the complete set of data presented in the figures from this section. P-values for the changes in means are not written explicitly, but the change is indicated with one star if the value is below 0.05. Additional stars are added if the p-value is below 0.01 and 0.001. Table 9 takes the average of all four quizzes, essentially giving students a course grade, excluding the hands-on project grades. All these hands-on projects and reports along with it were completed and all thirty-two students received perfect scores for their projects.

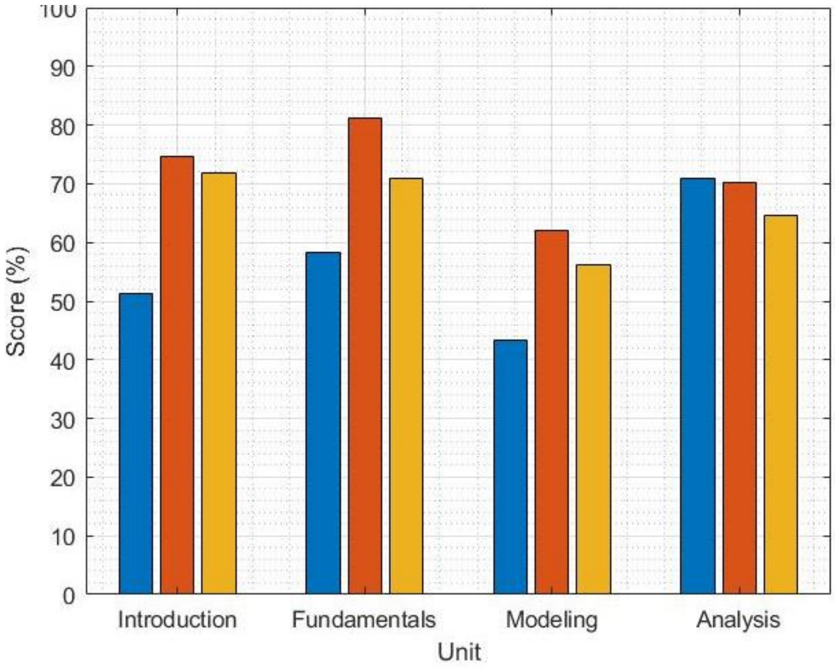


Figure 15: Average student quiz scores at each point in the course

For the first three quizzes students baseline scores, assessment 1 in Figure 13, were very low allowing for a lot of room for improvement. By assessment 2, which was taken after learning material in each section, students' scores had increased significantly in each of these three instances. The analysis quiz did not follow this trend likely because the score in assessment one was so high. It is believed that much of the material in the analysis quiz was learned though the first four units, although not explicitly taught. Although the analysis section saw a dip each time the scores remained high, and the drops were not significant. Overall students' assessment 3 scores were higher than assessment one meaning that students did learn the material. The drops in scores from assessment 2 to assessment 3 are believed to be due to the time between learning the material and taking the quiz. It is not believed that the hands-on part of the course caused students to develop misconceptions about the physics or mathematics of rocketry.

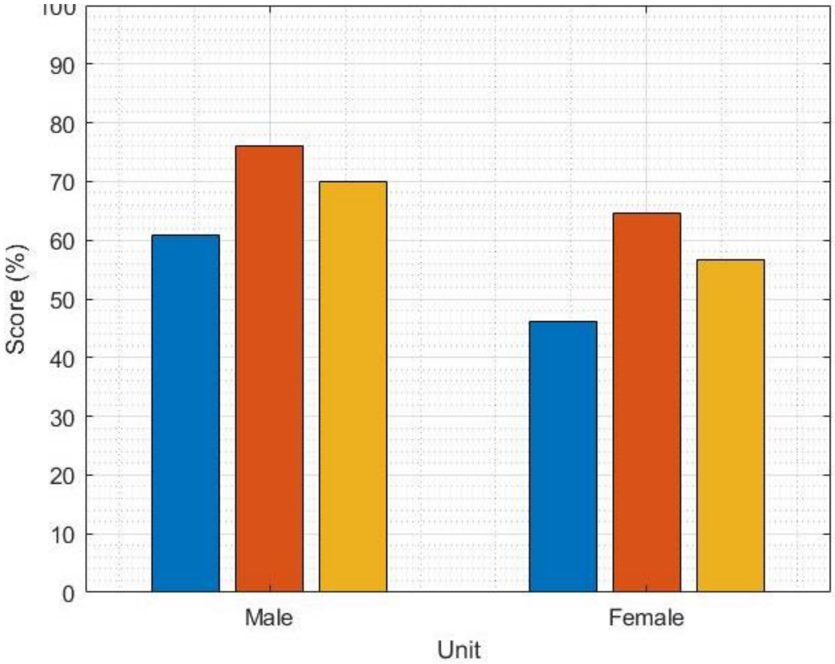


Figure 16: Overall scores divided by gender

The overall trend seen in Figure 15 seems to be independent of any background and demographics information of the sample. The trend being an increase in scores for from assessment 1 to 2, then a decrease from 2 to 3 with three remaining higher than 1. What was different for different groups of students was the values of these scores. Figure 16. Seems to indicate that male students entered and finished the course with higher knowledge in rocketry than female students. This is something to consider when teaching this course, but since the sample sizes are low, we cannot say for sure that this will hold up for the population. The same can be said for the data presented in Figure 17 and Figure 18. Figure 17 displays the scores of students that indicated they had previous experience in rocketry compared to those that did not. This is exactly what is expected, students who had experience started higher and retained their knowledge better than those who came in without experience. Figure 18 break down scores by learning styles. In each case the students had a significant increase in scores from assessment 1 to assessment 2 and from assessment 1 to assessment three. The differences between each of these learning styles is minimal and does not seem to have much impact on whether they learn the material or do not or whether they retain the material weeks after completing the lectures and after the hands-on project is completed.

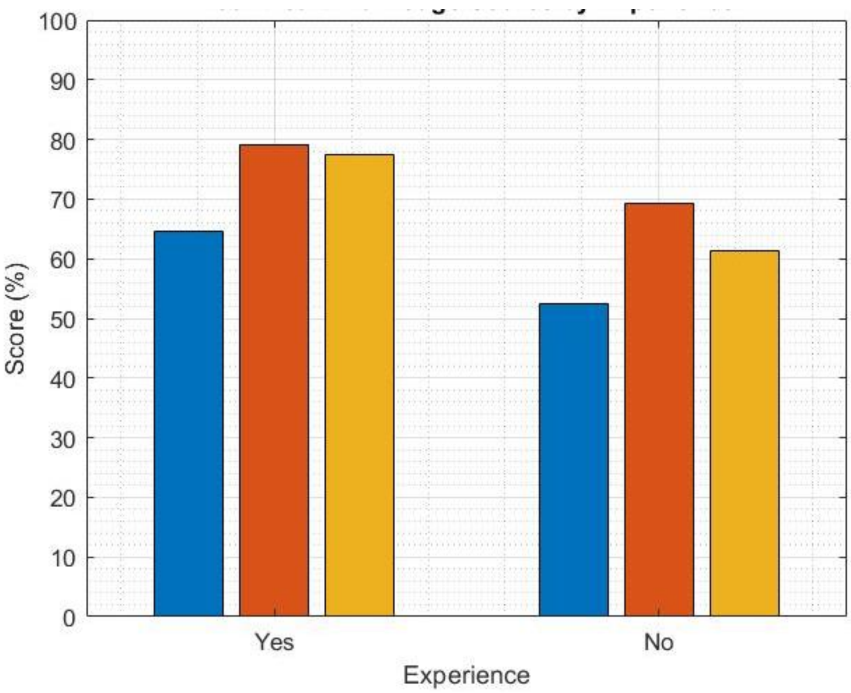


Figure 17: Overall scores divided by experience in rocketry.

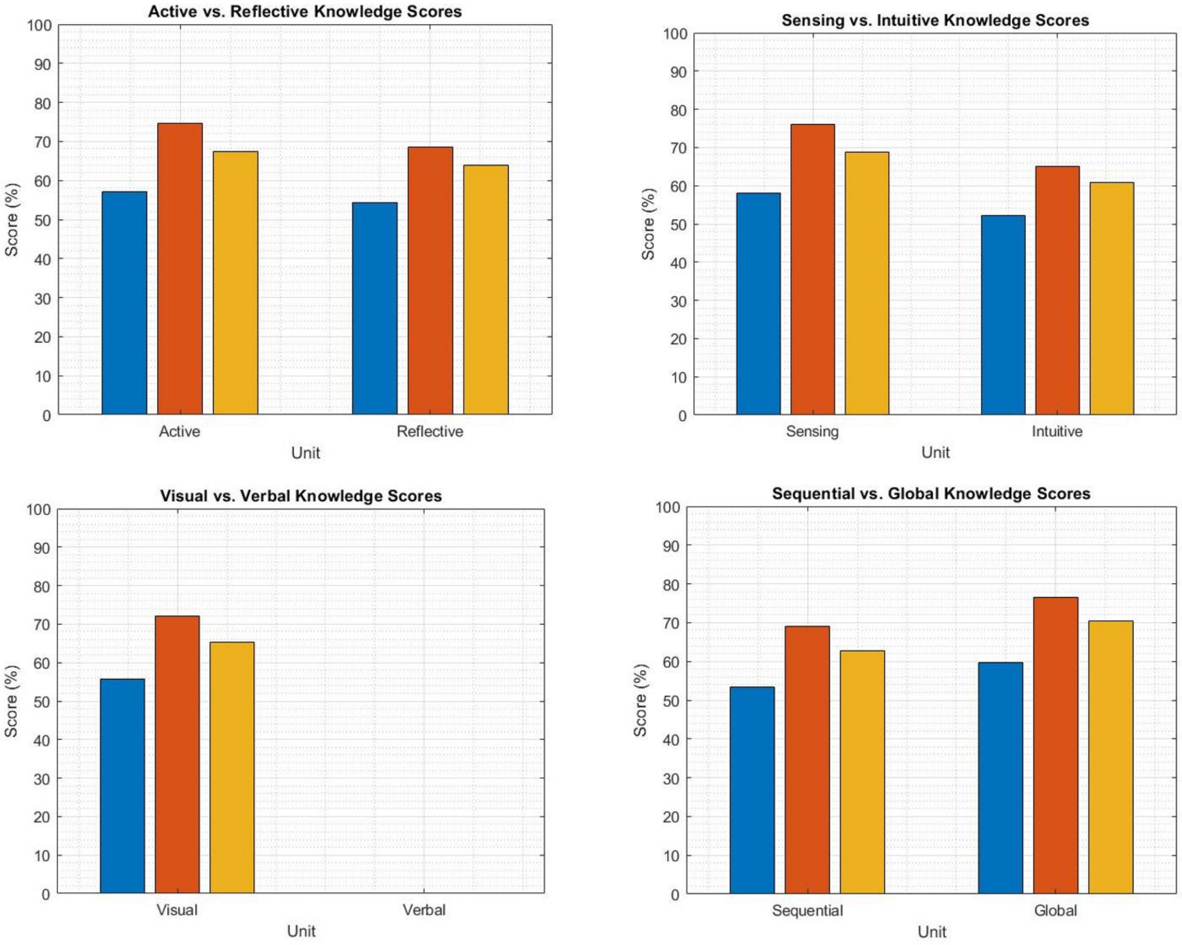
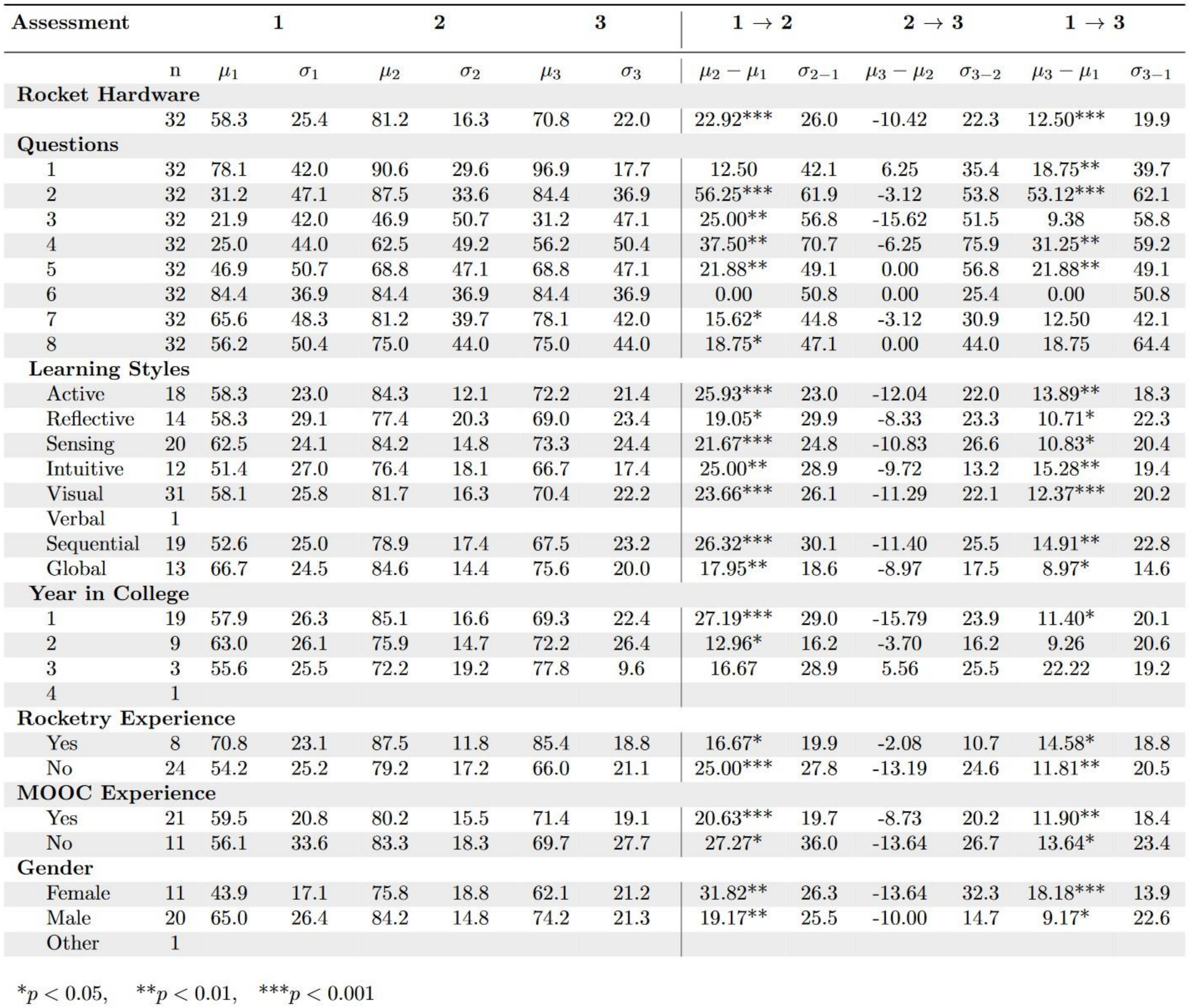


