ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022

Paper ID #37441

Design and Implementation of an Online Outreach Program for Experimental Measurements (Evaluation)

Aimee Monique Cloutier (Assistant Professor)

Eric Constans

Eric Constans is a Professor of Mechanical Engineering at Rose-Hulman Institute of Technology.

James Mayhew

Design and Implementation of an Online Outreach Program for Experimental Measurements (Evaluation)

Abstract

The purpose of this paper is to describe the design and implementation of the Creation Crates outreach program in the summer of 2020 and 2021. In the spring of 2020, most academic programs – both at the undergraduate and K-12 levels – were suddenly forced to move online. Because of health-related concerns, most in-person K-12 summer outreach programs were also cancelled. Creation Crates was developed to provide a remote alternative to the cancelled outreach programs that would still allow students to encounter engineering concepts and strengthen quantitative analytical skills. We believe the details of our program are worth sharing to provide new ideas for educators who are still teaching in an online setting or who are seeking low-cost options for course content related to experimental measurements.

Creation Crates is a virtual engineering outreach program designed for rising high school juniors and seniors. The program was inspired by the forced online implementation of an undergraduate Measurement Systems course in the spring of 2020 and focuses on skills related to experimental measurements. Over the course of two weeks, participants in Creation Crates perform five different experiments, all the while layering in increasingly complex techniques related to uncertainty analysis and design of experiments. At the beginning of the program, each participant receives a kit in the mail containing the necessary materials and measurement tools for each experiment. The program includes two hours of remote, synchronous classes each weekday as well as daily asynchronous content.

Feedback on the program was collected through a free response survey. Based on the comments of those who chose to participate, the reception to the program has been positive. In response to the question, "What did you enjoy about the program? What did you find valuable?" common positive features included the individual attention from instructors as well as the new and valuable information students were learning. The most common suggestion for improvement was to facilitate more student-student interaction (rather than just student-faculty interaction). Although the instructors did make an attempt to implement more student-student interaction in the second iteration of the program, it was largely unsuccessful.

Although the feedback the students provided was similar in both years, the instructors observed a dip in engagement in the second iteration of Creation Crates. We believe this is largely due to lightened pandemic-related restrictions in the summer of 2021 (as compared to the summer of 2020); since students had the freedom to pursue most "normal" activities in the summer of 2021, some participants tried to treat the program as fully asynchronous, which is not how it was intended to be experienced. As a proposed remedy to this issue, we plan to condense the program into a one-week experience that instead lasts four hours a day, and we are also developing new ideas for ways to facilitate student-student interaction more successfully.

Introduction

The purpose of this paper is to describe the design and implementation of the Creation Crates outreach program during the summer of 2020 and 2021. In March of 2020, COVID-19 became widespread in the United States, forcing lockdowns and the implementation of online education. As part of the transition to online education, the authors of this paper adapted a hands-on version of a Measurement Systems course for college junior mechanical engineering majors to function online. It seemed likely at the time that most, if not all, summer outreach programs throughout the country were likely to be cancelled. Inspired by the online adaptation of Measurement Systems, Creation Crates is a program that was created to provide a meaningful encounter with engineering concepts for high school students who would otherwise have attended some form of in-person engineering camp if available.

During the two-week program, participants design and run five different experiments which are intended to measure a particular parameter (e.g. gravitational acceleration or an object's moment of inertia), and they also learn to assess the quality of an experimental result using experimental uncertainty estimates. At the beginning of the program, each participant receives a kit in the mail containing the necessary materials and measurement tools for each experiment. Despite being offered in an online format, the majority of the program is driven by hands-on problem solving.

The idea of a hands-on engineering outreach program certainly is not unique. Each summer, hundreds of universities across the country host outreach events and programs for K-12 aspiring engineers. A common formula for such a program is to provide hands-on opportunities for K-12 students of a particular level to learn concepts related to various disciplines of engineering [1] or to base the program on engineering design challenges [2-4]. Prior to the COVID-19 pandemic, online outreach programs were relatively rare, although the benefits offered by the online setting (e.g. a lower cost alternative to an in-person experience and the opportunity to engage a broader audience) have led to the development of a few online outreach programs [5]. Unsurprisingly, a more popular model for the online outreach camp involves teaching concepts related to computer programming [6-7]. Finding an outreach program related to experimental work is quite rare, and it is even more rare to find one related specifically to engineering. One program, Paper to Plastics (P2P), provides opportunities for students to learn laboratory techniques in chemistry and biology [8], and several programs offer demonstrations of experiments for K-12 outreach purposes [9].

