

Leveraging Lessons Learned from a Virtual Hands-on Outreach Program to Cultivate Diversity in the Next Generation of Structural Engineers

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Abstract

A challenge that continues to face the structural engineering (SE) profession is the recruitment and retention of individuals from underrepresented minority (URM) groups, underscored over the years by findings reported on by the SE3 project committee. One approach to address this is by developing and conducting early outreach efforts with diverse populations of K-12 students, so they are aware of SE's meaningful contributions to society and the intriguing technical problem-solving opportunities in this field. During these educational activities it is also important for young students to be exposed to engineering practitioner-educators who represent diverse backgrounds and whose lived experience demonstrates a path forward for URM members in the industry.

This paper focuses on a virtual outreach program offered in Summer 2021, that yields insights about facilitating middle and high school students in a hands-on earthquake engineering project as well as software programming activities. This week-long program was affiliated with the Cal Poly Engineering Possibilities in College (EPIC) summer camp which provides pre-college experiences to students, specifically from underrepresented backgrounds. The instructor team prototyped, manufactured, and shipped over 120 low-cost engineering kits so students could construct a shake table and building model as well as test their baseline and retrofitted designs. These hands-on activities accompanied lectures to help students understand earthquake hazard, seismic design of

buildings, instrumentation, and data visualization among other topics.

The curriculum, mail-home engineering kit details, and reflection on student performance will be discussed in the paper to provide readers with a guide for developing meaningful outreach experiences that engage diverse groups of students in exploring SE. The group of all-female instructors will also share their perspective on some potentially effective methods to recruit diverse engineers to participate in outreach: to achieve their aspirations of impact the next generation, cultivate their interest in the SE field, and thus, be motivated to persist and ascend in their careers.

Background on the EPIC Program

History

Since 2007, California Polytechnic State University – San Luis Obispo (Cal Poly) has been hosting the Engineering Possibilities in College (EPIC) summer program. Initially it was a single week-long, half-day program with twenty female middle/high school students and by 2019 had grown to over 700 participants in five one-week, residential sessions. The primary goals of the EPIC program are to “attract more female, first-generation and low-income students to the field of engineering and inspire them to choose it as a career path”, though it does accept students from all backgrounds who are rising 6th-12th graders (Cal Poly EPIC, 2022). In an effort to promote diversity in the participants, EPIC has partnered with

the Migrant Education Program (MEP) and Advanced Via Individual Determination (AVID) programs, for which a brief description are provided in the *Definitions* section of this paper. Recent EPIC program data from the virtual offering in 2020 indicates that nearly 75% of middle school students are affiliated with MEP and nearly 15% of high schoolers are MEP/AVID members. Also, around half of all campers received full or partial scholarships, possible through contributions from various California school districts, MEPs, corporate sponsors, and revenue from the EPIC program. This funding is critical in creating opportunities for URM students since the cost per student has been \$1720 in 2019 for the residential camp and \$400 in 2020-2021 for the virtual camps. Detailed information on both in-person and virtual EPIC camp modalities can be found in Liptow et. al. (2018) and Manzano et. al. (2021), a summary in provided in the remainder of this section.

In-Person Offerings

During in-person years, the camper schedule starts with move-in on Sunday afternoon with a week schedule full of programming (from 7:30am-9:00pm each day) to explore different engineering fields and experience life on a university campus that ends with their departure on Friday afternoon. In terms of technical content, students:

- Select and participate in eight 2-hour engineering lab sessions from a sampler menu taught by Cal Poly faculty with support from undergraduate/graduate students that range from robotics to bridge design.
- Work on a design team project over multiple days culminating in a final presentation to their fellow campers, staff, and faculty.
- Attend panel sessions from current students and alumni to learn about the career opportunities associated with different engineering majors.
- Prepare for college applications through presentations from the Cal Poly admissions and financial aid offices as well as academic/campus life on tours of the College of Engineering and Housing.

From a community-building aspect, aside from living with other students in the residential halls, they:

- Eat all provided meals/snack together at on-campus dining venues or in communal spaces at the dorm.
- Participate in recreation center activities (outdoor pool, volleyball, climbing wall, and/or bowling).
- Gather for scavenger hunts, hikes, movies, talent shows, or other informal/free-time gatherings.