Figure 18: Overall scores divided by students learning styles.

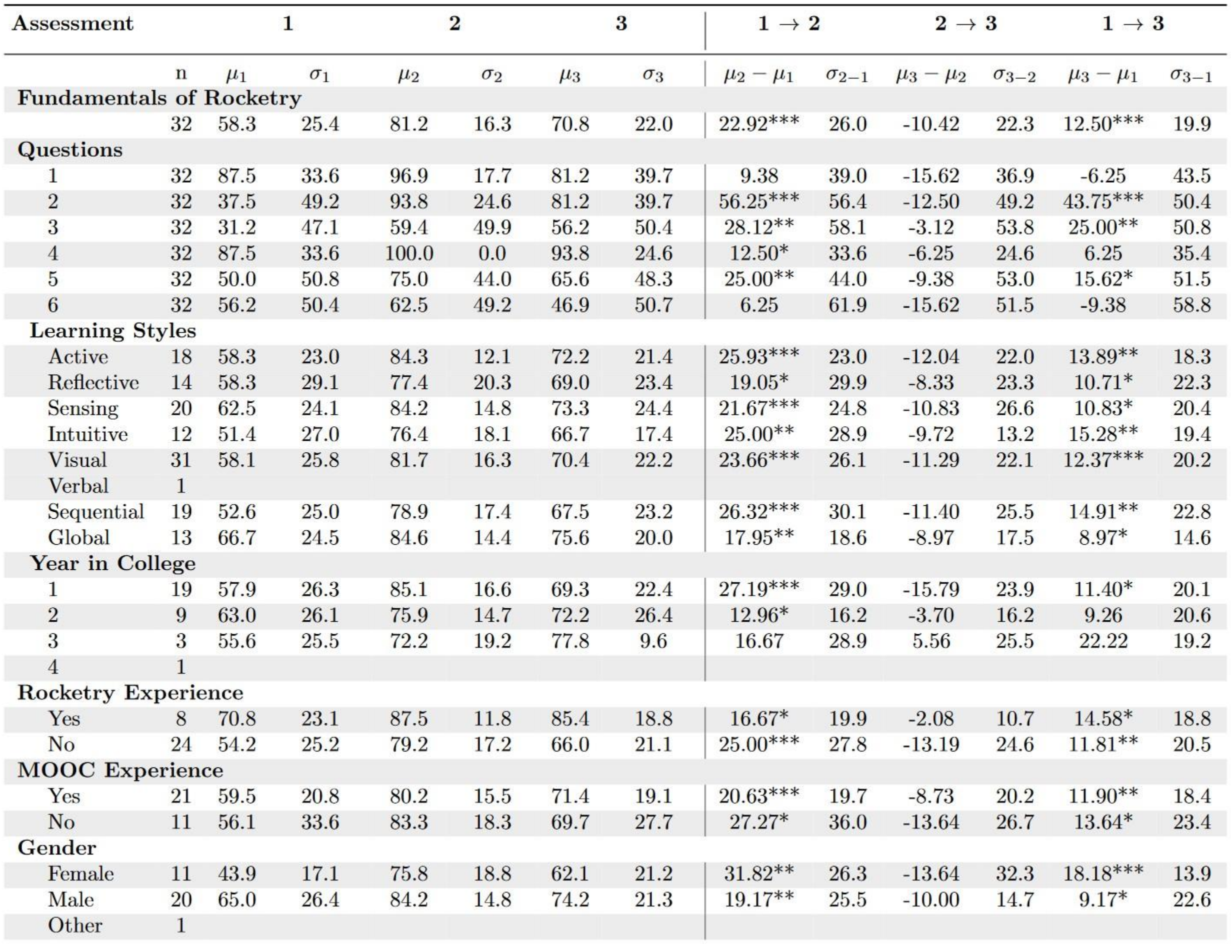
Table 5: Rocket Hardware quiz data



Assessment		1		2		3		1 → 2		2 → 3		1 → 3	
	n	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3	$\mu_2 - \mu_1$	σ_{2-1}	$\mu_3 - \mu_2$	σ_{3-2}	$\mu_3 - \mu_1$	σ_{3-1}
Rocket Hardware													
	32	58.3	25.4	81.2	16.3	70.8	22.0	22.92***	26.0	-10.42	22.3	12.50***	19.9
Questions													
1	32	78.1	42.0	90.6	29.6	96.9	17.7	12.50	42.1	6.25	35.4	18.75**	39.7
2	32	31.2	47.1	87.5	33.6	84.4	36.9	56.25***	61.9	-3.12	53.8	53.12***	62.1
3	32	21.9	42.0	46.9	50.7	31.2	47.1	25.00**	56.8	-15.62	51.5	9.38	58.8
4	32	25.0	44.0	62.5	49.2	56.2	50.4	37.50**	70.7	-6.25	75.9	31.25**	59.2
5	32	46.9	50.7	68.8	47.1	68.8	47.1	21.88**	49.1	0.00	56.8	21.88**	49.1
6	32	84.4	36.9	84.4	36.9	84.4	36.9	0.00	50.8	0.00	25.4	0.00	50.8
7	32	65.6	48.3	81.2	39.7	78.1	42.0	15.62*	44.8	-3.12	30.9	12.50	42.1
8	32	56.2	50.4	75.0	44.0	75.0	44.0	18.75*	47.1	0.00	44.0	18.75	64.4
Learning Styles													
Active	18	58.3	23.0	84.3	12.1	72.2	21.4	25.93***	23.0	-12.04	22.0	13.89**	18.3
Reflective	14	58.3	29.1	77.4	20.3	69.0	23.4	19.05*	29.9	-8.33	23.3	10.71*	22.3
Sensing	20	62.5	24.1	84.2	14.8	73.3	24.4	21.67***	24.8	-10.83	26.6	10.83*	20.4
Intuitive	12	51.4	27.0	76.4	18.1	66.7	17.4	25.00**	28.9	-9.72	13.2	15.28**	19.4
Visual	31	58.1	25.8	81.7	16.3	70.4	22.2	23.66***	26.1	-11.29	22.1	12.37***	20.2
Verbal	1												
Sequential	19	52.6	25.0	78.9	17.4	67.5	23.2	26.32***	30.1	-11.40	25.5	14.91**	22.8
Global	13	66.7	24.5	84.6	14.4	75.6	20.0	17.95**	18.6	-8.97	17.5	8.97*	14.6
Year in College													
1	19	57.9	26.3	85.1	16.6	69.3	22.4	27.19***	29.0	-15.79	23.9	11.40*	20.1
2	9	63.0	26.1	75.9	14.7	72.2	26.4	12.96*	16.2	-3.70	16.2	9.26	20.6
3	3	55.6	25.5	72.2	19.2	77.8	9.6	16.67	28.9	5.56	25.5	22.22	19.2
4	1												
Rocketry Experience													
Yes	8	70.8	23.1	87.5	11.8	85.4	18.8	16.67*	19.9	-2.08	10.7	14.58*	18.8
No	24	54.2	25.2	79.2	17.2	66.0	21.1	25.00***	27.8	-13.19	24.6	11.81**	20.5
MOOC Experience													
Yes	21	59.5	20.8	80.2	15.5	71.4	19.1	20.63***	19.7	-8.73	20.2	11.90**	18.4
No	11	56.1	33.6	83.3	18.3	69.7	27.7	27.27*	36.0	-13.64	26.7	13.64*	23.4
Gender													
Female	11	43.9	17.1	75.8	18.8	62.1	21.2	31.82**	26.3	-13.64	32.3	18.18***	13.9
Male	20	65.0	26.4	84.2	14.8	74.2	21.3	19.17**	25.5	-10.00	14.7	9.17*	22.6
Other	1												