Similarly motivated by the forced online implementation of education brought on by COVID-19, several other universities also adapted or created content to provide engineering outreach experiences in the online format. Such programs included opportunities for offering creative solutions to realistic engineering challenges [10-11], hands-on activities demonstrating topics in a particular engineering discipline [12-13], and hands-on activities showcasing interesting phenomena in STEM [14].

The Creation Crates program aligns well with the current Framework for P-12 Engineering Learning [15]. Measurements, which is the key topic of the Creation Crates program, is specifically listed in the Framework as a core concept. The Creation Crates program also supports the development of engineering knowledge (as defined in the Framework) by providing opportunities to practice data collection and quantitative analysis. Students also receive instruction in building circuits and performing calculations related to circuit theory, and although dynamics and mechanics and materials are not focal points of the program, most of the experiments are designed based on principles in these domains, providing the students with exposure to both topics. Additionally, the Standards for K-12 Engineering Education highlight that forming connections between concepts in engineering, mathematics, and the sciences is a desirable skill for K-12 students to learn [16]. The content provided in the Creation Crates program could provide a nice bridge between new engineering concepts and concepts that students are learning in their physics classes. We believe the details of our program are worth sharing to provide new ideas for educators who are still teaching in an online setting or who are seeking low-cost options for course content related to experimental measurements.

This paper is organized as follows. First, an example of an experimental measurement is provided as a means of illustrating the framework and learning objectives of the Creation Crates program. This section is most likely of interest to educators who may be interested in adopting similar techniques in their own classrooms or programs. Next, details of the program's implementation are provided, including learning objectives, experiments, and logistics of running the program in an online environment. Some insights into the program are then provided, including feedback from participants and reflections from the program's creators and instructors. Concluding remarks are then provided.

Experimental Measurements: An Illustrative Example

The inspiration for the Creation Crates program was drawn from the online adaptation of a Measurement Systems course. At Creation Crates, Measurement Systems is a required ten-week course for third-year mechanical engineering majors. The course covers topics related to experimental measurements. As part of the course, students learn two major experimental skills which are of interest to the development of Creation Crates: (1) quantifying experimental uncertainty, and (2) experiment planning and design.

Over the course of two weeks, participants in Creation Crates perform five different experiments, all the while layering in increasingly complex techniques related to uncertainty analysis and design of experiments. The goal of this section is to showcase, in the context of one experiment the Creation Crates participants perform, all of the skills participants learn and practice as part of the program. Although they are framed here as steps performed as part of a single experiment, the skills are actually spaced throughout five different experiments as aligned with the learning objectives in the next section. This section is most likely of interest to educators who may be interested in adopting similar techniques in their own classrooms or programs.

Experiment Development Based on a Physical Model

An engineer is given the task of measuring gravitational acceleration on Earth ($g = 9.81\,\frac{\text{m}}{\text{s}^2} = 32.2\ \text{ft}/\text{s}^2$). Unfortunately, there is no such device as a "gravity meter" which can be used to measure gravitational acceleration directly. The engineer then considers how to design an experiment that could be used to measure gravitational acceleration indirectly. The goal, then, is to identify a physical relationship between gravitational acceleration - the desired quantity (the resultant) - and parameters that are directly measurable (measurands).

One such physical relationship comes from the analysis of a simple pendulum as a harmonic oscillator. A simple pendulum consists of a hanging mass, *m*, on the end of a lightweight string of length L as shown in Figure 1. The pendulum bob begins at Position A where it is displaced from the vertical position by an angle θ. As the pendulum is released, it reaches the apex of its swing at Position B, then swings back to its original location, Position A. The time required for the pendulum to return to Position A is called the pendulum's period, represented with the variable *T*.