There are several Cal Poly engineering students hired as EPIC staff members to focus on planning and oversight of these community-building activities. This enables them to interact

with the campers and build relationships to support those students during camp and in years beyond. It is important to note that this may be the first time the campers have lived away from their family for a week, interacted extensively with individuals from outside of their community, while taking on exciting challenges of engineering labs/projects with university faculty and students.

Virtual Offerings

During 2020-2021, the program was conducted virtually due to the COVID-19 pandemic. The discussion in the remainder of the paper will focus on 2021 when the earthquake engineering session developed by the authors was offered. Instructors primarily used the Zoom web-conferencing, Google Classroom, and Replit interfaces to interact with and teach 20-25 middle/high school students each week for up to six hours per day. Rather than using a sampler class approach from in-person offerings, students chose from one of four interdisciplinary engineering design projects to work on for the entire week. Each project focused on a particular design objective for which the students learned new skills incrementally and carried out daily hands-on activities that would ultimately come together in the final deliverable they would present to the class. The four design projects topic areas were: (1) Rube Goldberg Machine on computer science, software and electrical engineering; (2) Designing Structures for Earthquakes on civil/structural engineering and computer science; (3) Automated Plant Care on agricultural engineering; and (4) Snap Circuits on electrical engineering. Note that Topic #4 was only offered to middle school students and the only option with dedicated sessions in Spanish, most other sessions had at least one instructor with conversational to bilingual proficiency in Spanish. The daily virtual schedule for all campers was:

8:10 am - 9:00 am	Icebreakers
9:10 am - 11:00 am	Engineering Class
11:10 am -12:00 pm	Programming Class
12:00 pm -1:00 pm	Lunch Break
1:10 pm -2:00 pm	Engineering Panels / Virtual Tours
2:10 pm -3:00 pm	Office Hours (Optional)

From a technical content standpoint, it may seem that the idea of developing a “virtual hands-on engineering laboratory” is a self-contradiction. Yet each of the four design projects would ultimately be made possible through sending every student either an off-the-shelf (for Topics #1 & 4) or custom engineering kit for use at home. The design parameters, prototyping, fabrication, and shipping of the custom kit for Topic #2 will be described in detail in *Engineering Kit for At-Home Lab Experience* section. Efforts to maintain other technical content from the in-person offering were accomplished by conducting engineering panel sessions and

campus office presentations in a synchronous virtual mode through Zoom. For tours of the colleges and housing, videos were recorded and uploaded to YouTube by university offices or the student government, these links were shared with the campers.

Another aspect that was important to convert from the in-person to the virtual format was the opportunity for socializing. This was made possible through the icebreaker portion that took place the hour prior to the engineering class. Campers were divided into smaller groups and led by a student instructor as they participated in activities like four quadrant poster or played games like Bingo, Geoguessr, and Codenames. These icebreakers were selected to generate student engagement, help them learn about one another and their instructors, and/or collaborate in fun online games. This got the campers energized and ready for engineering class when the faculty member would arrive to start discussing engineering content.

EPIC Model for Instruction Recruitment & Training

Recruitment

In alignment with the mission of the EPIC summer program to promote engineering among underrepresented rising 6th-12th graders, the leadership team actively recruits diverse Cal Poly engineering faculty and students to serve in instruction, planning of community-building events, and marketing roles. Solicitation of student staff members is conducted through organizations affiliated with the Multicultural Engineering Program and Women's Engineering Program which includes the Society of Hispanic Professional Engineers (SHPE), National Society of Black Engineers (NSBE), Society of Women Engineers (SWE), and others. One metric of success with these efforts has been seen in recent staff data with nearly 50% of the staff being bilingual in Spanish. On a personal note, the faculty co-author on this paper recruited by another female architectural engineering faculty member that had been involved in EPIC since its inception and was retiring. This new EPIC instructor in turn reached out and recruited the two female student instructors. Active recruitment of diverse faculty and student staff members is critical in addressing what Husbands et. al. (2002) refers to as "unproductive image of 'who a volunteer is'" where individuals involved in developing and executing outreach programs in engineering professional societies are predominantly White and male, though they are trying to attract young people of all races, ethnicities, and genders to the industry.

