

'It's Nothing Like October Sky!': Spurring 9th & 10th Graders to Think Like Engineers via Rockets Custom-Designed for Maximum Altitude

Dr. Matthew J. Traum, Engineer Inc.

Dr. Matthew J. Traum is founding CEO at Engineer Inc., a Florida-based STEM education social enterprise start-up. Traum invented @HOLM™ lab kits to enable students in on-line courses to build and run engineering experiments remotely at home.

Before founding Engineer Inc., Dr. Traum was a well-known higher education administrator, fund raiser, educator, and researcher with co-authorship of 12 peer-reviewed research journal articles, 18 refereed research conference articles, and 20 refereed pedagogical conference articles. As a PI or Co-PI, Traum has attracted over \$841 K in funding for research, education, and entrepreneurial ventures from multiple sources including NSF, NASA, ASHRAE, AIAA, Sigma Xi, the Texas State Energy Conservation Office, and several industry sponsors including Toshiba and Oshkosh.

Most recently as Associate Professor and Director of Engineering Programs at Philadelphia University, Dr. Traum led the Mechanical Engineering Program through a successful ABET interim visit resulting in no deficiencies, weaknesses, or concerns.

Previously, Dr. Traum was an assistant professor at the Milwaukee School of Engineering (MSOE), one of the top-ten undergraduate-serving engineering universities in the U.S. Dr. Traum coordinated MSOE's first crowd-funded senior design project. He also co-founded with students EASENET, a start-up renewable energy company to commercialize waste-to-energy biomass processors.

Dr. Traum began his academic career as a founding faculty member in the Mechanical & Energy Engineering Department at the University of North Texas - Denton where he established a successful, externally-funded researcher incubator that trained undergraduates to perform experimental research and encouraged matriculation to graduate school.

Traum received a Ph.D. in mechanical engineering from the Massachusetts Institute of Technology where he held a research assistantship at MIT's Institute for Soldier Nanotechnologies. At MIT he invented a new nano-enabled garment to provide simultaneous ballistic and thermal protection to infantry soldiers. Dr. Traum also holds a master's degree in mechanical engineering from MIT with a focus on cryogenics and two bachelor's degrees from the University of California, Irvine: one in mechanical engineering and the second in aerospace engineering. In addition, he attended the University of Bristol, UK as a non-matriculating visiting scholar where he completed an M.Eng thesis in the Department of Aerospace Engineering on low-speed rotorcraft control.

Dr. Sharon Liz Karackattu, Oak Hall School

Sharon L. Karackattu earned a B.S. in Interdisciplinary Studies: Biochemistry and Molecular Biology from the University of Florida in 2000 and completed a Ph.D. in Biology at the Massachusetts Institute of Technology in 2006. She served as a postdoctoral associate in MIT's Biological Engineering Division before spending two years as a Research Coordinator for Student Development at University of North Texas. She is currently a high school science instructor specializing in chemistry and the life sciences. She has taught college-level courses in the biosciences and maintains an interest in studying students pursuing the STEM fields.

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Abstract

K-12 STEM education literature reveals that conventional and traditional math, science, and computer programming classes often fail to effectively “do the ‘E’ in STEM”. New grade-level-appropriate curricula are required to address this omission. This paper presents and evaluates a model-rocket-based curriculum implemented in a stand-alone STEM course required for all 9th and 10th graders at a private high school. The project is unique because it melds the following five attributes into an open-ended, hands-on, high-school-level engineering design-and-build project: 1) Design-Build-Test pedagogy; 2) the engineering design process; 3) comprehensive technical coverage of rocket systems; 4) the seven axes of engineering practice; and 5) enabling computer simulations and micro-sensor technology for engineering design and analysis. This novel curriculum is evaluated using an indirect post-activity survey that probes students’ attitudes about STEM fields and self-perceived skills and abilities.

For the project, all students were given identical Estes LoadStar II model kits, commercially available in Educator Bulk Packs. The students’ challenge, framed as a class competition, was to modify the rocket’s design to maximize flight altitude with an Estes C6-5 motor. The instructor first guided students through creating functional digital renderings of the unmodified rocket kit using Rocket Simulator from Apogee Components. Virtual launches of simulated rockets corroborated by data from real launches established an altitude baseline. Students then brainstormed and explored a variety of design modifications using the modeling software to evaluate potential rocket altitude impacts of each change. With inexpensive hand tools available in the STEM classroom, students modified their rocket kits to match the designs they developed in the software. Student-designed and -built rockets were then launched. Flight altitudes were measured directly using an onboard JollyLogic AltimeterThree barometric altimeter carried aloft in the rocket payload section. In every class section, student-customized rockets outperformed the unmodified baseline vehicle.

At the class’s conclusion, 79 students (out of 107 enrolled) completed a computerized anonymous indirect survey to self-assess their attitudes about the course specifically and engineering in general as a result of the rocket project. Results were lackluster compared to expectations based on similar novel classroom lesson pedagogical studies previously conducted. Only 54.4% of students reported increased interest in the class over the semester. 62.0% reported improved understanding of the rocket design process. 57.0% reported being able to see interconnections between science, math, engineering, and technology as a result of the course. Despite these disappointing results, anecdotal observation suggested student participants were engaging in effective engineering thinking throughout the project. Reasons explaining middling survey results and discussion of the project’s next steps to improve student responses are described.

Introduction

The K-12 STEM education literature reveals that conventional and traditional math, science, and computer programming classes often fail to effectively “do the ‘E’ in STEM”. According to Parry, the ‘E’ in STEM is usually an afterthought with mathematics and science receiving more instructional attention [1]. Pleasants and Olson point out that most K-12 teachers are likely to have taken no engineering coursework, and thus they possess misconceptions about engineering practice and amalgamate engineering with science [2]. Conflating engineering with science in high school has real consequences for engineering student retention in college. Our own work shows that many freshmen who declare engineering majors enter college not really knowing what practicing engineers do despite the students’ professed interest in the field [3,4]. Once they do become informed about the duties and daily activities of engineering professionals, previously misinformed students leave engineering majors [5].

One key factor (often overlooked by K-12 teachers) that differentiates engineering from other STEM disciplines is emphasis on open-ended experimental problem solving [6]. Stiefel reports anecdotal comments from master STEM teachers emphasizing this critical and unique open-ended feature. “In most of schooling, you go from A to B, but in STEM, students are choosing their own path to get to B,” said one teacher Stiefel interviewed; “In my class, how students are going to get there is up to them. There’s a lot of trial and error” [7]. So, spurring high school students to think like engineers necessitates inducing an open-ended, creative, iterative, and design-oriented mindset.

Among best practice approaches that induce an engineering mindset in learners is the Design, Build, Test (DBT) pedagogy whose key attributes are outlined by Elger, et al [8]. DBT curricula must 1) be fun and motivating; 2) meet educational objectives; 3) include a major modeling component; 4) include aspects of engineering practice [CAD, teamwork, and technical communication]; and 5) be easy to implement [as measured by transferability, sustainability, and scalability]. DBT parallels the underlying pedagogy narrative of New Learning developed by Kalantzis and Cope [9], and it overlaps with Energy Engineering Laboratory Module (EELM™) pedagogy [10], which posits that learning experiences must be hands-on, accessible, student-centered, economical, and “turn-key”. DBT and EELM™ project hardware must be affordable for an institution with limited resources and be buildable and operable by a handy high school course instructor or technician without situated knowledge or access to specialized tools or equipment.

Anecdotally, educators have been using model rocketry for decades in middle/high schools and colleges to involve students in engaging, pragmatic, and interdisciplinary build-and-test activities. Where then is the associated literature? As pointed out by Campbell, et al, there is a surprising lack of available peer reviewed pedagogical literature on educational model rocket projects [11]. Campbell and Okutsu provide a broad contemporary review of existing model rocketry pedagogical literature, pointing out that all this work (with exception of their own papers) is either 1) focused on a single technical area without covering broad instruction or 2) meant to introduce engineering concepts without delving deeper into engineering practice [12].