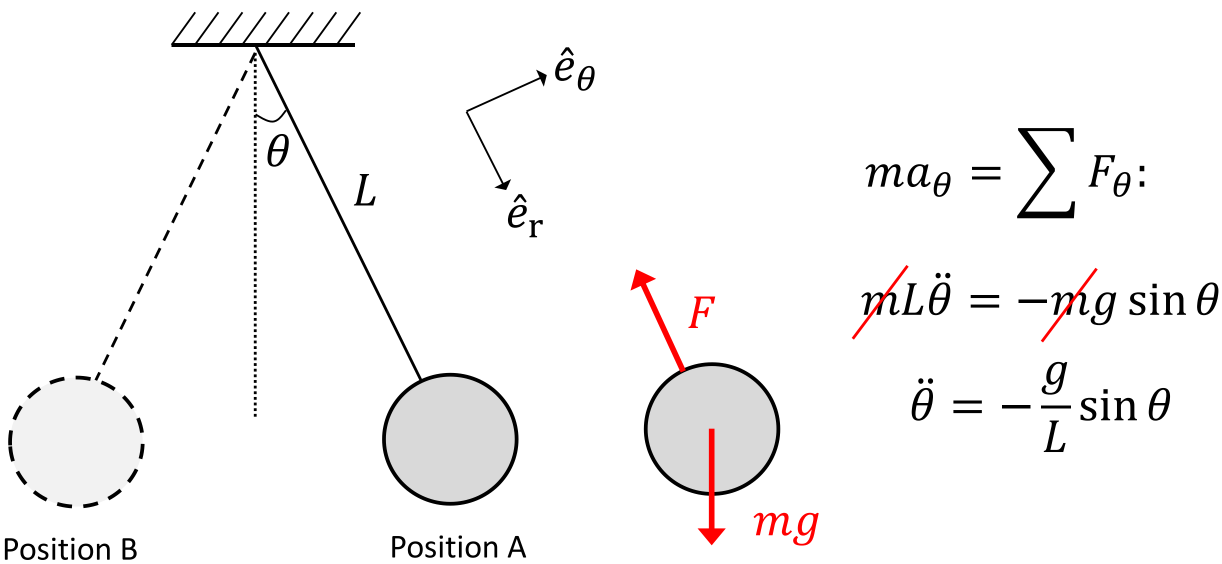

Figure 1. Schematic, free-body diagram, and dynamic equilibrium for a simple pendulum

The period, *T*, can be related to the gravitational constant using Equation (1):

$$g = \frac{4\pi^2 L}{T^2} \tag{1}$$

Equation 1 yields the style of physical relationship we originally sought – it provides a means for calculating g without needing to measure it directly and instead frames the data collection in terms of parameters that can easily be measured directly – the length of the pendulum string, *L*, which can be measured using any appropriate tool used to measure length (e.g. a ruler or measuring tape) and the period, T, which can be measured using any appropriate tool used to measure time (e.g. a stopwatch).

It seems now that the experiment is ready to be conducted; all that is needed is something to serve as the pendulum bob, something to use as the pendulum string, and measurement tools for both the length and period. At this stage, a person who is less familiar with good experimental work may measure the length of the string, release the pendulum, measure the pendulum's period, make a quick calculation for g, and be done. A good experimentalist, though, will carefully plan the experiment, considering how to tell if the results of the experiment are trustworthy and, furthermore, providing a quantitative estimate of how trustworthy they are. This is where the idea of quantifying experimental uncertainties becomes useful.

Quantifying Experimental Uncertainties

An experimental measurement should always be reported along with an uncertainty estimate (e.g. $g = 9.7 \pm 0.5\ \mathrm{m/s^2}$). The idea behind an uncertainty estimate is that the true value of the resultant – in this case g - is never actually known; an uncertainty estimate is intended to provide an upper and lower bound on where the true value is expected to fall. Uncertainty is inherent in the process of taking experimental measurements. It cannot be avoided, but it can certainly be minimized through careful experimental technique.

Experimental uncertainty generally falls into two categories: systematic and random. Systematic uncertainty does not vary with repetition, and it has two parts: accuracy and resolution. As an example of accuracy, imagine a tape measure is used to measure the length of the pendulum string which is 20 centimeters. The expectation, naturally, is that the number on the tape measure should read 20 centimeters, but it instead shows 20.3 centimeters. Although this number is off, it is off by a consistent amount; so, if the pendulum string is measured again and again, the tape measure will continue to read 20.3 centimeters. This source of error stems from accuracy, but the measurement tool can still be used as long as we calibrate it using a set of reference values we trust.