Training

Another key lesson from the EPIC program is that training touches on all the necessary skills that Bogue et. al. (2013)

indicates volunteer members from professional societies, though being passionate technical experts, often lack:

"...typically, they have little training beyond the mechanics of the activity, have no knowledge of marketing to young people, lack cultural and gender awareness, are inexperienced in the delivery of education, and generally do not have the expertise to implement the best outreach activities. It is illogical that any engineering professional would undertake outreach projects without appropriate preparation. How many engineers would design a new process or component using only ideas observed from others or without understanding the requirements of the design?"

EPIC training consists of one day in early May 2021 (5.5 hours) and one week in mid-June (4 hours/day) conducted as synchronous virtual on Zoom. Attendance was required for the student staff and recommended for faculty. The topics relevant to the social dimension of education are listed in the chronological order they were introduced in the training, and items taught by individuals from Cal Poly but outside of the EPIC program are indicated in the parentheses:

- UndocuAlly training (Dream Center Coordinator)
- Mental wellbeing training (Psychologist)
- Gender/heteronormativity training (Pre-Doctoral Scholar)
- Microaggression and Bias
- Cyberbullying
- Logistics: Spirit Points/Social Media
- Logistics: 3 Strike Rule, Group Management, Engagement

This training exposed instructional staff to various concerns that could arise with students coping with the stress of home isolation due to COVID-19 and other mental health concerns, trying to understand their own or others' gender and sexuality, addressing their uncertain status as an Undocumented student, and encountering negative interactions with other participants in the virtual environment. In addition to knowledge of the on-campus resources and access to the experts that came in to speak, through scenario-based training staff members became better prepared on how to respond when a situation arose related to one of these items. The last two bullet points were discussions describing the rewards structure to motivate positive student behaviors as well as stages of consequences to resolve misbehavior. Surprisingly, even the faculty co-author who had worked in some teaching capacity at three different institutions had not had extensive formal training on any of these topics except the fourth bullet point. Interested readers should consider reviewing the number of ASCE pre-college outreach training webinars developed in the last two years, some that address the social dimensions specific to engineering education (ASCE).

Other major blocks of time during the early May and mid-June training meetings were allocated for returning staff members to share what had been done in past offerings of the Python programming lab and so topic-specific teaching teams could work on refining their curriculum and week-long project. Throughout the months leading up to and during the summer camp, there was continual conversation between all the EPIC educators through a dedicated Slack channel and Google classroom. Outside the trainings, there was at least one weekly debriefing with all the instructors and many avenues available for new members to get assistance from community. This underscores the value for continual support from professional societies to industry members who are conducting outreach.

Value of Inclusive Outreach

Through staff trainings, the authors became aware that many of the 2021 EPIC student staff members were past campers in the EPIC program. Their anecdotes of EPIC as an early educational event that positively impacted their career path and relationships was powerful, and they communicated how it fueled their passion to engage in outreach to benefit the next generation. This is in line with the generally accepted goals of outreach by professional organizations to “create visibility for society beyond its membership” and “encourage[e] people to enter and persist in engineering studies and, ultimately, to pursue careers in science, technology, engineering, and mathematics (STEM) fields” with a specific goal of “increasing diversity in engineering [as it is] essential to fueling innovation” (Bogue, 2013). While this is the view of examining how current engineering students or practitioners provide value to others through teaching, it is worth considering how inclusive outreach benefits them as well.

In consideration of that question, the faculty author posits that EPIC summer program is as impactful in the professional development and retention of the student instructional staff in their engineering studies, as it is at serving the diverse population of campers. This is an educationally robust and tight-knit community created by the EPIC leadership for the student staff. Made possible through the extensive multi-dimensional training, peer and faculty mentorship, opportunities to lead curriculum development and teach, and the meaningful role of impacting young campers results in the EPIC summer program. Several of the staff have taught year after year and have indicated that this annual summer experience as something that sustains them through the rigor of their engineering degree. Similar outcomes can be found in Pickering et al. (2004) studying Tufts University students who are active in the Center for Engineering Educational Outreach (CEEO). The results showed that teaching in the CEEO programs had a greater impact on female students in strengthening their engineering knowledgebase, rapid problem-solving, leadership, self-confidence, and

communication. They were attracted and retained in the programs at a higher rate than proportional to their gender in the Tufts engineering population. The researchers suggest that these gains from outreach engagement could support a female engineer through their academic career, though more detailed investigation would be necessary to verify this for URM engineering students and further for practitioners. With one of the concerns identified by the SE3 Demographics report (NCSEA, 2020) being the recruitment and retention of women and minorities in the structural engineering through to leadership positions, then supporting them in outreach and engagement with a cohort of fellow diverse volunteers could provide the professional and personal value that may help combat the leaky pipeline problem.