What precisely constitutes “engineering practice”; what separates it pedagogically from merely studying engineering concepts; and how middle/high school science, math, and technology instructors should teach engineering practice remain open debates in the Engineering Education literature [13]. To provide clarity for our project, we identified two attributes we feel uniquely define high-quality middle/high school engineering practice instruction: 1) using a formal engineering design process and 2) conveying the complexity and interconnectivity associated with engineering practice. While there are variations, the formal engineering design process recommended for use in middle/high schools is proposed by Hynes et al, and it contains the following steps: 1) Identify the problem, 2) Research the problem, 3) Develop possible solutions, 4) Down-Select the best potential solution, 5) Model and prototype, 6) Test and evaluate the solution, 7) Communicate results, and 8) Iterate by redesign [14]. Conveying the complexity and interconnectivity of engineering practice requires students to experience the following seven axes: 1) How engineers work, 2) How engineers utilize and produce knowledge, 3) Engineering’s relation to science, 4) Engineering decision making, 5) Tools and strategies engineers use, 6) The importance of creativity and innovation, and 7) Engineering’s ethical implications. These axes represent our amalgamation of intersecting recommendations by Pleasants and Olson [2] as well as Cunningham and Kelly [15] on the nature of what constitutes engineering in K-12 educational practice.

Given this working definition for high-quality engineering practice instruction, the model rocket work of Campbell and Okutsu is joined in the literature, in our opinion, by Llanos, et al [16] and Buchanan, et al [17]. This trio of papers is unique among the model rocket pedagogical literature in that each one simultaneously covers multiple technical areas while demonstrating the DBT pedagogy of Elger et al. While these papers carve a unique pedagogical niche for collegiate model rocketry, there remains a dearth of similar literature for middle/high school projects. Widmark is notable in the K-12 space, but this work lacks a pedagogical element measuring the impacts of rocket projects on students’ understanding of and attitudes toward engineering [18]. So, our current paper attempts to fill this void with focus on rocketry engineering pedagogy for middle/high school while 1) using the formal engineering design process and 2) exposing students to the seven axes of engineering practice.

We present and evaluate a model-rocket-infused curriculum implemented in a stand-alone STEM course required for all 9th and 10th graders at St. Francis Catholic Academy (SFCA) in Gainesville, FL, USA. All students were given identical model rocket kits. Their challenge was to modify the rocket’s design to maximize flight altitude. This challenge was framed as a competition with recognition going to the student in each class section with the top-performing rocket. The instructor first guided students through creating functional digital simulations of their unmodified rocket kits. Software-simulated unmodified rocket launches established an altitude baseline, which was validated by experimental launches of a real rocket built to kit specifications and instrumented with an accelerometer and altimeter. Students then brainstormed and explored a variety of design modifications, using modeling software to evaluate the potential impact of each change on rocket altitude. Next, students modified their rocket kits to reflect changes they made in the computer model to increase flight altitude. Modified rockets were then instrumented with accelerometer and altimeter sensors and flown. Students evaluated the resulting flight data to determine how well the rocket modifications they selected and simulated performed in reality when their modified rockets were launched.

Literature Review

Many aspects of engineering teaching using model rocketry are reported in the literature including launch trajectory analysis [19,20], measurement/simulation of motor thrust curves [21,22], determination of drag coefficients [23], and presentation of custom design and fabrication methods [24]. In the area of model rocket propulsion systems, published work includes black powder combustion [21,22], pressurized water [25-27], pressurized air [28], and pressurized gas evolved from mixing baking soda and vinegar [29,30]. Pressurized rocket propulsion systems lack combustion, but combustion is deemed important to the comprehensive treatment championed by Campbell and Okutsu. So, when considering the type of rocket propulsion system for our educational module, we selected black powder combustion. This choice enables instructors to use the variety of commercial “turn-key” model rocket kits with prefabricated parts available from manufactures like Estes, Quest, Apogee, and others. Using black powder for propulsion also allows instructors to employ model rocket flight performance modeling software like Open Rocket [31] and Apogee’s Rocket Simulator (RockSim) [32]. These Computer-Aided Design (CAD) software packages provide learners with simulated flight performance data. There is no need to launch test rockets and employ inaccurate trigonometric [33] or timing [34,35] equations to assess impacts of rocket design changes on flight performance. Eliminating need for trial launches to estimate flight altitude for various experimental rocket configurations greatly speeds up the iterative design process. Also, black powder rocket motors more realistically mirror how full-scale rockets from organizations like SpaceX and NASA operate [36,37] should an instructor wish to use popular space history documentaries or movies as lesson components, as advocated by Goll and various co-authors [38-40]. Finally, black powder facilitates insertion of rocket lessons into chemistry classes since combustion processes can be analyzed and tied to motor performance [41,42]. Intrepid chemistry teachers may even consider segueing from black powder to sugar as fuel and developing lessons where students study stoichiometry by mixing, shaping, and launching their own propellant/oxidizer combinations [43,44].

The literature includes some examples of comprehensive model rocket programs targeted for high school, but these are developed by universities and are carried out with the support of college professors for purposes of recruiting [45,46] or as an intervention to strengthen students’ interest in STEM fields [47]. Perhaps the best reported comprehensive model rocket program for high school that was developed and carried out by a high school teacher is the 1998 work of Widmark [18]. Key to this work is demonstration that most parameters characterizing rocket flight (e.g., flight stability, aerodynamic drag, vehicle weight, fuel weight, motor thrust, flight dynamics, and apogee altitude) are relatively easy and inexpensive to measure. This beneficial attribute of model rockets for education has also been shown elsewhere [48]. Sadly, Widmark’s paper pre-dates the era of microsensors, and it relies on ground-based rocket sightings to estimate flight altitude, a method we found to be inaccurate. As noted by Horst, modern advances in miniaturized low-cost barometric altimeter and accelerometer sensors enable educators to engage students in complete design/simulate/build/test rocket creation cycles that supply reliable data to support iterative design [49]. Combining rocket flight performance modeling software with on-board micro-sensor altimeters, students can predict the performance of a model rocket using computer simulation then validate the prediction by comparison with real flight data.

Methods

To create a learning environment that “does the ‘E’ in STEM”, we designed a curriculum for 9th and 10th graders at SFCA that melded the following five attributes: 1) DBT pedagogy of Elger, et al [8]; 2) the engineering design process of Hynes, et al [14]; 3) the comprehensive technical coverage of Campbell & Okutsu [12] and Widmark [18]; 4) the seven axes of engineering practice of Pleasants & Olson [2] and Cunningham & Kelly [15]; and 5) enabling computer simulation and micro-sensor technologies of Horst [49].

To orient students, they were introduced to the project framed as a design competition whose ultimate goal was to modify a rocket kit to achieve maximum flight altitude with an Estes C6-5 motor; effectively a Customer Needs Statement to seed the formal engineering design process. Through videos, lectures, and prescribed hands-on experiments, the instructor taught the mathematics and science underpinning rocket propulsion, parts of a rocket, flight stability, aerodynamics drag, flight dynamics, recovery, and determination of altitude. Each student was then given an identical model kit: the Estes LoadStar II. This kit was selected because it is available in Educator Bulk Packs containing 12 individual kits to keep costs low. The LoadStar II also has a large, clear payload section to mount avionic sensors, and it is a two-stage rocket. For this class, students were instructed to only build the top stage, but the availability of spare parts from the booster stage dramatically expanded students’ ability to customize their rockets. For example, with the extra balsa and body tubes from the booster, students could easily change fin size, add fins, increase body tube length, and add external nacelles among other modifications.