Another source of systematic uncertainty also stems from the measurement tool's resolution, which is the smallest increment that a measurement tool is capable of reporting. The resolution of this tape measure is 0.1 centimeters, which comes from the smallest tick mark provided on the tape measure. This implies that, even if the tape measure were perfectly accurate, the indicated length could be anywhere between 20.250 and 20.349, but we are unable to see it. The uncertainty that stems from this resolution is called the readability uncertainty and is equal to half of the measurement tool's resolution. Uncertainties due to measurement tools' accuracy and readability can be combined as shown in Equation 2, where the letter w is used to represent an uncertainty.

$$w_{\text{sys}} = \sqrt{w_{\text{accuracy}}^2 + \left(\frac{1}{2}\text{resolution}\right)^2} \tag{2}$$

Random uncertainty is an estimate of how much a measurand is expected to vary in each trial of an experiment, and random uncertainty can be reduced by running more trials of the experiment. Random uncertainty can be calculated using Equation 3, where *n* is the number of trials of the experiment, S_{x} is the standard deviation of the data set, and *t* is the value of the t-statistic. The natural tendency of random uncertainty is to decrease as the number of trials *n* increases. Systematic and random uncertainty are then combined in a root sum of squares calculation as shown in Equation 4.

$$w_{\text{rand}} = \frac{tS_{\text{x}}}{\sqrt{n}} \tag{3}$$

$$w_{\text{total}} = \sqrt{w_{\text{sys}}^2 + w_{\text{rand}}^2} \tag{4}$$

Experiment Planning and Design: Relative Uncertainty

The pendulum experiment to measure gravitational acceleration is relatively simple, but some experiments may become more complex, requiring the balancing of many constraints at once. In this case, thoughtful experimental design is key to attaining a meaningful result. A helpful concept, both for experiment design and for assessing the quality of the experiment’s result, is relative uncertainty, w_{rel}. It is calculated as shown in Equation 5, where w_{x} is the uncertainty associated with the measurement of parameter *x*.

$$w_{\text{rel,x}} = \frac{\text{w}_{\text{x}}}{x} \times 100\% \tag{5}$$

The uncertainty of a measurement can never be separated from the context in which the measurement is taken. As an example, if a stop watch with a resolution of 0.1 seconds is used to measure a period, T_1, of 5 seconds, the 0.1 second resolution offered by the stop watch probably seems good enough. However, if that same stop watch is used to measure a period, T_2, of 0.2 seconds, the resolution may not seem acceptable. Equations 6 and 7 below offer sample calculations of the relative uncertainty that would be obtained in each of these cases. This example illustrates an important point regarding uncertainty analysis: although an amount of uncertainty may seem acceptable in isolation, it must always be compared to the expected value of the measured parameter to ensure that the chosen measurement tool is appropriate.

$$w_{\text{rel,T}_1} = \frac{\frac{1}{2}(0.1\text{ s})}{5\text{ s}} \times 100\% = 1\% \tag{6}$$

$$w_{\mathrm{rel,T_2}} = \frac{\frac{1}{2}(0.1\ \mathrm{s})}{0.2\ \mathrm{s}} \times 100\% = 25\% \tag{7}$$

From the perspective of experiment design, Equation 5 can be examined more closely to reveal that there are two general possibilities for improving the relative uncertainty associated with a measurement: (1) reduce the uncertainty of the measurement, w_{x}, or (2) increase the value of the measured quantity, x. The former approach may involve choosing a measurement tool with a better resolution, while the latter may involve a fundamental adjustment to the experimental apparatus. If relative uncertainty is considered prior to running the experiment, however, appropriate choices can be made for both the measured parameter and the measurement tool ahead of time such that a reasonably low relative uncertainty is obtained.

In the case of the pendulum experiment, consider the measurement of the period, *T*. Although it is possible to adjust the period by adjusting the pendulum's length, a more practical solution is possible. The relative uncertainty calculation is ultimately applied to the uncertainty of the measurement as well as the *measured* value of a parameter. If a stopwatch is used to measure multiple periods at once (e.g. 10 periods) rather than a single period, this has the effect of "diluting" the uncertainty in the measurement as shown in Equation 8.

$$w_{\mathrm{rel,period}} = \frac{\frac{1}{2}(\mathrm{res})}{10\,T} \times 100\% = \frac{\frac{1}{20}(\mathrm{res})}{T} \times 100\% \tag{8}$$