Initial Stages of Earthquake Engineering Session

Inception & Inspiration

As alluded to previously in the *Recruitment* section, faculty member Professor Emeritus Pamalee Brady from the Cal Poly architectural engineering department (ARCE) had been involved with the EPIC summer program since its earliest offering. During recent in-person years, her 2-hour session introduced students to structural engineering and specifically the strength, stiffness, and stability of truss steel bridges through the educational West Point Bridge Designer software. The inception of the virtual, hands-on earthquake engineering session described in this paper resulted from Dr. Brady’s recommendation in October 2020 to the faculty author to participate in EPIC. This presented itself as a meaningful K-12 engineering education opportunity with a focus specifically on promoting diversity within the STEM fields.

By December 2020, discussions between the faculty author and the EPIC Program Director identified that the camp would be conducted virtually and with the week-long structure described in the *Virtual Offerings* section. The faculty author formally signed on and then used the winter break to consider approaches to create an interdisciplinary, hands-on project that would reflect the Cal Poly ARCE department vision statement (Cal Poly ARCE):

“to educate students to enter and be successful in the practice of structural engineering. The program focuses primarily on the California practice of structural engineering, that emphasizes seismic design. As an architectural engineering program the curriculum goes beyond traditional structures program to give students an understanding of architecture and construction management as it relates a total project design.”

Having been involved in the planning committee as well as team advisor for the international undergraduate Earthquake

Engineering Research Institute (EERI) Seismic Design Competition since 2014, the faculty co-author used this as a source of inspiration because it is a multi-faceted, comprehensive design problem that addresses the major objectives of the ARCE mission. Competition tasks include investigation of precedents, architectural and structural design, fabrication of a small-scale prototype, experimental testing, and computational analysis of a mid-rise building in a seismic area. The challenge became how to identify the most salient aspects of this design problem to pose to the middle and high school audience that would be educational and engaging. At the same time, there was a question of the lecture and tutorial material that would set the students up for success with their project tasks. Early on, it appeared that it would be possible to adapt resources developed by the EERI School Earthquake Safety Initiative (SESI) by the Classroom Education and Outreach subcommittee to suit these needs (EERI SESI, 2015). By mid-January 2021 the class title and description were ready to share with students signing up for the camp:

“Designing Structures for Earthquakes: Students will participate in hands-on activities to learn how earthquakes impact buildings as well as the design methods and technologies that ensure greater seismic safety. They will learn about shake-table testing of small structures, applying sensors, writing software to analyze data, as well as constructing earthquake force resisting systems. Engineering fields that will be covered include Civil/Structural Engineering, Computer Science, and General Engineering.”

More specifically the week-long project would involve students assembling a shake-table; designing, fabricating, instrumenting, testing, and analyzing data from a basswood structural model; retrofitting and retesting the model; and presenting to their peers on this design process with commentary on their original and retrofitted structural response. A mail-home engineering kit would become the critical component that would make this hands-on learning experience possible and is described in detail in the *Engineering Kit for At-Home Lab Experience* section.

Student Instructor Recruitment

With the conceptual groundwork in place, recruitment efforts began for two student instructors who would collaborate in developing the curriculum, engineering kit, and teach during the summer session. Details about this process and the student instructors is provided in the following paragraphs because it directly relates to the earlier discussion in the *Recruitment* and *Value of Inclusive Outreach* sections. That is that the success of an engineering outreach program intending to reach underrepresented minority groups is impacted by whether the

volunteers or staff represent a similar diversity and/or have training to develop an awareness of those populations.

The first student instructor came onto the team in early February 2021 and was a recent Cal Poly alumnus that had completed her master’s thesis with the faculty author. At the time, she was working on her first-year requirements for her doctoral studies at the University of Auckland, remotely from Northern California. She had a proven track record of leading lecture and lab-based courses where she was able to communicate technical concepts while infusing enthusiasm. She was also versed in designing, fabricating, instrumenting, and testing experimental specimens as well as preparing presentations to share findings with research collaborators at other institutions. These experiences would be assets in prototyping the mail-home kit and creating engineering lectures that would educate and engage young learners. The opportunity to work with the EPIC program would serve her in refining skills that would be valuable to a potential future career in the academic arena, as well as a welcome interaction outside of her relatively solitary work of developing structural simulations and taking online classes.