To familiarize students with the parts of their rocket kits and the simulation software, they measured all components in their kits with calipers (Figure 1A) and digitized the dimensions

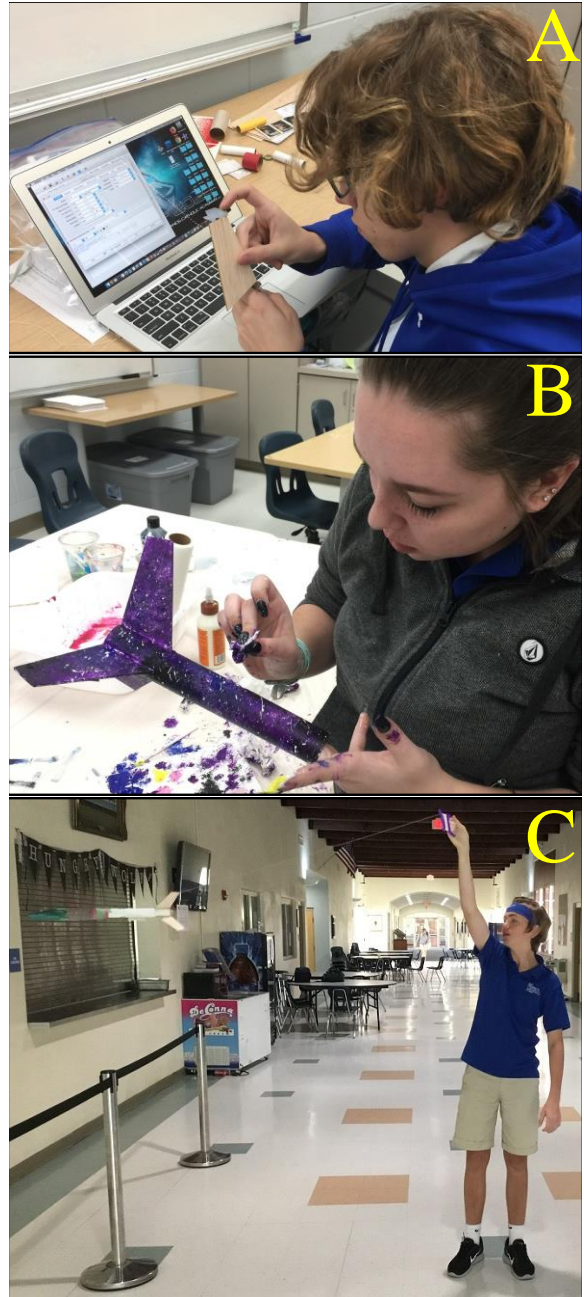


Figure 1: (A) Measuring a balsa rocket fin via caliper to digitize component dimensions into RockSim software. (B) Students customized their rockets both through unique component configuration and by applying individualized paint jobs. (C) The swing test for flight stability verifies that custom rockets will fly nosecone-first. This test is a critical validation step before rockets are certified to fly.

into the simulation program. The modeling program we selected was Rocket Simulator (RockSim) [32]. RockSim was selected over the competing free open source product, OpenRocket [31], because the software is available for and native to both Macs and PC's. OpenRocket runs in JAVA, which would have created security vulnerabilities for SFCA's computer network. In addition, Apogee Components, the company that created and distributes RockSim, provides an online tutorial library showing how to use the software. Viewing these tutorials can be assigned as homework, freeing the instructor from need to spend class time teaching the basics of the software and to focus class time on modeling the details specific to the selected rocket kit. In our case, the Loadstar II's offset launch lugs proved difficult for students to model; so, class time was allotted to demonstrate how to represent them in RockSim. Should a teacher be unable to figure out an important software feature or element, Apogee has a telephone helpline that teachers can call for troubleshooting and technical support with the software.

RockSim demo software is available as a free download to use for a 30-day trial period. The trial version allows full building capability and launch simulation features adequate for students to test altitude impacts of their rocket modification ideas. For this project, SFCA purchased 6 permanent RockSim licenses and installed them in the school's computer laboratory. Each SFCA student has their own Apple laptop issued through a school-wide computer program. In our rocket module, students downloaded the RockSim trial to their laptops, and the class was structured so they could complete all needed modeling and simulation within the 30-day trial period. Any additional simulation work needed beyond the trial software's expiration was completed on the SFCA computer lab machines hosting permanent RockSim licenses. RockSim operates with a graphical user interface and treed component structure (Figure 2) that is initiative for building up a digital simulation of a real rocket. Using this system, students can measure each individual part in their rocket kits, enter key dimensional and material composition details into RockSim, and the software builds the overall rocket accordingly.

To collect data from real rocket flights, the JollyLogic AltimeterThree was selected as the avionics package [50]. This instrument contains barometric altitude and acceleration sensors, and it is small and light enough to fit inside the LoadStar II rocket payload section without modification. It communicates with a variety of Bluetooth-enabled iOS base units; so, there is no need to physically connect it to a receiver to recover flight data. This feature greatly sped up the data collection process. With two AltimeterThree's, it was possible to run rocket flight and recovery operations nearly continuously. As one rocket was being recovered and returned to the launch site for flight data upload, a second rocket was being prepared for flight.

To help the launch/recovery/upload cycle run smoothly, students initially practiced data collection with the AltimeterThree's by mounting them inside wiffle balls, tossing the balls upward inside the gym, and then recovering the data. As expected, parabolic arcs represented ballistic ball trajectories under gravity.

Once students were familiar with the rocket kit components and the model-building capabilities of RockSim, the teacher instructed on how to select the appropriate virtual rocket motor consistent with planned launches and how to simulate flights of the virtual rockets. Considering the substantial weight of LoadStar II top stages and the fact each would be carrying an altimeter (adding more eight), the most powerful motor option recommended by Estes for top-stage

LoadStar II launches was used: the 18-mm-diameter Estes C6-5 rocket motor [51]. These motors are available in Educator Bulk Packs to keep costs low. Virtual RockSim launches of simulated unmodified LoadStar II top stages with C6-5 motors established an altitude baseline of 95.1 meters, which student-designed rocket customizations were meant to surpass.

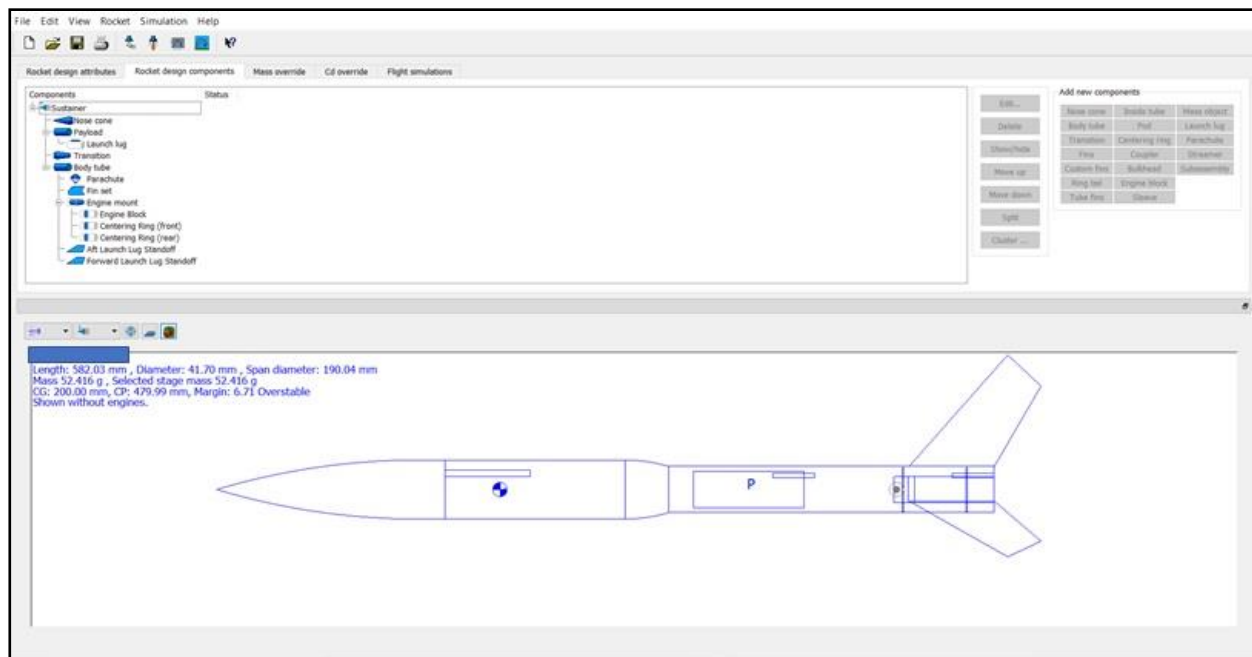


Figure 2: The RockSim graphic user interface uses a treed component structure, which lets students enter geometric and material data for each component then assemble them together through a CAD system into a completed virtual rocket.