Combining Uncertainties for Multiple Measurands and Assessing Experiment Quality

Using the techniques outlined previously in this section, it is possible to compute uncertainties and relative uncertainties for the pendulum length, *L*, and the period, *T*. The goal of the uncertainty analysis, though, is to determine an uncertainty estimate for the gravitational acceleration, *g*. So, the last step in the uncertainty analysis is to quantify how the uncertainties in *L* and *T* propagate to *g*. Because *T* is squared in Equation 1, a small error in *T* will be magnified more strongly than an error of similar magnitude in *L* and is likely to have a greater effect on the final estimate of *g*. To reflect this behavior, the exponents of *L* and *T* are used as uncertainty magnification factors in the uncertainty propagation equation shown in Equation (9).

$$\left(\frac{w_{\mathrm{g}}}{g}\right)^2 = (1)^2\left(\frac{w_{\mathrm{L}}}{L}\right)^2 + (2)^2\left(\frac{w_{\mathrm{T}}}{T}\right)^2 \tag{9}$$

The quality of the experiment can be assessed by examining the relative uncertainty and by comparing the measured value of the desired quantity to the expected value, if available. Earlier in this section, an example reported experimental result was given as $g = 9.7 \pm 0.5\ \mathrm{m/s^2}$. Equations 10 and 11 provide sample calculations showing how to use relative uncertainty and an expected value to assess the results of an experiment.

$$w_{\mathrm{rel,g}} = \frac{0.5\,\frac{\mathrm{m}}{\mathrm{s}^2}}{9.7\,\frac{\mathrm{m}}{\mathrm{s}^2}} \times 100\% = 5.15\% \tag{10}$$

$$\%\ \text{difference} = \frac{|9.81 - 9.7|\,\frac{\mathrm{m}}{\mathrm{s}^2}}{9.81\,\frac{\mathrm{m}}{\mathrm{s}^2}} \times 100\% = 1.12\% \tag{11}$$

Creation Crates Program

The Creation Crates program was run as a two-week, virtual outreach program in the summers of 2020 and 2021. The program is intended for rising high school juniors and seniors and introduces students to concepts related to experimental measurements (detailed in the previous section) through five experiments which they set up and run in their homes. As part of the program, each participant receives a kit in the mail containing a collection of basic materials that are necessary for experimental setups, a set of measurement tools which they learn to use throughout the course of the program (e.g. calipers and a digital multimeter), as well as a kit to build a motor and a set of components for building electric circuits (e.g. a mini breadboard and resistors). Each participant also receives a t-shirt for the program and a folder containing information about Creation Crates. The kits – including all materials they contain as well as the cost to ship – are limited to a cost of $100. The 2020 version of the program also included a 30-minute video chat with a current or recently graduated Creation Crates student and a virtual tour of the Creation Crates campus.

Participants

Participants in the Creation Crates program are rising high school juniors and seniors. 36 students per year participated in the program for a total of 72 students across both years. In 2020, the participants were drawn from the group of students who had initially applied for the residential summer outreach programs normally offered at Creation Crates that were subsequently cancelled due to COVID-19. In 2021, a separate application was made available for students to apply to Creation Crates directly.

Details of Online Implementation

The platform for online implementation includes daily, two-hour synchronous classes conducted on Microsoft Teams as well as asynchronous content – including worksheets, videos, and notes – which students access through Moodle. For each year of the program, the group of 36 students is divided into three classes of 12, each of which is taught by a faculty mentor. To participate in the program, students need a computer with an internet connection, Microsoft Excel, and access to tools like a scanner and stopwatch which are available through a student’s smart phone. All additional necessary tools are provided as part of the Creation Crates kit.

The synchronous class time is most often used for allowing students to run their experiments independently while the faculty mentors assist with troubleshooting and experimental choices. Sometimes, synchronous time is also used to provide additional details related to experimental uncertainty or to present new material that is likely to involve a physical demonstration or troubleshooting (e.g. circuits). Troubleshooting and discussion of experimental choices is typically done one-on-one with students. Students have the option of either raising their hands, typing in the group chat, or initiating a one-on-one chat with their faculty mentor when they have specific questions. When ready, the faculty mentor initiates a one-on-one video call with the student through Microsoft Teams. When no students have immediate questions, the faculty mentors rotate among the students by initiating one-on-one calls.