Finding a second student instructor took slightly more effort. Many Cal Poly ARCE students see their career path in industry and select to participate in summer internships, rather than outreach programs. To raise awareness of this EPIC student instructor opportunity as well as communicate qualifications, the job posting included in the *Appendix* was prepared for distribution. However, the effort that secured the second student instructor was a conversation with her in a company’s breakout room at a virtual ARCE career fair spurred by an alumni’s inquiry about upcoming research and teaching projects for the faculty author. This demonstrates that enlisting outreach educators should occur through multiple modes and venues. In mid-March 2021, the team was complete with the addition of this second student instructor, a rising Cal Poly master’s student. Her undergraduate years of service experience as a Cal Poly Engineers Without Borders (EWB) leader, technical knowledge from computational structural research, and teaching exposure as an instructional student assistant equipped her to make significant contributions to curriculum and kit development.

Engineering Kit for an At-Home Lab Experience

Kit Criteria

Within the chronology of curriculum development, the authors started working on the mail-home engineering kit before the lectures or programming material, since it had to be procured from a manufacturer or designed in-house to ship to all 123 students before the first session of camp starting June 21, 2021. It was the critical path item to ensuring that the week-long,

interdisciplinary, hands-on project even existed. The established requirements of this kit to meet the educational objectives described in the *Inception & Inspiration* section, the potentially limited access to technology and materials to camper at home, need for lightweight and durable pieces for shipping, and budget of approximately \$50-60 (with tax + shipping) per kit, were:

- Design Materials: ruler and vellum for drawing design and fabricating dimensioned parts
- Shake table: system with a shake table platen activated by a motor to simulate actuator-driven shake tables
- Structural materials: structural elements (columns, beams, walls, etc.), connectors for structural elements, footings with angle bracket and anchorage
- Retrofit materials: braces with gusset plates, dampers (pendulum mass, viscous fluid, friction), base isolation (laminated rubber bearing, pendulum bearing)
- Sensor: USB wired and/or Bluetooth triple-axis accelerometer to quantify structural response of the original versus retrofitted building conditions, as it was assumed students would not have smartphones to download accelerometer applications (a survey during camp showed 98% of students did have access)

The kit materials were intended to approximate the structural design, materials, and testing tasks that would have been executed in the small-scale setup of the Cal Poly Seismic Lab. There are many examples of effective earthquake engineering outreach conducted with other materials that one could consider for in-person classroom visits. For the shake-table, a hand-crank option or one with plywood and dowels are common. Easily accessible items can also be used for structural elements (pasta noodles, toothpicks, coffee stirrers) and connections (marshmallows, gumdrop candies, Styrofoam balls, modelling clay). Typically, a sensor is not used.

Kit Development

As with any design problem, the authors started by conducting a precedent study to see if a solution already existed. Thus, two of the authors spent February reviewing what shake table kits were available on the educational market and encountered examples like: (1) LEGO MINDSTORMS shake table instructions, (2) Cubit Workshop software and 3D-printed table kit, (3) Pitsco Education Earthquake Towers multi-student project pack, and (4) KiwiCo's Tinker Crate shake table kit. The obstacle with using these kits were that most of them only addressed the shake table assembly activity, and even at that were already too costly or time extensive which would prohibit the other planned portions of the week-long project. Ultimately, the co-authors pivoted to creating a custom kit leveraging some of the lessons learned from reviewing these existing options. Specifically, photos and videos of the

out-of-stock Tinker Crate was a reference that helped the team develop an inexpensive, lightweight shake table that could be ship flat and could be easily assembled by campers.