To validate the simulation, the instructor built an unmodified rocket (Figure 3 – Top), precisely following the LoadStar II kit instructions. This archetype was launched and recovered at least once by each class section to generate launch data for comparison to the RockSim flight simulation. On average, the unmodified rocket achieved a maximum altitude of 77.1 meters, less than 95.1 meters predicted by RockSim. The 18.9% difference between simulated/actual results is attributed to extra weight in the actual rocket not accounted for in the simulation: glue, paint, shock cord, the altimeter itself, and tape to prevent nosecone separation from the payload section. Also, using an entry-level Estes launch pad, it was difficult to ensure the rocket fired straight up. Assuming the rocket flies straight, any initial launch angle reduces its ultimate maximum altitude. Identifying these simulation/experiment inconsistencies and reducing their diverging influence on model/actual flight results will be ongoing to improve future iterations of this activity.

Despite simulation/experiment maximum altitude quantitative mismatch, students understood that modifications improving the simulation corresponded to analogous (albeit qualitative) improvements in actual flight. To this end, students began brainstorming in groups and exploring on their individual RockSim simulations a variety of design modifications that might improve maximum flight altitude.

Guided by earlier lessons on the impact of drag and weight on performance, major areas for design exploration included 1) changing nosecone shape/size/weight, 2) decreasing/increasing payload section length, 3) decreasing/increasing body tube length, 4) changing the size/number of fins, 5) changing the axial location and/or radial placement of fins, 6) changing the motor mount assembly location, and 7) reducing recovery system weight [as in Figure 3 – Bottom]. Interestingly, many modifications that most improved flight altitude also negatively impacted stability (e.g., shorter body tube, smaller fins). Students inadvertently discovered an engineering optimization problem embedded in the rocket altitude contest: by reducing drag and weight too much, the rocket's straight flight path to higher altitude was compromised.



Figure 3: An unmodified Estes LoadStar II rocket (Top) was built by the instructor to establish an altitude performance baseline. Here, it is compared against a student-modified rocket. In this case, the student realized weight from the original rocket's parachute recovery system could be reduced by switching to streamer recovery, which facilitated safe return of the rocket but with less initial takeoff weight.

To confirm flight stability and safety, completed modified rockets were loaded with motors and stability tested via the swing test (Figure 1C) [52]. In some cases, student designs pushed drag and weight reduction too far, and the resulting rockets were not swing-test-stable. In these instances, students had to redesign and rebuild their rocket and demonstrate stability before they

were allowed to fly. Their RockSim models also had to be changed to reflect these last-minute modifications. Upon passing flight stability swing testing, each rocket was subjected to a final instructor quality assurance certification to locate any anomalies that could potentially make the rockets dangerous to launch.

In preparation for launch, each student packed their safety-certified rockets' recovery systems, installed C6-5 rocket motors, placed a JollyLogic AltimeterThree in the payload section, and taped the rocket joints to assure nothing came loose in flight (Figure 4). Each student's rocket was launched, recovered, and flight data were collected and sent electronically to each student for analysis.

The final course deliverable from each student was a report comparing RockSim predicted maximum flight altitude to the real performance of their actual rocket. As observed with the unmodified rocket, RockSim tended to over-predict actual achieved maximum flight altitude measured by the JollyLogic AltimeterThree by about 20%. Again, we think this discrepancy arises from two main factors: 1) weight-adding rocket elements absent from the simulations and 2) difficulty orientating the launch pad to fire vertically. Generally, however, actual rockets performed relative to others as RockSim had predicted. For example, the modified rocket with the highest simulated altitude (157.4 meters) did, in fact, fly the highest in reality (125.9 meters). This rocket capitalized on all common drag- and weight-reducing variations the students discovered without passing the instability margin: reduced payload and body tube lengths, reduced fin size, and a recovery system modified to minimize weight while facilitating safe recovery.

Pedagogical Data Collection

To indirectly assess the rocket project's impact on students' attitudes toward STEM and the engineering concepts taught within the project, an anonymous post-activity student survey was posted online and administered via Survey Monkey. Of the 107 students enrolled in the classes that conducted the rocket project, $n = 79$ completed the survey, which contained nine questions posed on a five-point Likert-like response scale [see Appendix A].



Figure 4: This student's rocket, loaded with a C6-5 motor is being prepared for launch. The AltimeterThree is visible, secured in the payload section, and the nosecone is taped to prevent it from falling off during flight and recovery.

Results

This section presents quantitative results from both the pedagogical and the engineering project portions of the rocket project module.

Pedagogical Survey Results

Results from the indirect assessment survey are presented in Figure 5.

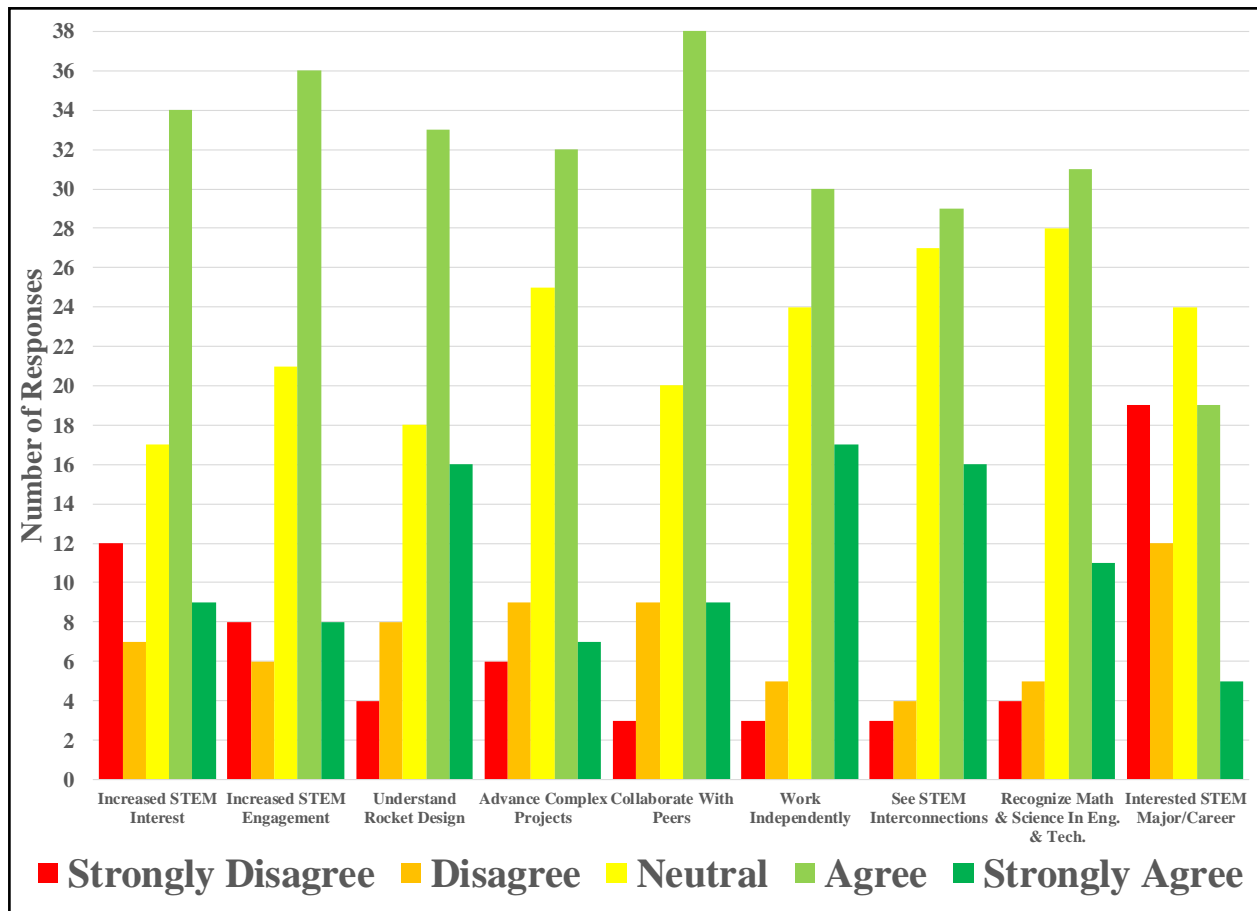


Figure 5: Students ($n = 79$) responded to an online post-activity survey answering questions posed on a five-level Likert-like scale. The survey assessed their STEM attitudes, interest, and self-reported abilities resulting from participation in the project.