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

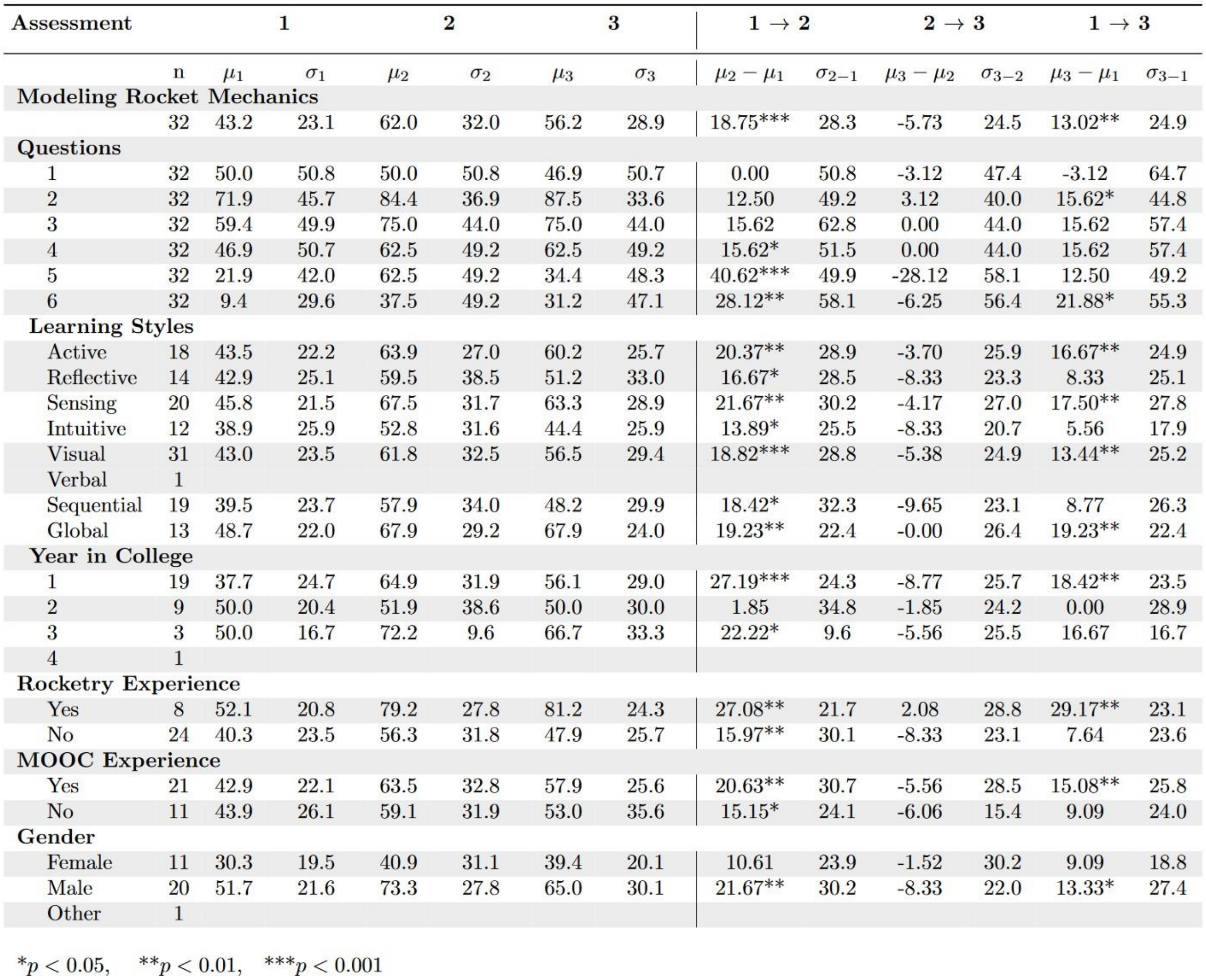
Table 6: Fundamentals of Rocketry quiz data



Assessment		1		2		3		1 → 2		2 → 3		1 → 3	
	n	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3	$\mu_2 - \mu_1$	σ_{2-1}	$\mu_3 - \mu_2$	σ_{3-2}	$\mu_3 - \mu_1$	σ_{3-1}
Fundamentals of Rocketry													
	32	58.3	25.4	81.2	16.3	70.8	22.0	22.92***	26.0	-10.42	22.3	12.50***	19.9
Questions													
1	32	87.5	33.6	96.9	17.7	81.2	39.7	9.38	39.0	-15.62	36.9	-6.25	43.5
2	32	37.5	49.2	93.8	24.6	81.2	39.7	56.25***	56.4	-12.50	49.2	43.75***	50.4
3	32	31.2	47.1	59.4	49.9	56.2	50.4	28.12**	58.1	-3.12	53.8	25.00**	50.8
4	32	87.5	33.6	100.0	0.0	93.8	24.6	12.50*	33.6	-6.25	24.6	6.25	35.4
5	32	50.0	50.8	75.0	44.0	65.6	48.3	25.00**	44.0	-9.38	53.0	15.62*	51.5
6	32	56.2	50.4	62.5	49.2	46.9	50.7	6.25	61.9	-15.62	51.5	-9.38	58.8
Learning Styles													
Active	18	58.3	23.0	84.3	12.1	72.2	21.4	25.93***	23.0	-12.04	22.0	13.89**	18.3
Reflective	14	58.3	29.1	77.4	20.3	69.0	23.4	19.05*	29.9	-8.33	23.3	10.71*	22.3
Sensing	20	62.5	24.1	84.2	14.8	73.3	24.4	21.67***	24.8	-10.83	26.6	10.83*	20.4
Intuitive	12	51.4	27.0	76.4	18.1	66.7	17.4	25.00**	28.9	-9.72	13.2	15.28**	19.4
Visual	31	58.1	25.8	81.7	16.3	70.4	22.2	23.66***	26.1	-11.29	22.1	12.37***	20.2
Verbal	1												
Sequential	19	52.6	25.0	78.9	17.4	67.5	23.2	26.32***	30.1	-11.40	25.5	14.91**	22.8
Global	13	66.7	24.5	84.6	14.4	75.6	20.0	17.95**	18.6	-8.97	17.5	8.97*	14.6
Year in College													
1	19	57.9	26.3	85.1	16.6	69.3	22.4	27.19***	29.0	-15.79	23.9	11.40*	20.1
2	9	63.0	26.1	75.9	14.7	72.2	26.4	12.96*	16.2	-3.70	16.2	9.26	20.6
3	3	55.6	25.5	72.2	19.2	77.8	9.6	16.67	28.9	5.56	25.5	22.22	19.2
4	1												
Rocketry Experience													
Yes	8	70.8	23.1	87.5	11.8	85.4	18.8	16.67*	19.9	-2.08	10.7	14.58*	18.8
No	24	54.2	25.2	79.2	17.2	66.0	21.1	25.00***	27.8	-13.19	24.6	11.81**	20.5
MOOC Experience													
Yes	21	59.5	20.8	80.2	15.5	71.4	19.1	20.63***	19.7	-8.73	20.2	11.90**	18.4
No	11	56.1	33.6	83.3	18.3	69.7	27.7	27.27*	36.0	-13.64	26.7	13.64*	23.4
Gender													
Female	11	43.9	17.1	75.8	18.8	62.1	21.2	31.82**	26.3	-13.64	32.3	18.18***	13.9
Male	20	65.0	26.4	84.2	14.8	74.2	21.3	19.17**	25.5	-10.00	14.7	9.17*	22.6
Other	1												

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

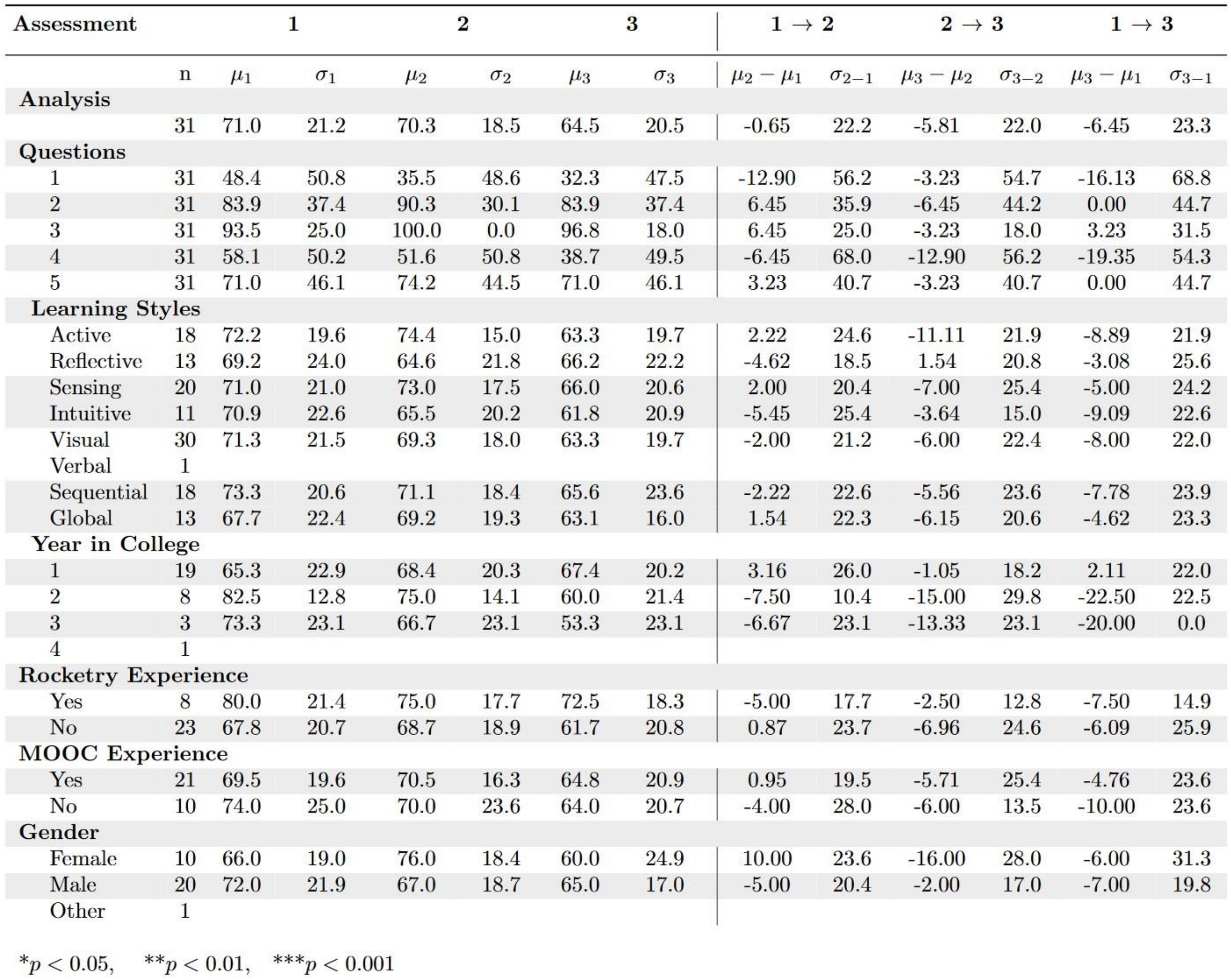
Table 7: Modeling Rocket Mechanics quiz data



Assessment		1		2		3		1 → 2		2 → 3		1 → 3	
	n	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3	$\mu_2 - \mu_1$	σ_{2-1}	$\mu_3 - \mu_2$	σ_{3-2}	$\mu_3 - \mu_1$	σ_{3-1}
Modeling Rocket Mechanics													
	32	43.2	23.1	62.0	32.0	56.2	28.9	18.75***	28.3	-5.73	24.5	13.02**	24.9
Questions													
1	32	50.0	50.8	50.0	50.8	46.9	50.7	0.00	50.8	-3.12	47.4	-3.12	64.7
2	32	71.9	45.7	84.4	36.9	87.5	33.6	12.50	49.2	3.12	40.0	15.62*	44.8
3	32	59.4	49.9	75.0	44.0	75.0	44.0	15.62	62.8	0.00	44.0	15.62	57.4
4	32	46.9	50.7	62.5	49.2	62.5	49.2	15.62*	51.5	0.00	44.0	15.62	57.4
5	32	21.9	42.0	62.5	49.2	34.4	48.3	40.62***	49.9	-28.12	58.1	12.50	49.2
6	32	9.4	29.6	37.5	49.2	31.2	47.1	28.12**	58.1	-6.25	56.4	21.88*	55.3
Learning Styles													
Active	18	43.5	22.2	63.9	27.0	60.2	25.7	20.37**	28.9	-3.70	25.9	16.67**	24.9
Reflective	14	42.9	25.1	59.5	38.5	51.2	33.0	16.67*	28.5	-8.33	23.3	8.33	25.1
Sensing	20	45.8	21.5	67.5	31.7	63.3	28.9	21.67**	30.2	-4.17	27.0	17.50**	27.8
Intuitive	12	38.9	25.9	52.8	31.6	44.4	25.9	13.89*	25.5	-8.33	20.7	5.56	17.9
Visual	31	43.0	23.5	61.8	32.5	56.5	29.4	18.82***	28.8	-5.38	24.9	13.44**	25.2
Verbal	1												
Sequential	19	39.5	23.7	57.9	34.0	48.2	29.9	18.42*	32.3	-9.65	23.1	8.77	26.3
Global	13	48.7	22.0	67.9	29.2	67.9	24.0	19.23**	22.4	-0.00	26.4	19.23**	22.4
Year in College													
1	19	37.7	24.7	64.9	31.9	56.1	29.0	27.19***	24.3	-8.77	25.7	18.42**	23.5
2	9	50.0	20.4	51.9	38.6	50.0	30.0	1.85	34.8	-1.85	24.2	0.00	28.9
3	3	50.0	16.7	72.2	9.6	66.7	33.3	22.22*	9.6	-5.56	25.5	16.67	16.7
4	1												
Rocketry Experience													
Yes	8	52.1	20.8	79.2	27.8	81.2	24.3	27.08**	21.7	2.08	28.8	29.17**	23.1
No	24	40.3	23.5	56.3	31.8	47.9	25.7	15.97**	30.1	-8.33	23.1	7.64	23.6
MOOC Experience													
Yes	21	42.9	22.1	63.5	32.8	57.9	25.6	20.63**	30.7	-5.56	28.5	15.08**	25.8
No	11	43.9	26.1	59.1	31.9	53.0	35.6	15.15*	24.1	-6.06	15.4	9.09	24.0
Gender													
Female	11	30.3	19.5	40.9	31.1	39.4	20.1	10.61	23.9	-1.52	30.2	9.09	18.8
Male	20	51.7	21.6	73.3	27.8	65.0	30.1	21.67**	30.2	-8.33	22.0	13.33*	27.4
Other	1												