In addition to the two-hour, synchronous sessions each day, students often have some required activities to complete asynchronously. Asynchronous activities typically include watching videos related to new topics in uncertainty analysis and experiment planning/design, setting up the apparatus for the next experiment, or completing steps of their experiments that they did not complete during the synchronous time. For each experiment, students are given a worksheet which they use to summarize their experimental results and uncertainty calculations, and at the end of each experiment, they submit their worksheets to their faculty mentor via Moodle. Although these worksheets are not graded in the traditional sense, the faculty mentors provide concrete feedback that students could use when conducting their next experiment. The time required to complete asynchronous activities varies from day-to-day depending on the amount of new content and the amount of work students had left to complete after the synchronous portion of the class ended. As a rough estimate, students likely spend an average of an hour per day working on asynchronous activities and are unlikely to exceed two hours in a single day.

Program Structure and Objectives

The structure of the program is designed so that students have an opportunity to discover and learn in small doses the new techniques related to experimental planning and uncertainty quantification which are detailed in the previous section. As part of the program, students complete a total of five experiments: (1) measuring gravitational acceleration, g, using a simple pendulum, (2) measuring the power delivered by an electric motor, (3) measuring an object's moment of inertia using a trifilar pendulum, (4) measuring the flexural modulus of a sample of wood, and (5) measuring the rupture modulus of a sample of wood. A sixth experiment was also included for the 2021 year in which students measured the coefficient of restitution of an object of their choosing.

For the first experiment, participants are not provided with any prior instruction about experiment design and uncertainty quantification; rather, the goals are for them to rely on reason and intuition to develop a good experiment and to get them asking questions about what constitutes a good experiment. The last experiment is run as an in-class activity on the last day of the program. By the end of the program, the expectation is that participants should be able to quantify experimental uncertainty and to use experimental design techniques to create some assurance prior to running an experiment that it will work in the way it was intended. Because measuring a material's rupture modulus requires breaking the sample (and we only provide one sample of wood), this experiment creates an excellent opportunity for the students to showcase their skills in experiment planning and design. Table 1 provides a general overview of the timing and objectives of each experiment.

Table 1. Program schedule organized by experiment

Experiment	Program Days	Main Objectives
Gravitational Acceleration	1-2	1. Design and perform an experiment to measure gravitational acceleration. 2. Use an equation to relate the desired quantity (resultant) to directly measured quantities (measurands). 3. Use intuition and reasoning to provide an estimate of "plus or minus" (uncertainty). 4. Calculate systematic uncertainty, random uncertainty, total uncertainty, and relative uncertainty for a measurand.
Coefficient of Restitution	3	1. Design an experiment to measure an object's coefficient of restitution, including an equation to relate measurands to the resultant as well as an uncertainty estimate. 2. Combine uncertainty estimates for individual measurands to provide an uncertainty estimate for a resultant.
Motor Power	4-6	1. Build a brushless DC motor (note: kit provided by instructors). 2. Design an experiment to measure the power consumed by a brushless DC motor. 3. Calculate experimental uncertainty estimates for the resultant and all measurands using a table built in Excel.
Moment of Inertia	6-7	1. Explain, conceptually, how a moment of inertia is used. 2. Construct an apparatus (trifilar pendulum) to measure an object's moment of inertia. 3. Calculate the expected value of the moment of inertia and compare this to the measured value.
Flexural Modulus	8-9	1. Perform a three-point bending test to measure a material's flexural modulus. 2. Use relative uncertainty concepts to redesign a poorly performing experiment. 3. Create a graphical representation of interacting constraints which represents the solution space of possible experiment designs.
Rupture Modulus	10	1. Use experiment planning and design techniques from previous days to design an experiment to measure a material's rupture modulus.

		2. Perform the experiment and report an experimental result with an uncertainty estimate.

Program Reception and Faculty Impressions

After completing Creation Crates, each participant was sent a survey to provide feedback on the program. The survey included the following four free response prompts:

1. What did you enjoy about the program? What did you find valuable?
2. Describe one or more ways the program could be improved.
3. Would you have preferred more or less content, or was the amount of content about right?
4. Any other comments?

20 out of 72 students chose to provide feedback on their experiences in the program. Table 2 provides a breakdown of the positive features of the program, the features participants would suggest changing, and impressions about the appropriateness of the amount of content. Themes are ordered based on the number of times they appeared in student comments.