As detailed in Figure 5, several important and unexpected results emerged from the student survey. Only 54.4% participants (43.0% Agree, 11.4% Strongly Agree) reported feeling increased interest toward the class compared to at the semester's start, and only 55.7% (45.6% Agree, 10.1% Strongly Agree) self-reported increasing engagement in the class as the semester unfolded. After going through all the described learning, design, build, and test steps described in this paper, only 62.0% (41.8% Agree, 20.2% Strongly Agree) of responding students self-reported improved understanding of the rocket design process. Less than half, only 49.4% (40.5% Agree, 8.9% Strongly Agree), felt their ability to take on complex projects had improved as a result of the class. With respect to seeing how science, math, and engineering fit together

only 57.0% (36.7% Agree, 20.3% Strongly Agree) reported seeing how these subjects interconnect, and just over half, 53.2% (39.2% Agree, 14.0% Strongly Agree), felt they could recognize math or science used for engineering analysis. Only 30.4% (24.1% Agree, 6.3% Strongly Agree) reported that the class sparked their interest in pursuing a STEM degree in college and/or a STEM career. In fact, a larger portion of students, 39.2%, effectively reported that the class *reduced* their interest in pursuing a STEM field career.

Rocket Flight Results

Figure 6 shows representative student rocket flight altitude as a function of time. Data are reported for the highest-flying rocket in each of the 5 class sections where the lesson was taught. Happily, at least one student in every class period developed and implemented a combination of modifications allowing their rocket to outperform the baseline unmodified rocket.

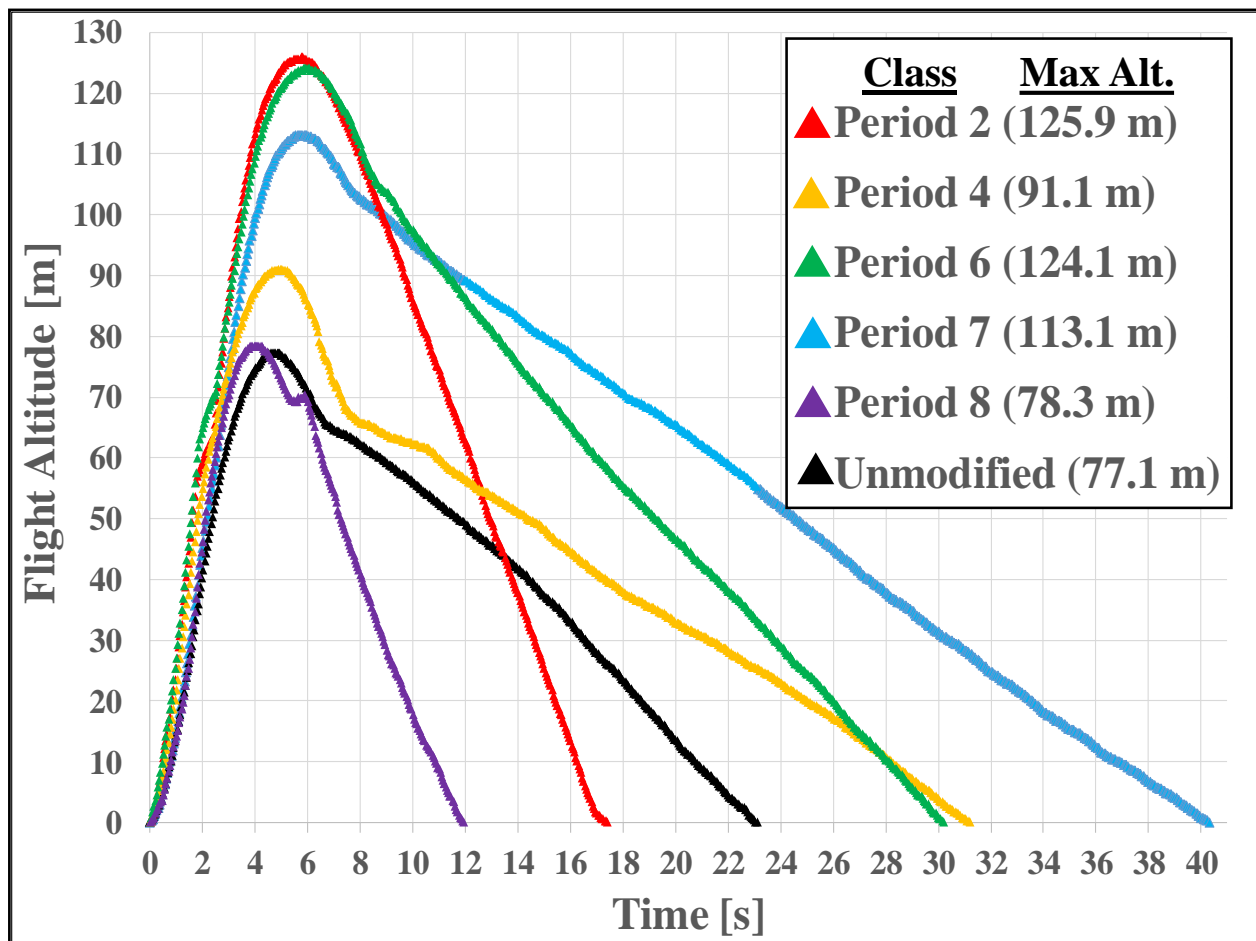


Figure 6: Flight data from each modified rocket achieving the highest altitude in each of the five STEM class sections where the rocket module was taught. Maximum altitude for each rocket, measured by an onboard Jolly Logic AltimeterThree, is noted in the legend. Unmodified rocket flight data and maximum altitude are shown for comparison.

Recovery system deployment is apparent in most Figure 6 flight curves as a change in the data shape after apogee from parabolic (ballistic descent) to linear (terminal velocity – with recovery system deployed). Note in Period 2 (Figure 6 – Red Curve), the nosecone was not properly taped

onto the payload bay before launch. So, the nosecone (with the altimeter attached to it) fell off the rocket at apogee and followed an unimpeded ballistic flight path before it smashed into the ground.

Figure 6 reveals interesting features of the overall model rocket flight cycle when vehicles derived from the LoadStar II kit are fitted with C6-5 motors. The Estes C6-5 thrust curve published by the National Association of Rocketry indicates the motor's thrust phase lasts 1.86 seconds [53]. Based on the motor's "5" designation, the delay fuse should burn for 5 seconds after the thrust is exhausted before firing the ejection charge to deploy the recovery system. Thus, we expect to see in Figure 6 all ejection charges firing about 7 seconds ($1.86\text{ s} + 5.00\text{ s}$) after launch. Instead, however, there is range from about 5.5 to 8.5 seconds. Each rocket reached apogee before its recovery charge fired. So, early/late recovery charge firing did not directly impact any rocket's maximum altitude. However, later recovery charge firing correlates to higher flight altitude, suggesting these motors contained more fuel that burned for longer. The large variability in delay time suggests Estes C6-5 motors themselves might be inconsistent in their manufacture. In other words, while good rocket design was certainly a factor in observed altitude performance, variation in the motors themselves might also be a significant and unknown factor. For example, Haw reports an average impulse of $2.36 \pm 0.16\text{ N}\cdot\text{s}$ over six Estes A8-3 rocket motors tested, representing 13.6% variability in this parameter [21]. While outside the scope of the current paper, data collected here recommends a study of rocket motor thrust curve variability to quantify this effect. Such a project could certainly be carried out by an advanced high school chemistry or physics class. Until variability in Estes C6-5 motor thrust is quantified, future iterations of this project should allow each rocket to be fired at least twice (assuming time and resources are available) with students using the better altitude in their performance evaluations to reduce impact of motor variability on quantitative outcome.