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

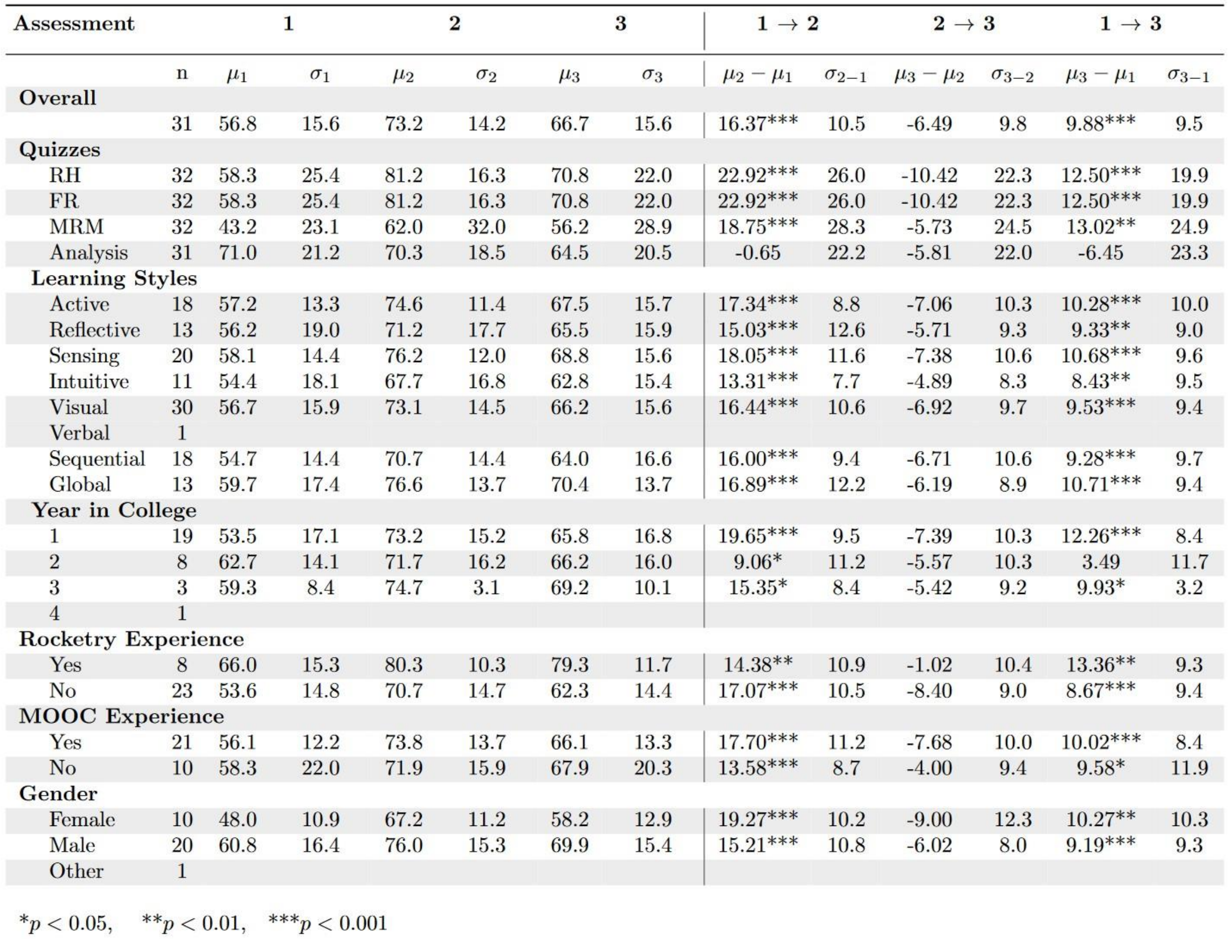
Table 8: Analysis quiz data



Assessment		1		2		3		1 → 2		2 → 3		1 → 3	
	n	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3	$\mu_2 - \mu_1$	σ_{2-1}	$\mu_3 - \mu_2$	σ_{3-2}	$\mu_3 - \mu_1$	σ_{3-1}
Analysis													
	31	71.0	21.2	70.3	18.5	64.5	20.5	-0.65	22.2	-5.81	22.0	-6.45	23.3
Questions													
1	31	48.4	50.8	35.5	48.6	32.3	47.5	-12.90	56.2	-3.23	54.7	-16.13	68.8
2	31	83.9	37.4	90.3	30.1	83.9	37.4	6.45	35.9	-6.45	44.2	0.00	44.7
3	31	93.5	25.0	100.0	0.0	96.8	18.0	6.45	25.0	-3.23	18.0	3.23	31.5
4	31	58.1	50.2	51.6	50.8	38.7	49.5	-6.45	68.0	-12.90	56.2	-19.35	54.3
5	31	71.0	46.1	74.2	44.5	71.0	46.1	3.23	40.7	-3.23	40.7	0.00	44.7
Learning Styles													
Active	18	72.2	19.6	74.4	15.0	63.3	19.7	2.22	24.6	-11.11	21.9	-8.89	21.9
Reflective	13	69.2	24.0	64.6	21.8	66.2	22.2	-4.62	18.5	1.54	20.8	-3.08	25.6
Sensing	20	71.0	21.0	73.0	17.5	66.0	20.6	2.00	20.4	-7.00	25.4	-5.00	24.2
Intuitive	11	70.9	22.6	65.5	20.2	61.8	20.9	-5.45	25.4	-3.64	15.0	-9.09	22.6
Visual	30	71.3	21.5	69.3	18.0	63.3	19.7	-2.00	21.2	-6.00	22.4	-8.00	22.0
Verbal	1												
Sequential	18	73.3	20.6	71.1	18.4	65.6	23.6	-2.22	22.6	-5.56	23.6	-7.78	23.9
Global	13	67.7	22.4	69.2	19.3	63.1	16.0	1.54	22.3	-6.15	20.6	-4.62	23.3
Year in College													
1	19	65.3	22.9	68.4	20.3	67.4	20.2	3.16	26.0	-1.05	18.2	2.11	22.0
2	8	82.5	12.8	75.0	14.1	60.0	21.4	-7.50	10.4	-15.00	29.8	-22.50	22.5
3	3	73.3	23.1	66.7	23.1	53.3	23.1	-6.67	23.1	-13.33	23.1	-20.00	0.0
4	1												
Rocketry Experience													
Yes	8	80.0	21.4	75.0	17.7	72.5	18.3	-5.00	17.7	-2.50	12.8	-7.50	14.9
No	23	67.8	20.7	68.7	18.9	61.7	20.8	0.87	23.7	-6.96	24.6	-6.09	25.9
MOOC Experience													
Yes	21	69.5	19.6	70.5	16.3	64.8	20.9	0.95	19.5	-5.71	25.4	-4.76	23.6
No	10	74.0	25.0	70.0	23.6	64.0	20.7	-4.00	28.0	-6.00	13.5	-10.00	23.6
Gender													
Female	10	66.0	19.0	76.0	18.4	60.0	24.9	10.00	23.6	-16.00	28.0	-6.00	31.3
Male	20	72.0	21.9	67.0	18.7	65.0	17.0	-5.00	20.4	-2.00	17.0	-7.00	19.8
Other	1												

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 9: Overall course score data



Assessment		1		2		3		1 → 2		2 → 3		1 → 3	
	n	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3	$\mu_2 - \mu_1$	σ_{2-1}	$\mu_3 - \mu_2$	σ_{3-2}	$\mu_3 - \mu_1$	σ_{3-1}
Overall													
	31	56.8	15.6	73.2	14.2	66.7	15.6	16.37***	10.5	-6.49	9.8	9.88***	9.5
Quizzes													
RH	32	58.3	25.4	81.2	16.3	70.8	22.0	22.92***	26.0	-10.42	22.3	12.50***	19.9
FR	32	58.3	25.4	81.2	16.3	70.8	22.0	22.92***	26.0	-10.42	22.3	12.50***	19.9
MRM	32	43.2	23.1	62.0	32.0	56.2	28.9	18.75***	28.3	-5.73	24.5	13.02**	24.9
Analysis	31	71.0	21.2	70.3	18.5	64.5	20.5	-0.65	22.2	-5.81	22.0	-6.45	23.3
Learning Styles													
Active	18	57.2	13.3	74.6	11.4	67.5	15.7	17.34***	8.8	-7.06	10.3	10.28***	10.0
Reflective	13	56.2	19.0	71.2	17.7	65.5	15.9	15.03***	12.6	-5.71	9.3	9.33**	9.0
Sensing	20	58.1	14.4	76.2	12.0	68.8	15.6	18.05***	11.6	-7.38	10.6	10.68***	9.6
Intuitive	11	54.4	18.1	67.7	16.8	62.8	15.4	13.31***	7.7	-4.89	8.3	8.43**	9.5
Visual	30	56.7	15.9	73.1	14.5	66.2	15.6	16.44***	10.6	-6.92	9.7	9.53***	9.4
Verbal	1												
Sequential	18	54.7	14.4	70.7	14.4	64.0	16.6	16.00***	9.4	-6.71	10.6	9.28***	9.7
Global	13	59.7	17.4	76.6	13.7	70.4	13.7	16.89***	12.2	-6.19	8.9	10.71***	9.4
Year in College													
1	19	53.5	17.1	73.2	15.2	65.8	16.8	19.65***	9.5	-7.39	10.3	12.26***	8.4
2	8	62.7	14.1	71.7	16.2	66.2	16.0	9.06*	11.2	-5.57	10.3	3.49	11.7
3	3	59.3	8.4	74.7	3.1	69.2	10.1	15.35*	8.4	-5.42	9.2	9.93*	3.2
4	1												
Rocketry Experience													
Yes	8	66.0	15.3	80.3	10.3	79.3	11.7	14.38**	10.9	-1.02	10.4	13.36**	9.3
No	23	53.6	14.8	70.7	14.7	62.3	14.4	17.07***	10.5	-8.40	9.0	8.67***	9.4
MOOC Experience													
Yes	21	56.1	12.2	73.8	13.7	66.1	13.3	17.70***	11.2	-7.68	10.0	10.02***	8.4
No	10	58.3	22.0	71.9	15.9	67.9	20.3	13.58***	8.7	-4.00	9.4	9.58*	11.9
Gender													
Female	10	48.0	10.9	67.2	11.2	58.2	12.9	19.27***	10.2	-9.00	12.3	10.27**	10.3
Male	20	60.8	16.4	76.0	15.3	69.9	15.4	15.21***	10.8	-6.02	8.0	9.19***	9.3
Other	1												

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

3.4.3 Student Interest Results

Unlike the technical knowledge section, students’ interest in rocketry and space increased after each assessment. The survey, shown in Appendix B was broken into rocketry and space related interest questions. Figure 19 shows these scores after each of the assessments and the increases seem to be very minimal, but the increases are in fact significant when performing a paired t-test. As seen in Table 11, overall scores in both were deemed to be significantly increasing after assessment 2 and 3. Figure 1Table 10 gives more insight into how students interest scores changed. A higher Likert score here indicates more interest. Since the Likert scale maxed out a five there was not much room for improvement for students starting at four, but we can see the there is clearly a decrease in the number of students selecting ones, twos, and threes, with an increase in fours and fives.