Table 2. Themes in feedback from program participants organized in descending order of response frequency

Category	Themes
Positive Features	-Enjoyed the experiments. (8) -Enjoyed the hands-on aspect of the work. (7) -Learned valuable skills. (7) -Learned new skills. (7) -Great feedback/attention/help from instructors. (6) -Instructor quality (6) -Enjoyed the motor project specifically. (4) -Enjoyed the challenge of experiment design techniques. (2)
Room for Improvement	-Not enough interaction with other participants. (8) -It was not always clear which activities (mostly asynchronous) were intended to be done on which day. (4)
Amount of Content	-Appropriate. (16) -Appropriate, but I could have handled more. (1) -Appropriate, but allot more time for experiment design. (1) -Include more. (1) -Include less but make it more in-depth. (1)

It is unsurprising that the experiments themselves – particularly the hands-on aspects – were rated as a positive feature for participants. Many students who choose to pursue engineering do so because they are drawn to hands-on work, and in addition to this natural tendency, the opportunity to perform hands-on work had been significantly diminished by COVID-19 precautions. Finding ways for students to engage actively in learning in an online setting is one of the most valuable features of the Creation Crates program. Another encouraging trend, though, is that students both recognized and enjoyed that they were learning new skills related to high-quality experimental work. We anticipated that this program would be both challenging and new to all participants. Although lab work is typically part of the high school science experience, it is highly unlikely that most of the techniques which are introduced in Creation Crates are taught in K-12 science courses. Students embraced and enjoyed the challenge, though, and seemed to appreciate the value in the skills they were learning. In fact, the most highly rated project – measuring the power delivered by a motor – was also by far the most challenging. Most students remained undaunted in the face of significant troubleshooting obstacles, and the obstacles seemed to make the eventual successful result even more impactful.

The feature students wish to change about the program is the lack of interaction with other students. Meaningful student-student interaction has been a significant challenge to achieve in the online format. In the first iteration of the program, not much effort was made to facilitate interactions among the students, and although they did appreciate the individual work and the attention from faculty mentors, the number of students who wished for more interaction with their classmates made us consider how this might be better facilitated in the program's second year. We incorporated an engineering-themed Pictionary game for students to play in small groups on the first day of class, and we also created breakout rooms that students were instructed to use while working on their experiments. These rooms remained mostly silent, though, unless the faculty instructors intervened directly. One possible idea for improving student-student connections is to create a Discord server that is entirely separate from the Microsoft Teams page where we meet for class. Students could use it to work together on experiments, to do asynchronous work together, or simply to get to know each other. This is a medium that is much more commonly used by high school students, and it may allow them to interact in a way that is more familiar, comfortable, and casual. Another idea is to plan some group activities in advance that can be used daily during synchronous sessions. Think-pair-share, for example, is a style of activity that would be relatively easy to implement in an online setting. Prediction-style activities (e.g. asking groups of students if a specific change to an experimental procedure would increase or decrease the experimental uncertainty) are also a form of active learning which could translate well to the online environment. Students could also work with break-out groups to compare their experimental choices and share suggestions for improving the next iteration of their experiment.

For future iterations of the program, transitioning Creation Crates to an in-person format could be an attractive option. However, one of the benefits of the current offering is that it does create an alternative path for students to experience high-quality hands-on engineering work. For some students, an in-person, residential program is infeasible because of timing constraints or the higher cost associated with travel, housing, and meals. Participation in the Creation Crates program currently costs $500, a fee that would be impossibly low for a residential program.

Although the feedback the students provided was similar in both years, we observed a dip in engagement in the second iteration of Creation Crates. We believe this is largely due to lightened pandemic-related restrictions in the summer of 2021 (as compared to the summer of 2020). Since students had the freedom to pursue most "normal" activities in the summer of 2021, some participants tried to treat the program as fully asynchronous, which is not how it was intended to be experienced. Although the majority of students were present every day for synchronous sessions, some students had scheduled additional activities for themselves, such as participation in sports teams, which conflicted with some or all of the Creation Crates sessions. Some students had also enrolled in the program when their school years had not yet ended, creating time conflicts which prevented them from participating fully in synchronous activities. Although we cannot say with certainty what led to the choice to "overbook," we suspect that some participants assumed that an online program would be available as a fully asynchronous option. As a proposed remedy to this issue, we plan to condense the program into a one-week experience that lasts four hours a day. We also plan to provide clearer advertising for the program so that prospective participants know what to expect.