Discussion

In an attempt to provide a comprehensive student experience representative of engineering practice, this project melded the following five attributes into an open-ended hands-on design-and-build project for high school freshman and sophomores: 1) DBT pedagogy; 2) the engineering design process; 3) comprehensive technical coverage of rocket systems; 4) the seven axes of engineering practice; and 5) use of enabling computer simulations and micro-sensor technology.

Since STEM was a required SFCA class, all students took it even if their interest in the material was limited. So, there was a small student cohort who did not resonate with the course and complained about being compelled to take it. To partially explain the large proportion of unfavorable survey responses, it is possible these disgruntled students intentionally mismarked the survey (e.g., marked "Strongly Disagree" on all questions) to berate the instructor or express frustration with the course. This unfortunate phenomenon is reported in the literature [54], and we have also observed it in our own previous attempts to introduce novel or innovative teaching techniques to the classroom [5]. Alternatively, some students may have been confused by the survey and simply selected the wrong response (e.g., they marked "Strongly Disagree" when they intended "Strongly Agree"). While we do not have any way to measure the magnitude of

these effects, they are likely not large enough to create the overall lackluster survey responses we observed.

In comparison to other novel hands-on educational projects we have run both at the high school and college levels, self-reported student responses for this rocket project were dreary. Only about half the class said they felt stimulated, motivated, and engaged. Half did not build confidence to tackle complex projects, and only about half saw how engineering fits together with other technical disciplines. Most surprisingly, nearly 40% reported that the STEM class dissuaded them from pursuing a STEM field career. Despite all the hands-on activities, academic connections, and student learning we thought should be happening given such an engaging project, the instructor wrestled daily with student discipline, moral, and focus problems in all five class sections. Anecdotally, students approached the instructor after the class concluded stating that they rarely understood what they were doing and why. In most cases, enrolled students did not possess the prerequisite math, physics, chemistry, or computer experience to perform some of the tasks the class demanded. To fill this gap, needed material and content was taught to the class using a Just-In-Time technique that we have used successfully for similar situations in the past [55,56]. However, many students did not internalize or learn this material as readily as the instructor hoped. Some students stated that their disinterest arose because the material was not relevant to their other classes. So, the instructor collaborated with colleagues in math and science to incorporate rocket concepts into their courses to buttress connections with STEM, but this intervention had little positive general impact. By contrast, some students were highly engaged in and devoted to the STEM class. The instructor invested time in class, during lunch, and after school to work with these motivated students one-on-one and in small groups to ensure their understanding and success with the technical material. Nothing presented in the STEM class was truly beyond the capabilities or comprehension of the 9th and 10th graders enrolled. Ultimately, students who wanted to learn and succeed did, and students who did not want to learn did not.

Anecdotally, despite middling post-project survey results concerning their perceptions of engineering, the students were observed engaged in engineering thinking along the seven axes of engineering practice recommended by Pleasants and Olson [2] and Cunningham and Kelly [15]. A prime example was when students realized their strategies to reduce rocket drag and weight were impacting stability. In this open-ended problem, students discovered that there was not necessarily one right answer but a range of solutions that yielded similar performance results; an example of *Axis 4: Engineering Decision Making* and *Axis 6: The Importance of Creativity and Innovation*. Students also thought like engineers when rocket modifications that seemed feasible in their RockSim simulation faced impediments in reality. To reduce weight, some students shortened the payload section only to realize the JollyLogic AltimeterThree would no longer fit. Reducing the body tube length too much left no room for the recovery system inside the real rocket. This experience conveyed the importance of visualizing and measuring the real system being designed to ensure component fitment; an example of *Axis 1: How Engineers Work* and *Axis 5: Tools and Strategies Engineers Use*. One student found a one-fin configuration that the simulation reported as stable. This configuration dramatically reduced weight and drag, increasing simulated altitude to a winning height, but the student doubted whether the real one-finned rocket would be stable. The instructor let this student try the one-fin solution, but it ultimately failed the swing test for stability, conveying the critical engineering lesson that the

simulation cannot always be trusted; an example of *Axis 2: How Engineers Utilize and Produce Knowledge* and *Axis 3: Engineering's Relation to Science*. At one point, the football team occupied the field used for rocket recovery, and launches were postponed to prevent injuries. This incident demonstrated the importance of engineering decision-making to safeguard the public's wellbeing; an example of *Axis 7: Engineering's Ethical Implications*. These engineering experiences and many others like them occurring throughout the rocket module were unique and valuable for high school students. The general lack of student recognition revealed by their surveys that they were, in fact, doing engineering may arise from the conflation of engineering with science endemic in schools identified by Pleasants and Olson [2]. The instructor could have done a better job illuminating for students these “engineering teaching moments” as they occurred. Our own research contains examples of advanced projects adapted for high school that failed to hold student interest and attention because they were not designed or implemented with the P-12 environment in mind [57]. Perhaps the rocket project reported here failed to have a more positive impact on its student participants because it was not properly adapted and evolved for a high school environment.

Conclusion

This paper summarizes the practical implementation of “doing the ‘E’ in STEM” for high school 9th and 10th graders at Saint Francis Catholic Academy using model rockets as the educational platform. The project is unique because it melded the following five attributes into an open-ended hands-on engineering design-and-build high school project: 1) DBT pedagogy; 2) the engineering design process; 3) comprehensive technical coverage of rocket systems; 4) the seven axes of engineering practice; and 5) enabling computer simulations and micro-sensor technology.

The project was framed for students as a competition to redesign the first stage of an Estes LoadStar II model rocket kit flying on an Estes C6-5 motor with maximizing altitude as the goal. Students used a variety of engineering tools (computer simulations, hand tools for fabrication, and sensors for data collection) to first predict rocket performance and then implement design improvements to maximize rocket flight altitude. The process was iterative and included key project and performance milestones (e.g., modeling deadlines, build deadlines for launch, and tests for rocket stability) to ensure high-quality and safe systems were built.

Impact of this project on students' attitudes and interest toward STEM was evaluated via an indirect online survey given at the end of class that garnered 79 student responses. To our surprise, the results were lackluster in comparison to similar novel hands-on learning activities we have run in the past. Only 54.4% of participants reported feeling increased interest in the material between the start and end of class, and only 55.7% self-reported increasing engagement in the class as the semester unfolded. Despite working on rocket designs all semester, only 62.0% of responding students self-reported improved understanding of the rocket design process. Only 57.0% reported increased understanding of how STEM subjects interconnect, and only 53.2% felt they could recognize uses of math or science in engineering problem solving. Shockingly, 39.2% reported that the class *reduced* their interest in pursuing a STEM field career. Anecdotally, the class was challenging to teach due to lack of math and physics prerequisite preparation by the students. However, despite disappointing exit survey results, the instructor observed genuine engineering thinking by students across all project activities and assignments.

Future Plans

It is our belief that mediocre student survey results with respect to desired outcomes arose because the STEM class in which the rocket module was taught 1) was required for all students [i.e., a cohort with no interest in engineering was forced to enroll], 2) was not adapted to the high school environment in which it was taught, and 3) enrolled students who lacked the needed math and science prerequisites to carry out some of the analysis required to understand and navigate the project.

More work is needed to refine the rocket curriculum presented here to make it grade-level appropriate. Moreover, it should not be taught in a required class where students with no interest in engineering (and no motivation to learn about engineering) are forced to enroll. To continue moving the project forward and testing students' responses to refinements, the project is being converted into an immersive week-long engineering summer camp. The summer camp is advertised to the community as a rigorous and academically challenging experience suited only for high schoolers interested in learning about what engineering majors do in college. This approach is expected to draw student participants who self-select based on their interest in engineering to take on a challenging technical project.