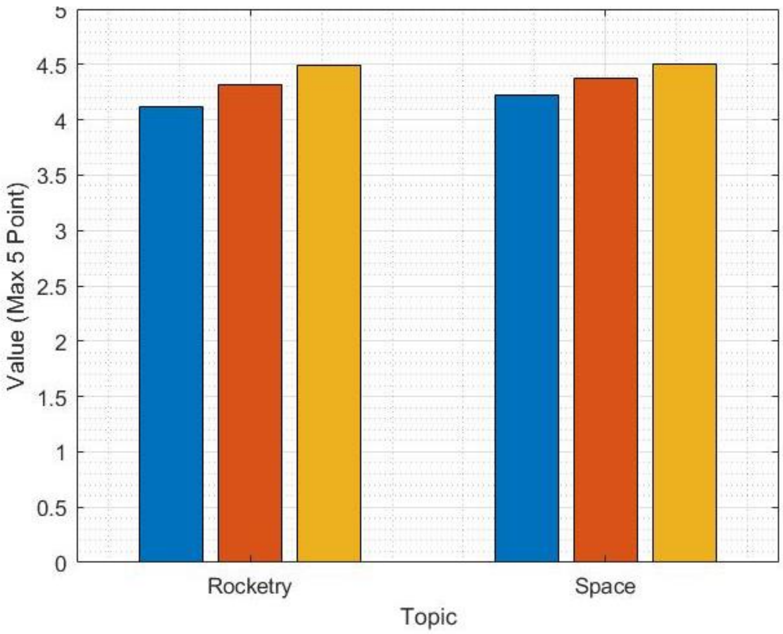


Figure 19: Overall interest scores by topic

Table 10: Percentage of Likert scale selections for each assessment

	Assessment 1					Assessment 2					Assessment 3				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	0	0	0	37.5	62.5	0	0	3.12	37.5	59.38	0	0	0	28.12	71.88
2	0	0	9.38	59.38	31.25	0	3.12	9.38	34.38	53.12	0	0	3.12	34.38	62.5
3	0	0	12.5	53.12	34.38	0	0	6.25	31.25	62.5	0	0	6.25	25	68.75
4	0	0	15.62	43.75	40.62	0	3.12	12.5	40.62	43.75	0	0	12.5	34.38	53.12
5	0	3.12	6.25	46.88	43.75	0	0	3.12	37.5	59.38	0	0	6.25	21.88	71.88
6	0	9.38	21.88	43.75	25	0	3.12	15.62	50	31.25	0	3.12	9.38	37.5	50
7	9.38	21.88	6.25	46.88	15.62	0	28.12	3.12	25	43.75	0	15.62	15.62	15.62	53.12
8	0	0	0	46.88	53.12	0	0	3.12	34.38	62.5	0	0	0	28.12	71.88
9	0	3.12	6.25	53.12	37.5	0	6.25	0	31.25	62.5	0	0	6.25	31.25	62.5
10	0	0	6.25	37.5	56.25	0	3.12	3.12	21.88	71.88	0	0	3.12	18.75	78.12
11	0	3.12	18.75	37.5	40.62	0	6.25	3.12	31.25	59.38	0	3.12	9.38	25	62.5
12	0	0	6.25	40.62	53.12	3.12	0	0	31.25	65.62	0	3.12	0	18.75	78.12
13	0	6.25	18.75	53.12	21.88	0	3.12	21.88	34.38	40.62	0	3.12	12.5	28.12	56.25
14	3.12	18.75	9.38	37.5	31.25	0	18.75	18.75	21.88	40.62	3.12	12.5	15.62	25	43.75

The same increases happened across the board no matter what students initial experience or demographics. Looking Table 11, again there a decrease in interest occurs between assessment two and three for third year students, but with such a small sample likely does not represent the population. One interesting trend that appeared when comparing students who did not have experience coming into those who did. Students with experience started out with a higher amount of interest in rocketry and space but by the end of the course the students without experience had nearly matched their counterparts in terms of interest.

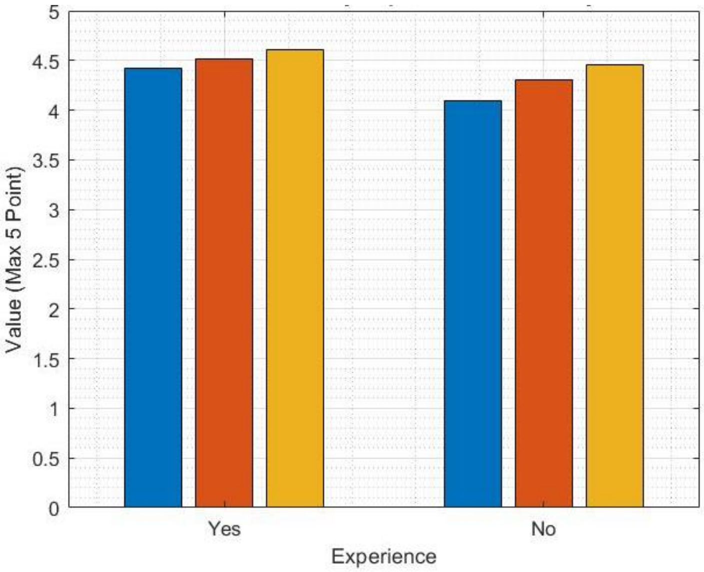
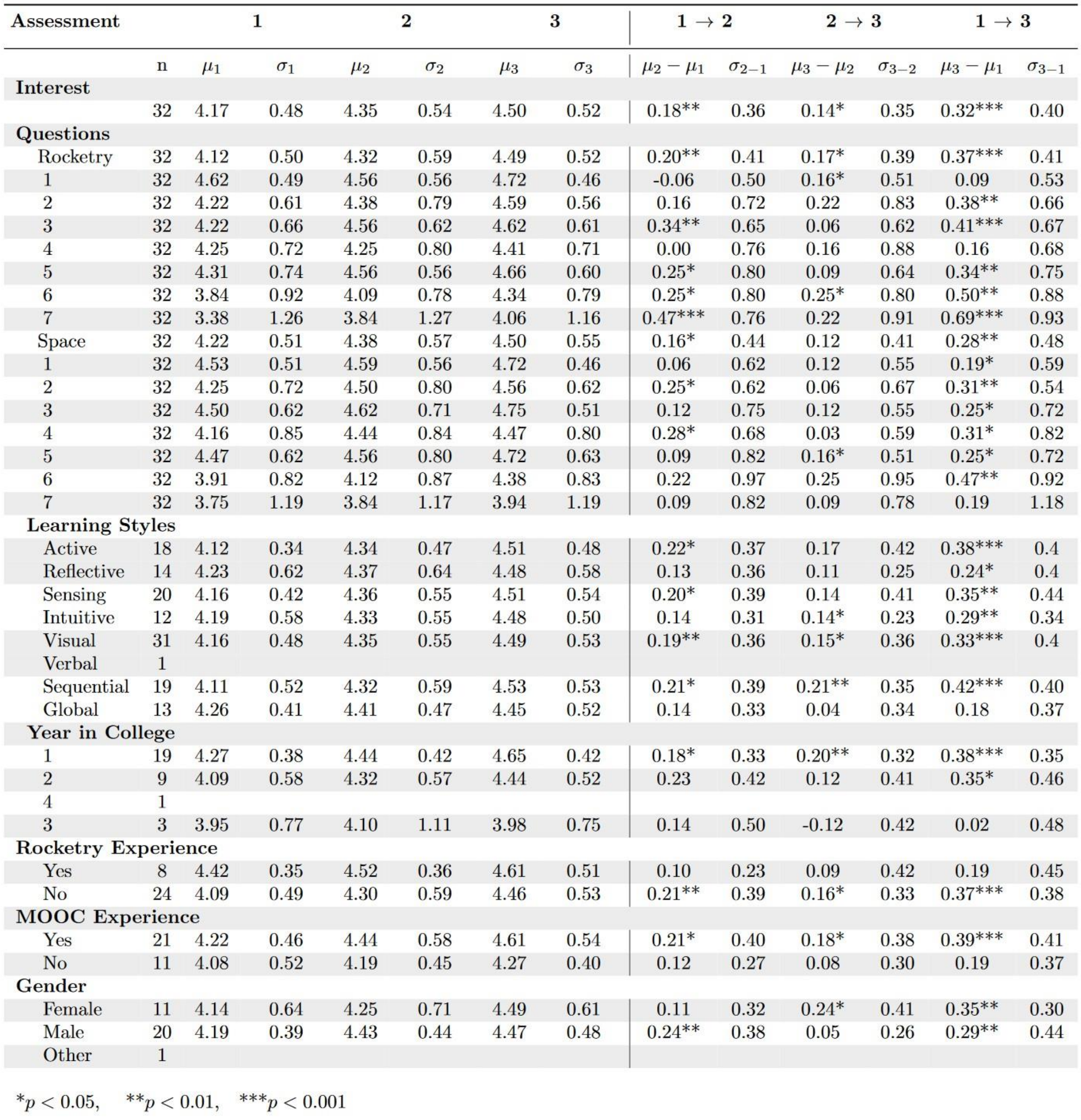


Figure 20: Interest of students with and without previous experience in rocketry

Table 11: Interest assessment data



Assessment		1		2		3		1 → 2		2 → 3		1 → 3	
	n	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3	$\mu_2 - \mu_1$	σ_{2-1}	$\mu_3 - \mu_2$	σ_{3-2}	$\mu_3 - \mu_1$	σ_{3-1}
Interest													
	32	4.17	0.48	4.35	0.54	4.50	0.52	0.18**	0.36	0.14*	0.35	0.32***	0.40
Questions													
Rocketry	32	4.12	0.50	4.32	0.59	4.49	0.52	0.20**	0.41	0.17*	0.39	0.37***	0.41
1	32	4.62	0.49	4.56	0.56	4.72	0.46	-0.06	0.50	0.16*	0.51	0.09	0.53
2	32	4.22	0.61	4.38	0.79	4.59	0.56	0.16	0.72	0.22	0.83	0.38**	0.66
3	32	4.22	0.66	4.56	0.62	4.62	0.61	0.34**	0.65	0.06	0.62	0.41***	0.67
4	32	4.25	0.72	4.25	0.80	4.41	0.71	0.00	0.76	0.16	0.88	0.16	0.68
5	32	4.31	0.74	4.56	0.56	4.66	0.60	0.25*	0.80	0.09	0.64	0.34**	0.75
6	32	3.84	0.92	4.09	0.78	4.34	0.79	0.25*	0.80	0.25*	0.80	0.50**	0.88
7	32	3.38	1.26	3.84	1.27	4.06	1.16	0.47***	0.76	0.22	0.91	0.69***	0.93
Space	32	4.22	0.51	4.38	0.57	4.50	0.55	0.16*	0.44	0.12	0.41	0.28**	0.48
1	32	4.53	0.51	4.59	0.56	4.72	0.46	0.06	0.62	0.12	0.55	0.19*	0.59
2	32	4.25	0.72	4.50	0.80	4.56	0.62	0.25*	0.62	0.06	0.67	0.31**	0.54
3	32	4.50	0.62	4.62	0.71	4.75	0.51	0.12	0.75	0.12	0.55	0.25*	0.72
4	32	4.16	0.85	4.44	0.84	4.47	0.80	0.28*	0.68	0.03	0.59	0.31*	0.82
5	32	4.47	0.62	4.56	0.80	4.72	0.63	0.09	0.82	0.16*	0.51	0.25*	0.72
6	32	3.91	0.82	4.12	0.87	4.38	0.83	0.22	0.97	0.25	0.95	0.47**	0.92
7	32	3.75	1.19	3.84	1.17	3.94	1.19	0.09	0.82	0.09	0.78	0.19	1.18
Learning Styles													
Active	18	4.12	0.34	4.34	0.47	4.51	0.48	0.22*	0.37	0.17	0.42	0.38***	0.4
Reflective	14	4.23	0.62	4.37	0.64	4.48	0.58	0.13	0.36	0.11	0.25	0.24*	0.4
Sensing	20	4.16	0.42	4.36	0.55	4.51	0.54	0.20*	0.39	0.14	0.41	0.35**	0.44
Intuitive	12	4.19	0.58	4.33	0.55	4.48	0.50	0.14	0.31	0.14*	0.23	0.29**	0.34
Visual	31	4.16	0.48	4.35	0.55	4.49	0.53	0.19**	0.36	0.15*	0.36	0.33***	0.4
Verbal	1												
Sequential	19	4.11	0.52	4.32	0.59	4.53	0.53	0.21*	0.39	0.21**	0.35	0.42***	0.40
Global	13	4.26	0.41	4.41	0.47	4.45	0.52	0.14	0.33	0.04	0.34	0.18	0.37
Year in College													
1	19	4.27	0.38	4.44	0.42	4.65	0.42	0.18*	0.33	0.20**	0.32	0.38***	0.35
2	9	4.09	0.58	4.32	0.57	4.44	0.52	0.23	0.42	0.12	0.41	0.35*	0.46
4	1												
3	3	3.95	0.77	4.10	1.11	3.98	0.75	0.14	0.50	-0.12	0.42	0.02	0.48
Rocketry Experience													
Yes	8	4.42	0.35	4.52	0.36	4.61	0.51	0.10	0.23	0.09	0.42	0.19	0.45
No	24	4.09	0.49	4.30	0.59	4.46	0.53	0.21**	0.39	0.16*	0.33	0.37***	0.38
MOOC Experience													
Yes	21	4.22	0.46	4.44	0.58	4.61	0.54	0.21*	0.40	0.18*	0.38	0.39***	0.41
No	11	4.08	0.52	4.19	0.45	4.27	0.40	0.12	0.27	0.08	0.30	0.19	0.37
Gender													
Female	11	4.14	0.64	4.25	0.71	4.49	0.61	0.11	0.32	0.24*	0.41	0.35**	0.30
Male	20	4.19	0.39	4.43	0.44	4.47	0.48	0.24**	0.38	0.05	0.26	0.29**	0.44
Other	1												