Conclusion

Creation Crates is an online outreach program for rising junior and senior high school students. The program focuses on designing and conducting high-quality experimental measurements and quantifying experimental uncertainty. As part of the program, each participant receives a kit in the mail containing resources to build experimental setups and measurement tools for conducting experiments. In the 2020 and 2021 sessions, the program ran for two weeks and contained two hours of daily, synchronous interaction with a faculty mentor and a class of students as well as asynchronous content to help introduce new concepts. Students noted as positive features of the program the inclusion of hands-on, engaging experiments, the interaction with faculty instructors, and the challenge of learning new and valuable skills. A feature we wish to improve for future iterations is facilitating meaningful student-student interactions. Overall, the program provides a lower-cost, unique online option for high school students to experience high-quality and hands-on experimental work.

References

1. R. R. Essig, B. Elahi, J. L. Hunter, A. Mohammadpour, K. W. O'Connor, "Future girls of STEM summer camp pilot: Teaching girls about engineering and leadership through hands-on activities and mentorship," *Journal of STEM Outreach,* vol 3, ED-1: pp. 1-9, 2020.
2. T. Innes, A. M. Johnson, K. L. Bishop, J. Harvey, M. Reisslein, "The Arizona Science Lab (ASL): fieldtrip based STEM outreach with a full engineering design, build and test cycle," *Global Journal of Engineering Education,* vol 14, ED-3, pp. 225-232, 2012.
3. J. H. Kwon, "The design focused engineering outreach to a middle school using Arduino projects," in *Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2017.

4. T. McClary, J. A. Zeiber, P. Sullivan, S. Stochaj, "Using multi-disciplinary design challenges to enhance self-efficacy within a summer STEM outreach program, " in *Proceedings of the 2018 ASEE Southwest Section Conference,* Austin, TX, 2019.
5. A. Reynolds Warren, K. Harp, N. Ben Aissa, E. Specking, "Responding to COVID-19: Insights into making summer camps virtual," in *Proceedings of the 2021 ASEE Midwest Section Conference,* Virtual, 2021.
6. J. J. Rogers, T. G. Ganesh, J. Velez, "Engineering virtual design competition – a solution for high school summer outreach during the pandemic and beyond," in *Proceedings of the 2021 ASEE Annual Conference,* Virtual, 2021.
7. M. E. Foltz, and S. Koloutsou-Vakakis, "Can online summer camps work? Evidence from adapting a high school hands-on water quality module for online delivery," in *Proceedings of the ASEE 2021 Illinois-Indiana Regional Conference,* Virtual, 2021.
8. S. Z. Krayem, M. Bugallo, K. Dinota, H. Wang, A. Esposito, in *Proceedings of the 2021 ASEE Annual Conference*, Virtual, 2021.
9. B. D. Tedeschi, J. K. Miller, A. M. Lucietto, N. L. Denton, "The development of Techie Times," in *Proceedings of the 2021 ASEE Annual Conference*, Virtual, 2021.
10. J. D. Steinmeyer, "Online EECS curriculum for high school students," in *Proceedings of the 2015 IEEE Integrated STEM Education Conference*, 2015.
11. C. Robertson, and A. Doloc-Mihu, "Assessing the effectiveness of teaching programming concepts through online interactive outreach workshops," in *Proceedings of the 22nd Annual Conference on Information Techonlogy Education,* 2021.
12. J. Allison, D. Holmes, Z. Berkowitz, A. Pfalz, W. Conlin, N. Hwang, B. Taylor, "Programming music camp: Using web audio to teach creative coding," in *Proeeedings of the Web Audio Conference,* 2016.
13. F. Tamburini, T. Kelly, E. Weerapana, J. A. Byers, "Paper to Plastics: An interdisciplinary summer outreach project in sustainability," *Journal of Chemical Education* **2014**, vol. 91 ED-10, pp. 1574-1579, 2014.
14. P. J. Hill, "K-12 demos for outreach in chemical engineering," in *Proceedings of the 2012 ASEE Southeast Section Conference,* 2012.
15. AE3 and American Society for Engineering Education, "Framework for P-12 engineering learning: A defined and cohesive educational foundation for P-12 engineering," 2020.
16. National Academy of Engineering, "Standards for K-12 engineering education?" *The National Academies Press,* Washington, D.C., 2010.