From a pedagogical research perspective, the current study suffered from lack of a pre-activity survey to gauge students' perceptions before embarking on the project. While the exit survey scores seem low compared against exit surveys for similar engineering projects we have run, it would have been more effective to know students' pre-activity baseline. Perhaps students' self-reported engineering thinking results produced by exposure to this activity were good relative to their starting point. In the next study, a survey assessing that baseline is needed. In addition, even though students' responses were disappointing on metrics reflecting engineering thinking and the relationship between engineering math and science, it is important to remember that these results were self-reported. By contrast, the instructor observed ongoing engineering thinking by student participants, which they perhaps did not recognize as engineering. So, a direct assessment of engineering learning and skills independent of student self-perception would be beneficial. In the future, pre/post direct assessments will be embedded in graded project assignments to give a direct measure of the impact this rocket module has on tangible engineering skills students develop from the activity.

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Appendix A:
Post-Activity Student Survey Questions (Administered Online Via Survey Monkey)

1. My interest level in the STEM class has increased since the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

2. My engagement level in the STEM class has increased since the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

3. My understanding of rocket design for flight stability has improved since the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

4. My ability to advance a complex project has improved since the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

5. My ability to collaborate and seek information from my peers has improved since the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

6. My ability to work independently has improved since the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

7. I see more interconnections between Science, Math, Engineering, and Technology than when the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

8. I better recognize Math and Science applications to Engineering and Technology than when the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

9. I am more interested in majoring in a STEM field in college and/or pursuing a STEM career than I was when the semester started.

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

References

- [1] E. A. Parry, "The 'E' in STEM: Explicitly Teaching Engineering", Source newsletter, Spring 2015. [Online]. Available: Advance Education Inc., <https://www.advanc-ed.org/source/e-stem-explicitly-teaching-engineering>. [Accessed March 24, 2019].
- [2] J. Pleasants and J. K. Olson, "What is engineering? Elaborating the nature of engineering for K-12 education," *Science Education*, vol. 103, no. 1, pp. 145-166, January 2019.
- [3] M. J. Traum, S. L. Karackattu, and C. Heiden, "Impact of Early Exposure to Engineering Practice on Retention Rates Among Engineering Students," *Proceedings of the Conference On Being an Engineer: Cognitive Underpinnings of Engineering Education*, Lubbock, TX, USA, February 1-2, 2008.
- [4] P. A. Sable, S. L. Karackattu, and M. J. Traum, "First-Year Student Persistence and Retention Influenced by Early Exposure to Engineering Practitioners Co-Teaching Entry-Level Courses: A Four-Year Indirect Assessment," *Proceedings of the 121st American Society for Engineering Education Conference and Exposition*, Indianapolis, IN, USA, June 15-18, 2014.
- [5] M. J. Traum and S. L. Karackattu, "Early Exposure to Engineering Practice Provides Informed Choices for Students Continuing Engineering Programs," Paper AC 2009-432, *Proceedings of the 116th American Society for Engineering Education Annual Conference and Exposition*, Austin, TX, USA, June 14-17, 2009.
- [6] M. J. Traum and S. L. Karackattu, "The Pencil-Top Fidget: Reinventing Shop (Metal Drilling and Tapping) in High School Science Classrooms," *Proceedings of the American Society for Engineering Education 126th Annual Conference and Exposition*, Tampa, FL, USA, June 16-19, 2019.
- [7] C. Stiefel, "The 'E' in STEM – How engineering is transforming K-8 classrooms," *Scholastic Teachers Magazine*, 2017. [Online]. Available: Scholastic Inc., <https://www.scholastic.com/teachers/articles/2017/the-e-in-stem/>. [Accessed March 24, 2019]
- [8] D. F. Elger, S. Beyerlein, and R. Budwig, "Using design, build, and test projects to teach engineering," *Proceedings of the 30th ASEE/IEEE Frontiers in Education Conference*, vol. 2, pp. F3C/9-F3C13, Kansas City, MO, USA, October 18-21, 2000. <https://arxiv.org/ftp/arxiv/papers/1708/1708.01970.pdf>
- [9] M. Kalantzis and B. Cope, *New Learning: Elements of a Science Education, 2nd Edition*, New York, NY: Cambridge University Press, 2012.
- [10] Z. Yang, H. L. Weiss, and M. J. Traum, "Gas Turbine Dynamic Dynamometry: A New Energy Engineering Laboratory Module," *Proceedings of the 2013 American Society for Engineering Education North Midwest Section Conference*, Fargo, ND, USA, October 17-18, 2013.
- [11] T. A. Campbell, S. T. Seufert, R. C. Reis, J. C. Brewer, R. L. Tamiozzo, C. E. Whelan, and M. Okutsu. "Model Rocket Projects for Aerospace Engineering Course: Simulation of Flight Trajectories," Paper 2016-1577, *Proceedings of the 54th AIAA Aerospace Science Meeting*, San Diego, CA, USA, January 4–8, 2016. doi: 10.2514/6.2016-1577.
- [12] T. A. Campbell and M. Okutsu, "Model Rocket Project for Aerospace Engineering Course: Trajectory Simulation and Propellant Analysis," arXiv preprint, 2017. [Online]. Available: <https://arxiv.org/ftp/arxiv/papers/1708/1708.01970.pdf>. [Accessed March 24, 2019]
- [13] R. B. Hill, "New perspectives: Technology teacher education and engineering design," *Journal of Industrial Teacher Education*, vol. 43, no. 3, p. 45, 2006.
- [14] M. Hynes, M. Portsmouth, E. Dare, E. Milto, C. Rogers, D. Hammer, and A. Carberry, "Infusing engineering design into high school STEM courses," National Center for Engineering

and Technology Education. [Online]. Available: <https://files.eric.ed.gov/fulltext/ED537364.pdf>. [Accessed March 24, 2019]

[15] C. M. Cunningham and G. J. Kelly, "Epistemic Practices of Engineering for Education," *Science Education*, vol. 101, no. 3, pp. 486-505, May 2017.

[16] P. Llanos, R. Haley, S. N. Gangadharan, V. V. Duraisamy, G. Maupin, and C. Stockton, "Educating the Space Scientists at Embry-Riddle through Design, Build and Fly Rocketry Experience," *AIAA Scitech 2019 Forum*, p. 0612, 2019.

[17] G. Buchanan, D. Wright, C. Hann, H. Bryson, M. Snowdon, A. Rao, A. Slee, H. P. Sülthrop, B. Jochle-Rings, Z. Barker, A. McKinstry, C. Meffan, G. Xian, R. Mitchell, and X. Q. Chen, "The Development of Rocketry Capability in New Zealand—World Record Rocket and First of Its Kind Rocketry Course," *Aerospace*, vol. 2, pp. 91-117, 2015. doi:10.3390/aerospace2010091.

[18] S. A. Widmark, "Rocket physics," *The Physics Teacher*, vol. 36, no. 3, pp. 148-153, 1998.

[19] R. A. Nelson and M. E. Wilson, "Mathematical analysis of a model rocket trajectory Part I: The powered phase," *The Physics Teacher*, vol. 14, no. 3, pp. 150-161, 1976.

[20] R. A. Nelson, P. W. Bradshaw, M. C. Leinung, and H. E. Mullen, "Mathematical analysis of a model rocket trajectory Part II: The coast phase," *The Physics Teacher*, vol. 14, no. 5, p. 287-293, 1976. <https://doi.org/10.1119/1.2339385>.

[21] M. Haw, "A8-3 Model Rocket Impulse Measurement," Undergraduate Research Report, University of British Columbia, Vancouver, BC, Canada 2009. doi:

<http://dx.doi.org/10.14288/1.0107222>. [Online]. Available:

<https://open.library.ubc.ca/cIRcle/collections/undergraduateresearch/51869/items/1.0107222>.

[Accessed March 24, 2019]

[22] T. A. Dooling, "An Eight-Parameter Function for Simulating Model Rocket Engine Thrust Curves," *The Physics Teacher*, vol. 45, pp. 280-283, 2007.

[23] R. Barrio-Perotti, E. Blanco-Marigorta, K. Argüelles-Díaz, and J. Fernández-Oro, "Experimental evaluation of the drag coefficient of water rockets by a simple free-fall test," *European Journal of Physics*, vol. 30, no. 5, p.1039, 2009.

[24] S. G. Bilen, T. F. Wheeler, and R. G. Bock, "MAKER: Applying 3D Printing to Model Rocketry to Enhance Learning in Undergraduate Engineering Design Projects," *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Seattle, WA, USA, June 14-17, 2015.