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

3.5 CONCLUSION

The data collected form this study clearly shows that this group of students benefited from the intervention that was this course. Their interest in rocketry increased at each point in the course and their overall knowledge of rocketry from the beginning to the end of the course increased. The goal of this course was to do just this, but we also want to reach students outside of the population tested. The significant increases shown are for a population of university students that volunteered for a rocketry course. Our goal is to get this course in the hands of students who might not volunteer for this course and inspire them towards a career in the space industry. Based on the data collected there is no reason to suggest that the same benefits could not be achieved for this larger population and future studies should be done to verify the impact of this course and similar ones. The team at SLI hopes to do this and will be putting the course into he hands of many more students over the next few years. Will these students pivot to a career in aerospace? Right now, it is impossible to know, but so far, the evidence has suggested that at least a few will give the space industry a shot.

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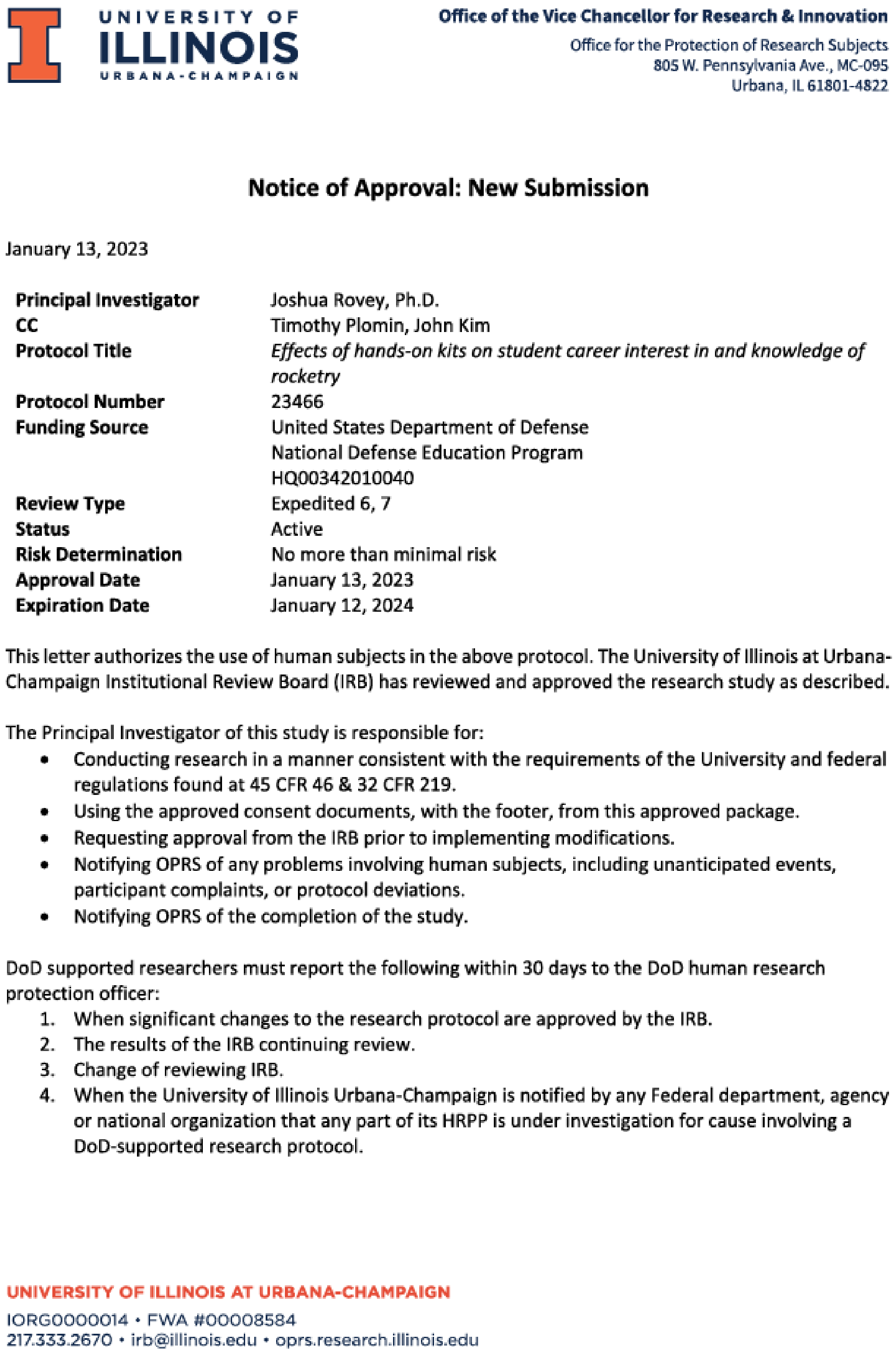
APPENDIX A: PROTECTION OF RESEARCH SUBJECTS

A.1 APPROVAL FROM UNIVERSITY OF ILLINOIS INSTITUTIONAL REVIEW BOARD



UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

Office of the Vice Chancellor for Research & Innovation
Office for the Protection of Research Subjects
805 W. Pennsylvania Ave., MC-095
Urbana, IL 61801-4822

Notice of Approval: New Submission

January 13, 2023

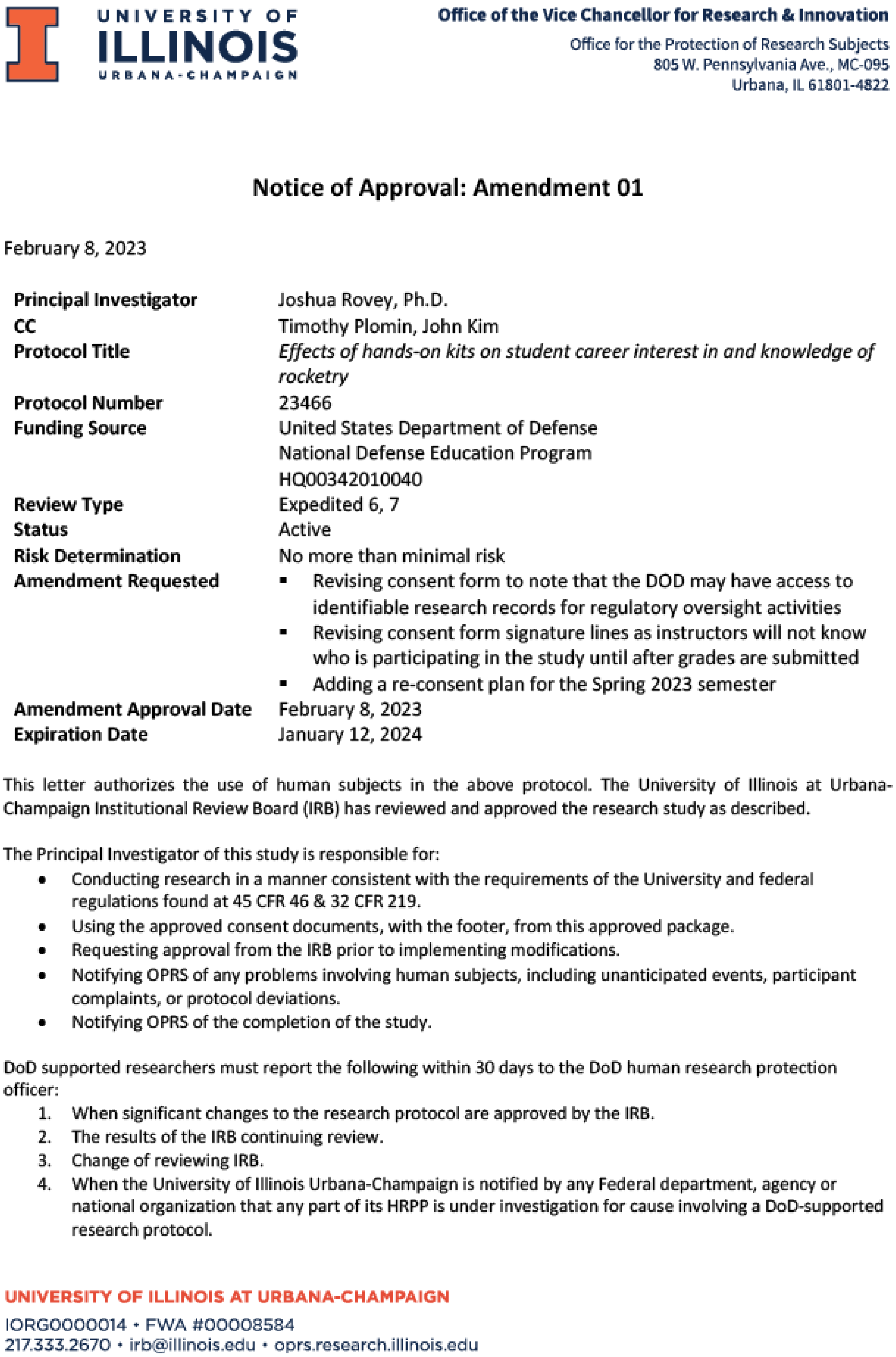
Principal Investigator	Joshua Rovey, Ph.D.
CC	Timothy Plomin, John Kim
Protocol Title	*Effects of hands-on kits on student career interest in and knowledge of rocketry*
Protocol Number	23466
Funding Source	United States Department of Defense National Defense Education Program HQ00342010040
Review Type	Expedited 6, 7
Status	Active
Risk Determination	No more than minimal risk
Approval Date	January 13, 2023
Expiration Date	January 12, 2024

This letter authorizes the use of human subjects in the above protocol. The University of Illinois at Urbana-Champaign Institutional Review Board (IRB) has reviewed and approved the research study as described.

The Principal Investigator of this study is responsible for:
- Conducting research in a manner consistent with the requirements of the University and federal regulations found at 45 CFR 46 & 32 CFR 219.
- Using the approved consent documents, with the footer, from this approved package.
- Requesting approval from the IRB prior to implementing modifications.
- Notifying OPRS of any problems involving human subjects, including unanticipated events, participant complaints, or protocol deviations.
- Notifying OPRS of the completion of the study.

DoD supported researchers must report the following within 30 days to the DoD human research protection officer:
1. When significant changes to the research protocol are approved by the IRB.
2. The results of the IRB continuing review.
3. Change of reviewing IRB.
4. When the University of Illinois Urbana-Champaign is notified by any Federal department, agency or national organization that any part of its HRPP is under investigation for cause involving a DoD-supported research protocol.