[25] N. Tomita, R. Watanabe, and A. V. Nebylov, "Hands-on education system using water rocket," *Acta Astronautica*, vol. 61, no. 11-12, pp. 1116-1120, 2007.

[26] K.-I. Oyama, A. Hidayat, E. Sofyan, H. S. S. Sinha, K. Herudi, T. Kubota, S. Sukkarieh, J. L. Arban, D. M. Chung, I. Medagangoda, Z. B. Mohid, S. Pitan, C. Chin, F. R. Sarkar, "Asia-Pacific Region Water Boosted Rocket Events," *Advances in Geosciences: Volume 19: Planetary Science*, pp. 639-657, 2010.

[27] G. A. Finney, "Analysis of a water-propelled rocket: A problem in honors physics," *American Journal of Physics*, vol. 68, no. 3, pp. 223-227, 2000.

[28] T. Mitterer, L. M. Faller, H. Müller, and H. Zangl, "A Rocket Experiment for Measurement Science Education," *Journal of Physics: Conference Series*, vol. 1065, no. 2, p. 022005, 2018.

[29] J. R. Claycomb, C. Zachary, and Q. Tran, "Baking soda and vinegar rockets," *The Physics Teacher*, vol. 47, no. 2, pp. 88-92, 2009.

[30] D. Nichols, "Improved baking soda vinegar rocket," *The Physics Teacher*, vol. 56, no. 9, p. 611, 2018.

- [31] OpenRocket, "OpenRocket v15.03," March 28, 2015, [Online]. Available: OpenRocket: <http://openrocket.info/>. [Accessed March 24, 2019].
- [32] Apogee Components, "Rocket Simulator (RockSim) v9," [Online]. Available: Apogee Components: https://www.apogeerockets.com/Rocket_Software/RockSim. [Accessed March 24, 2019].
- [33] T. Benson, "Determine Maximum Altitude," April 8, 2018, [Online]. Available: NASA Glenn Research Center Web site, <https://www.grc.nasa.gov/www/k-12/rocket/rkthowhi.html>. [Accessed March 24, 2019].
- [34] D. A. Caughey, "Altitude measurement for model rocketry," *American Journal of Physics*, vol. 75, no. 5, pp. 472-477, 2007.
- [35] H. H. Hickam, *Rocket boys: A memoir*. New York, NY: Random House Publishing Group, 1999.
- [36] P. B. Kelter, W. E. Snyder, and C. S. Buchar, "Using NASA and the space program to help high school and college students learn chemistry. Part I: The shuttle and our living earth," *Journal of Chemical Education*, vol. 64, no. 1, p. 60, 1987. DOI: 10.1021/ed064p60.
- [37] P. B. Kelter, W. E. Snyder, and C. S. Buchar, "Using NASA and the space program to help high school and college students learn chemistry. Part II: The current state of chemistry in the space program," *Journal of Chemical Education*, vol. 64, no. 3, p. 228, 1987.
- [38] J. G. Goll, L. J. Wilkinson, and D. M. Snell, "Teaching chemistry using October sky," *Journal of Chemical Education*, vol. 86, no. 2, p. 177, 2009.
- [39] J. G. Goll and B. J. Woods, "Teaching chemistry using the movie Apollo 13," *Journal of Chemical Education*, vol. 76, no. 4, p. 506, 1999.
- [40] J. G. Goll and S. L. Mundinger, "Teaching chemistry using From the Earth to the Moon," *Journal of Chemical Education*, vol. 80, no. 3, p. 292, 2003.
- [41] P. Schacht, "Determination of Black Powder Model Rocket Motor Fuel Specific Energy," B.S. dissertation, Dept. Mech. Eng., Fachhochschule Lübeck and Milwaukee School Of Engineering, Milwaukee, WI, 2014.
- [42] R. Turcotte, R. C. Fouchard, A.-M. Turcotte, and D. E. G. Jones. "Thermal Analysis Of Black Powder," *Journal of Thermal Analysis and Calorimetry*, vol. 73, pp. 105-118, 2003.
- [43] D. A. Singh, "Sugar Based Rocket Propulsion System-Making, Analysis & Limitations," *International Journal of Engineering Trends and Applications*, vol. 2, no. 5, pp. 30-37, 2015.
- [44] D. Bontorin, S. R. Gomes, L. Rocco, R. Jachura, J. A. Rocco, and K. Iha, "ITA Candy rocket motor design and solid propellant manufacture challenges," *Proceedings of the 52nd AIAA/SAE/ASEE Joint Propulsion Conference*, p. 4937, Salt Lake City, TU, USA, July 25-27, 2016.
- [45] J. K. Villarreal, K. Mahon, S. Shark, J. Dennis, "ROCKS K-12 Model Rocketry Outreach Program at Arizona State University," Paper 2010-892, *Proceedings of the 48th AIAA Aerospace Sciences Meeting*, Orlando, FL, USA, January 4-8, 2010. doi: 10.2514/6.2010-892.
- [46] A. S. Fletcher, J. A. Cato, J. A. Barrett, and J. S. Huebner, "Micro-Rockets for the Classroom," *American Journal of Physics*, vol. 67, pp. 1031-1033, 1999.
- [47] W. Keith, C. Martin, and P. Veltkamp, "This Is Rocket Science!," *The Physics Teacher*, vol. 51 no. 6, pp. 362-363, 2013.
- [48] M. J. Traum, V. C. Prantil, W. C. Farrow, and H. L. Weiss, "Interconnecting the Mechanical Engineering Curriculum Through An Integrated Multicourse Model Rocketry Project," *Proceedings of the 120th American Society for Engineering Annual Education Conference and Exposition*, Atlanta, GA, June 23-26, 2013.

- [49] K. Horst, "Model Rocketry in the 21st-Century Physics Classroom," *The Physics Teacher*, vol. 42, no. 394, 2004. <https://doi.org/10.1119/1.1804655>.
- [50] Jolly Logic, "AltimeterThree," [Online]. Available: <https://www.jollylogic.com/products/altimeterthree> [Accessed March 24, 2019].
- [51] Estes Industries LLC, "Engines for Model Rockets – C6-5 Engines," [Online]. Available: <https://estesrockets.com/product/001614-c6-5-engines/> [Accessed April 25, 2019].
- [52] W. Simon, *Model Rocketry Technical Manual*. Editors: T. Beach and J. Guzik, Penrose CO, USA: Estes Industries, Publication 2819, 2012. [Online]. Available: https://estesrockets.com/wp-content/uploads/Educator/Estes_Model_Rocketry_Technical_Manual.pdf [Accessed March 24, 2019].
- [53] National Association of Rocketry, "Estes C6," [Online]. Available: NAR Standards and Testing, <https://www.nar.org/SandT/pdf/Estes/C6.pdf>. [Accessed March 24, 2019].
- [54] D. E. Clayson and D. A. Haley, "Are students telling us the truth? A critical look at the student evaluation of teaching," *Marketing Education Review*, vol. 21, no. 2, pp. 101-112, 2011.
- [55] M. J. Traum and S. L. Karackattu, "The Researcher Incubator: Fast-tracking Undergraduate Engineering Students into Research via Just-in-Time Learning," Paper 09-33, *Proceedings of the American Society for Engineering Education Gulf-Southwestern Section Annual Conference*, Waco, TX, March 18 – 20, 2009.
- [56] M. J. Traum, S. L. Karackattu, D. Houston Jackson, and J. D. McNutt, "Organization to Fast-Track Undergraduate Students Into Engineering Research via Just-In-Time Learning," *Proceedings of the Conference On Being an Engineer: Cognitive Underpinnings of Engineering Education*, Lubbock, TX, USA, February 1-2, 2008.
- [57] M. J. Traum, L. M. Flewellen, and E. L. Legare, "College-Level Multi-Step Energy Conversion Efficiency Experiments Should be Decomposed for High School Deployment," *Proceedings of the American Society for Engineering Education Southeastern Section Annual Conference*, Daytona Beach, FL, USA, March 4-6, 2018.