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
IORG0000014 • FWA #00008584
217.333.2670 • irb@illinois.edu • oprs.research.illinois.edu



UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

Office of the Vice Chancellor for Research & Innovation
Office for the Protection of Research Subjects
805 W. Pennsylvania Ave., MC-095
Urbana, IL 61801-4822

Notice of Approval: Amendment 01

February 8, 2023

Principal Investigator	Joshua Rovey, Ph.D.
CC	Timothy Plomin, John Kim
Protocol Title	*Effects of hands-on kits on student career interest in and knowledge of rocketry*
Protocol Number	23466
Funding Source	United States Department of Defense National Defense Education Program HQ00342010040
Review Type	Expedited 6, 7
Status	Active
Risk Determination	No more than minimal risk
Amendment Requested	▪ Revising consent form to note that the DOD may have access to identifiable research records for regulatory oversight activities ▪ Revising consent form signature lines as instructors will not know who is participating in the study until after grades are submitted ▪ Adding a re-consent plan for the Spring 2023 semester
Amendment Approval Date	February 8, 2023
Expiration Date	January 12, 2024

This letter authorizes the use of human subjects in the above protocol. The University of Illinois at Urbana-Champaign Institutional Review Board (IRB) has reviewed and approved the research study as described.

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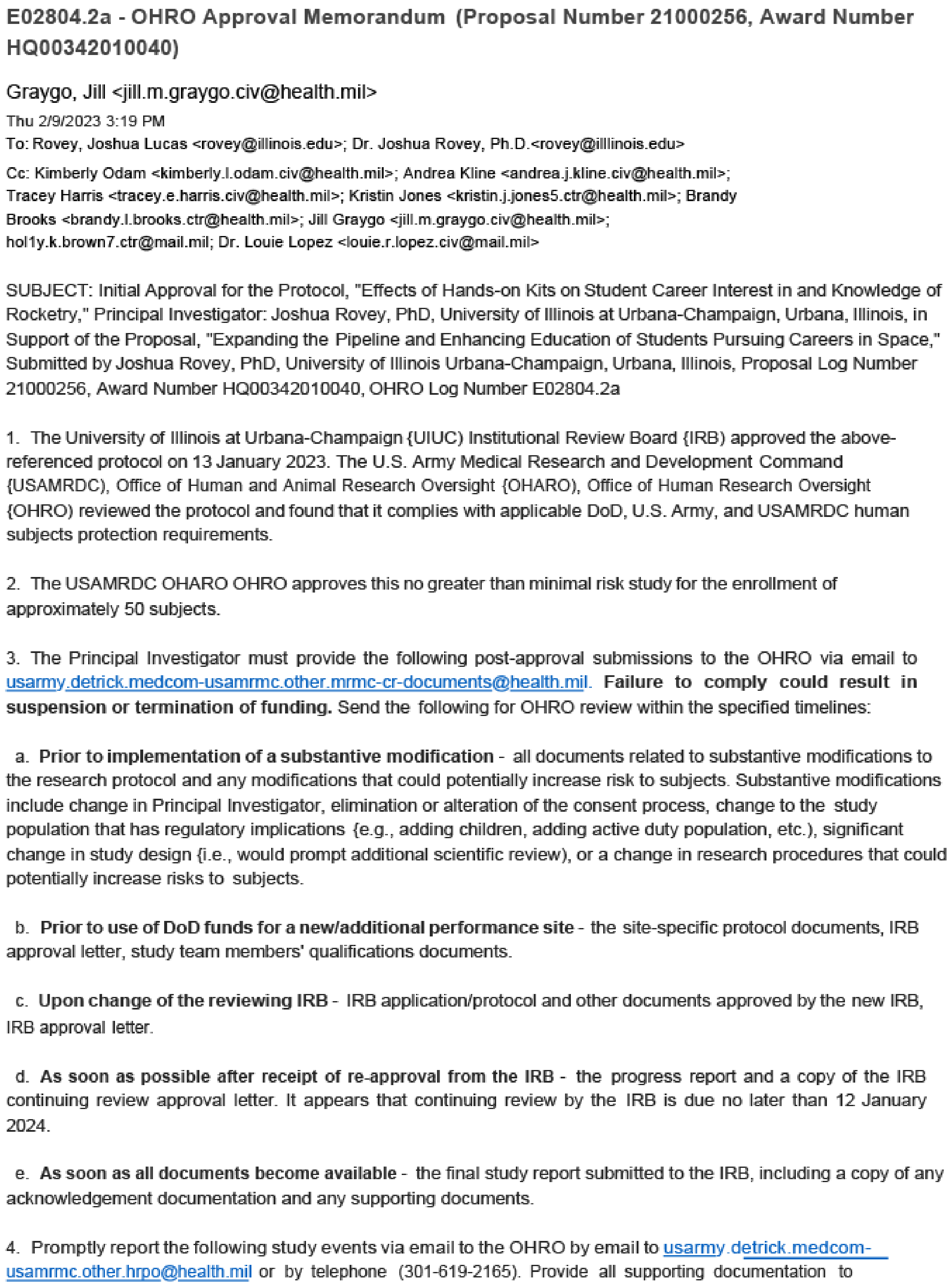
3. Change of reviewing IRB.
4. When the University of Illinois Urbana-Champaign is notified by any Federal department, agency or national organization that any part of its HRPP is under investigation for cause involving a DoD-supported research protocol.

A.2 APPROVAL FROM THE U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND, OFFICE OF HUMAN AND ANIMAL RESEARCH OVERSIGHT, OFFICE OF HUMAN RESEARCH OVERSIGHT



E02804.2a - OHRO Approval Memorandum (Proposal Number 21000256, Award Number HQ00342010040)

Graygo, Jill <jill.m.graygo.civ@health.mil>
Thu 2/9/2023 3:19 PM
To: Rovey, Joshua Lucas <rovey@illinois.edu>; Dr. Joshua Rovey, Ph.D.<rovey@illlinois.edu>
Cc: Kimberly Odam <kimberly.l.odam.civ@health.mil>; Andrea Kline <andrea.j.kline.civ@health.mil>; Tracey Harris <tracey.e.harris.civ@health.mil>; Kristin Jones <kristin.j.jones5.ctr@health.mil>; Brandy Brooks <brandy.l.brooks.ctr@health.mil>; Jill Graygo <jill.m.graygo.civ@health.mil>; hol1y.k.brown7.ctr@mail.mil; Dr. Louie Lopez <louie.r.lopez.civ@mail.mil>

SUBJECT: Initial Approval for the Protocol, "Effects of Hands-on Kits on Student Career Interest in and Knowledge of Rocketry," Principal Investigator: Joshua Rovey, PhD, University of Illinois at Urbana-Champaign, Urbana, Illinois, in Support of the Proposal, "Expanding the Pipeline and Enhancing Education of Students Pursuing Careers in Space," Submitted by Joshua Rovey, PhD, University of Illinois Urbana-Champaign, Urbana, Illinois, Proposal Log Number 21000256, Award Number HQ00342010040, OHRO Log Number E02804.2a

1. The University of Illinois at Urbana-Champaign {UIUC) Institutional Review Board {IRB) approved the above-referenced protocol on 13 January 2023. The U.S. Army Medical Research and Development Command {USAMRDC), Office of Human and Animal Research Oversight {OHARO), Office of Human Research Oversight {OHRO) reviewed the protocol and found that it complies with applicable DoD, U.S. Army, and USAMRDC human subjects protection requirements.

2. The USAMRDC OHARO OHRO approves this no greater than minimal risk study for the enrollment of approximately 50 subjects.

3. The Principal Investigator must provide the following post-approval submissions to the OHRO via email to usarmy.detrick.medcom-usamrmc.other.mrmc-cr-documents@health.mil. **Failure to comply could result in suspension or termination of funding.** Send the following for OHRO review within the specified timelines:

a. **Prior to implementation of a substantive modification** - all documents related to substantive modifications to the research protocol and any modifications that could potentially increase risk to subjects. Substantive modifications include change in Principal Investigator, elimination or alteration of the consent process, change to the study population that has regulatory implications {e.g., adding children, adding active duty population, etc.), significant change in study design {i.e., would prompt additional scientific review), or a change in research procedures that could potentially increase risks to subjects.

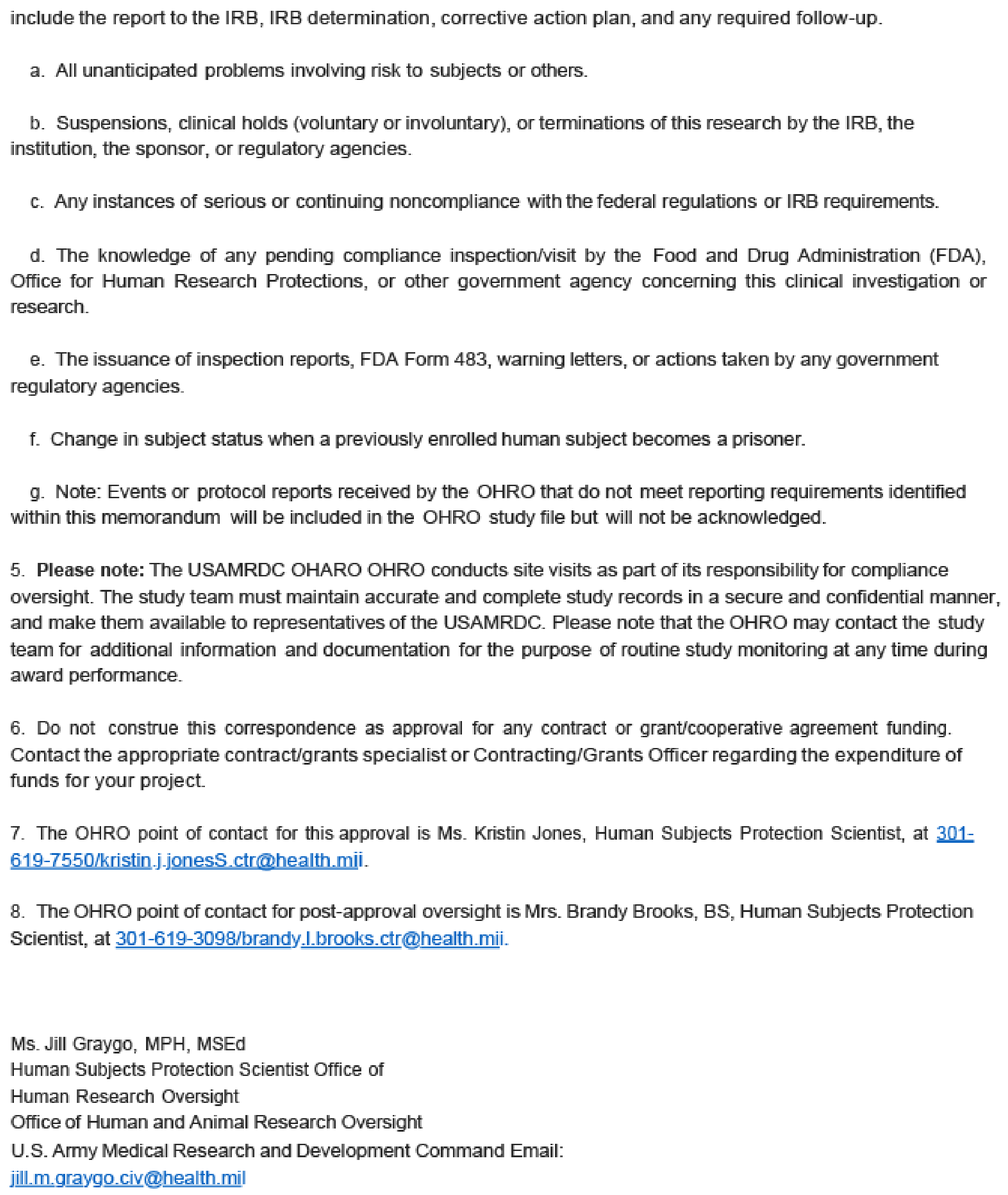
b. **Prior to use of DoD funds for a new/additional performance site** - the site-specific protocol documents, IRB approval letter, study team members' qualifications documents.

c. **Upon change of the reviewing IRB** - IRB application/protocol and other documents approved by the new IRB, IRB approval letter.

d. **As soon as possible after receipt of re-approval from the IRB** - the progress report and a copy of the IRB continuing review approval letter. It appears that continuing review by the IRB is due no later than 12 January 2024.

e. **As soon as all documents become available** - the final study report submitted to the IRB, including a copy of any acknowledgement documentation and any supporting documents.

4. Promptly report the following study events via email to the OHRO by email to usarmy.detrick.medcom-usamrmc.other.hrpo@health.mil or by telephone (301-619-2165). Provide all supporting documentation to



include the report to the IRB, IRB determination, corrective action plan, and any required follow-up.

a. All unanticipated problems involving risk to subjects or others.

b. Suspensions, clinical holds (voluntary or involuntary), or terminations of this research by the IRB, the institution, the sponsor, or regulatory agencies.

c. Any instances of serious or continuing noncompliance with the federal regulations or IRB requirements.

d. The knowledge of any pending compliance inspection/visit by the Food and Drug Administration (FDA), Office for Human Research Protections, or other government agency concerning this clinical investigation or research.

e. The issuance of inspection reports, FDA Form 483, warning letters, or actions taken by any government regulatory agencies.

f. Change in subject status when a previously enrolled human subject becomes a prisoner.

g. Note: Events or protocol reports received by the OHRO that do not meet reporting requirements identified within this memorandum will be included in the OHRO study file but will not be acknowledged.

5. **Please note:** The USAMRDC OHARO OHRO conducts site visits as part of its responsibility for compliance oversight. The study team must maintain accurate and complete study records in a secure and confidential manner, and make them available to representatives of the USAMRDC. Please note that the OHRO may contact the study team for additional information and documentation for the purpose of routine study monitoring at any time during award performance.

6. Do not construe this correspondence as approval for any contract or grant/cooperative agreement funding. Contact the appropriate contract/grants specialist or Contracting/Grants Officer regarding the expenditure of funds for your project.

7. The OHRO point of contact for this approval is Ms. Kristin Jones, Human Subjects Protection Scientist, at 301-619-7550/kristin.j.jonesS.ctr@health.mii.

8. The OHRO point of contact for post-approval oversight is Mrs. Brandy Brooks, BS, Human Subjects Protection Scientist, at 301-619-3098/brandy.l.brooks.ctr@health.mii.

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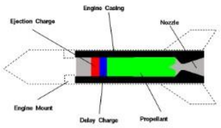
APPENDIX B: EDUCATIONAL RSEARCH STUDY SURVEYS

Introduction and Rocket Hardware

1. In industry, what is the goal of most rocket launches?
   - (a) Achieving the highest apogee.
   - (b) Achieving something that has never been done.
   - (c) Space tourism
   - (d) Delivering a scientific or commercial payload
2. What two components of a model rocket should the recovery wadding be placed between?
   - (a) Payload and Nose Cone
   - (b) Payload and Parachute
   - (c) Shock cord and Parachute
   - (d) Motor and Parachute
   - (e) Motor and fins
3. What would be the effect of having the shock cord break or detach from a model rocket during flight?
   - (a) Lack of parachute support on one or both halves of the rocket
   - (b) The parachute fails to deploy from the body tube
   - (c) Minimal altitude achieved
   - (d) All of the above
4. In a model rocket, why are rocket body tubes joined by a coupler, rather than being glued together?
   - (a) Glue adds too much mass to the rocket
   - (b) The body tubes need to break open during flight for parachute deployment
   - (c) The body tubes need to break open during flight to deploy the payload
   - (d) All of the above
   - (e) None of the above
5. What is the purpose of fins on a rocket?
   - (a) Decrease drag (air resistance) on the back of the rocket to keep it moving vertical during flight
   - (b) Increase drag (air resistance) on the back of the rocket to keep it moving vertical during flight
   - (c) Decrease mass at the back of the rocket to increase thrust
   - (d) Increase mass at the back of the rocket to keep it moving vertical during flight
6. Which solid motor component shown here initiates parachute deployment?



   - (a) Engine casing
   - (b) Propellant
   - (c) Delay charge
   - (d) Ejection charge
7. On a full scale rocket (not a model rocket), what makes up the largest part of a rocket's mass?
   - (a) Propellant
   - (b) Payload
   - (c) Structure and hardware
   - (d) Rocket Engine
   - (e) Depends on the rocket
8. During what stages of flight will a model rocket motor produce thrust?
   - (a) Launch Phase
   - (b) Burn Phase
   - (c) Coast Phase
   - (d) Decent Phase

Answers: 1. (d), 2. (d), 3. (a), 4. (b), 5. (b), 6. (d), 7. (a), 8. (a,b)

Modeling Rocket Mechanics

1. Which of these will always happen when you reduce the mass of your rocket by using a lighter body tube? (Assume the rocket remains stable)
   (a) Thrust will Increase
   (b) Apogee will increase
   (c) drag will decrease
   (d) All of the above
   (e) None of the above

2. To accurately derive acceleration mathematically, what forces on the rocket must be accounted for? **(Check all that apply.)**
   (a) Compression
   (b) Drag
   (c) Gravity
   (d) Tension
   (e) Thrust
   (f) None of the above

3. What number or set of numbers best represents the velocity of the rocket at the end of the coast phase?
   (a) Less than 0
   (b) 0
   (c) More than 0

4. Which of the following remain constant for a commercial rocket in flight?
   (a) Mass
   (b) Thrust
   (c) Drag
   (d) Acceleration
   (e) All of the Above
   (f) None of the Above

Use the following information to answer the next questions,

A model rocket with a mass of 0.2 kilograms is launched with a motor that provides a constant thrust of 10 Newtons for 1 second.

Ignore drag and assume the rockets flight is perfectly vertical.

Use an acceleration due to gravity of $10m/s^2$ instead of 9.8.

These equations will be useful.

$$y_{final} = y_{initial} + v_{initial} \cdot t + \frac{1}{2} \cdot a \cdot t^2$$
$$v_{final} = v_{initial} + a \cdot t$$
$$v_{final}^2 = v_{initial}^2 + 2 \cdot a \cdot (y_{final} - y_{initial})$$
$$\Sigma F = m \cdot a$$

Feel free to use a calculator and a notepad but no internet.

5. What is the velocity of the rocket after the motor burns out.

6. What is the maximum height that the rocket achieves? (also known as the apogee)

Answers: 1. (b), 2. (b,c,e), 3. (b), 4. (f), 5. (40), 6. (100)

Fundamentals of Rocketry

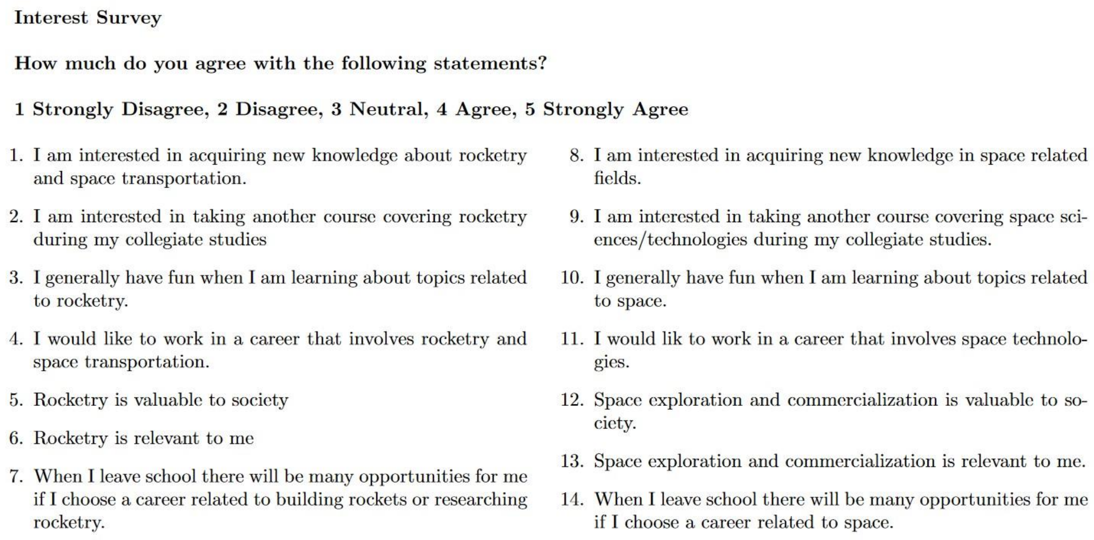
1. On a full-scale rocket (not a model rocket), what makes up the largest part of a rocket's mass?
   (a) Payload
   (b) Propellant
   (c) Rocket Body
   (d) Rocket Engine
   (e) It depends on the rocket
   (f) Part not listed here
2. What must be true for a rocket to remain stable during flight?
   (a) The center of gravity is in the middle of the rocket
   (b) The center of pressure is in front of the center of gravity.
   (c) The center of pressure is behind the center of gravity.
   (d) The center of gravity is in the same location as the center of
   (e) All of these are stable configurations
   (f) None of the Above
3. Which of the following help provide stability for a <u>model rocket</u> at low velocities?
   (a) Launch lugs and rail
   (b) Motor and motor mount
   (c) Avionics system
   (d) Fins and body tube
   (e) All of the above
   (f) None of the above
4. There is a certain point on a body that responds as though the whole mass were concentrated there. What is this point called?
   (a) Center of Pressure
   (b) Static Margin
   (c) Center of Gravity
   (d) Equilibrium Point
   (e) All of the above
   (f) Such a point does not exist
5. What single parameter do engineers use to compare engine efficiency?
   (a) Engine Burn Time
   (b) Exhaust velocity
   (c) Specific Impulse
   (d) Thrust
   (e) Such a parameter does not exit
6. What happens to the stability of a model rocket if the thrust to weight ratio is only slightly above 1?
   (a) It will be moving too slowly for high velocity stability to work.
   (b) It will be moving too fast for high velocity stability to work.
   (c) It will be moving too slowly for low velocity stability to work.
   (d) It will be moving too fast for low velocity stability to work.

Answers: 1. (b), 2. (c), 3. (a), 4. (c), 5. (c), 6. (a)

Analysis

1. What are some reasons that your rocket's predicted apogee might not match your experimental apogee, select all that apply.
    - (a) Flight is not perfectly vertical
    - (b) Error measuring payload mass
    - (c) Parachute did not deploy
    - (d) Drag force was neglected
    - (e) No Model will perfectly match a rockets flight every time
2. How do you expect the apogee calculated from your model without drag will compare to the actual flight of the rocket?
    - (a) Actual will be higher
    - (b) Actual will be lower
    - (c) Actual will be the same
    - (d) It depends on the weather conditions at launch
3. What is one reason a commercial company would choose to go to space?
    - (a) Tourism
    - (b) Communication satellites
    - (c) NASA Contract
    - (d) All of the above
4. How can a launch vehicle services reduce the cost of a launch?
    - (a) Fly reusable launch vehicles
    - (b) Increase fuel storage on launch vehicles
    - (c) Add more payload
    - (d) All of the above
5. When creating a model for the real world what do engineers have to keep in mind
    - (a) Balancing accuracy vs complexity
    - (b) The model must predict the experimental exactly
    - (c) You should remove all assumptions to get a useful model
    - (d) All of the above
    - (e) None of the above

Answers: 1. (a,b,d,e), 2. (b), 3. (d), 4. (a), 5. (a)



Interest Survey

How much do you agree with the following statements?

1 Strongly Disagree, 2 Disagree, 3 Neutral, 4 Agree, 5 Strongly Agree

1. I am interested in acquiring new knowledge about rocketry and space transportation.
2. I am interested in taking another course covering rocketry during my collegiate studies
3. I generally have fun when I am learning about topics related to rocketry.
4. I would like to work in a career that involves rocketry and space transportation.
5. Rocketry is valuable to society
6. Rocketry is relevant to me
7. When I leave school there will be many opportunities for me if I choose a career related to building rockets or researching rocketry.
8. I am interested in acquiring new knowledge in space related fields.
9. I am interested in taking another course covering space sciences/technologies during my collegiate studies.
10. I generally have fun when I am learning about topics related to space.
11. I would lik to work in a career that involves space technologies.
12. Space exploration and commercialization is valuable to society.
13. Space exploration and commercialization is relevant to me.
14. When I leave school there will be many opportunities for me if I choose a career related to space.