During this same time, since it was clear that none of the kit options seemed to include a sensor, efforts were made to identify a low-cost accelerometer that could be sent to each student. From a budget perspective, it was not clear if it would be necessary to include a return envelope for students to mail the sensors back to Cal Poly and send to the next group. The objective was to avoid this scenario not just for the logistical complications it would generate, but also out of the desire to allow and encourage students to use the sensor following the camp. Review of engineering education manufacturers led to systems like the PocketLab Voyager sensor and the PASCO wireless load cell, but in both cases a single unit exceeded the budget for an entire kit. After further investigation the team ultimately selected the WitMotion sensor (as a note: Mac computers required installation of Parallels to run the Windows-based data acquisition application). A sensor chip would be an even cheaper option, but these come without protective body enclosing and likely a greater hardware/software learning curve for the instructors.

With one of the student authors having completed dimensioned sketches and a parts list project's hands-on activities, the initial purchase of construction materials and a sensor was executed in late March. These items began to arrive to Cal Poly in early April, and one student instructor was shipped the construction materials while the other given the sensor, so they could begin finalizing the kit-related aspects of the camp. Within a week, both had finalized their trial efforts and the full batch of materials and sensors were purchased by early May. The faculty author began transforming fabrication sketches into CAD drawings to prepare for laser-cutting of custom parts as well as writing a grant to the College of Architecture and Environmental Design (CAED) that was in part to fund student shop personnel support needed for kit fabrication.

The first laser-cutting training for the faculty and one of the student authors was in mid-May. Within the span of less than two weeks around 125+ sets of parts (basswood, chipboard, foam) had been fabricated, typically using three laser-cutters simultaneously for around four hours per day and longer on weekends. The subsequent week consisted of packing all the parts into individual bags sorted by the hands-on activity. These bags were placed with larger kit items into UPS Large Express boxes (18"x13"x3") and shipping labels attached, so that finally in early June all the kits were processed through the CampusShip for delivery to the campers and one of the student authors. At around three pounds each, the average shipping rate of a kit was \$6.70. A kit parts list with photographs of the contents is included in the *Appendix*. During those three weeks of time laser-cutting and packing kits, the second student

author had begun developing the lecture slides and tutorial documentation for assembling the shake table, designing and fabricating the structural model, as well as implementing retrofits.

Curriculum Development

Engineering Lectures

The creation of the engineering lecture slides began with the review and adaption of the first three lectures from the EERI SESI High School Curriculum (EERI SESI, 2015). Major modifications were made for the EPIC camp to include more in-depth discussion of recording earthquakes, instrumenting buildings, earthquake warning systems, and seismic retrofit options. These were topics critical to providing students context to the engineering activities on Days 3-4, as indicated in the weekly schedule shown in Table 1. Additionally, efforts were made to develop lecture material that would appeal to diverse student interests and learning styles by incorporating different multimedia approaches and stories of case studies (described in the following paragraphs) and inquiry approaches (described later in the *Inquiry Methods to Promote Student Engagement* section).

Videos: These recordings are generally between 1-3 minutes and were produced recently to insure high-resolution images, clear audio, and up-to-date knowledge. It was necessary to review video content for accuracy and source for reputability to introduce students to the experts and leading organizations in the field. Consideration was also taken of the diversity of the individuals featured in the videos. Some example video topics that were utilized in the camp included: recordings from recent/local earthquakes, researchers discussing sensors in Los Angeles tall buildings, along with shake table tests at Cal Poly and E-Defense Facility.

Animations: These GIF style images replay on a continuous loop to demonstrate a concept that varies over time or with different scenarios. Some examples included: comparison of the how the various types of seismic waves move through solid media, simulation of ground motion propagation if a certain magnitude earthquake occurred in a nearby major city, demonstrating the difference in the seismic performance of an un-retrofitted versus retrofitted building with a soft story mechanism, and the mechanics of how base isolators and damping devices function.

Physical models: These consist of table-top demonstrations that the instructor shows in real-time on camera. If various parameters are going to be tested, like the impact of the height of a single degree of freedom system on its period, it is helpful to show students the multiple height options and poll them on which will vibrate the fastest when released from rest. This keeps the student engaged to see if their intuition was accurate. Another opportunity is to have students help solve a problem. For example, with the Mola Structural Model it is possible to set up a one bay frame that is unstable and show that it collapses under very little lateral force. Then ask students for ideas of how to fix the issue. Often their responses (add a brace or a wall, stiffen connections) are all possible to demonstrate with the components in the Mola kit to show how their solution affects structural stability.

Software Tools/Websites: This involves introducing students to free, public tools that are accessible on a computer or smartphone. The most engaging options include those with alerts, visual features like maps, or that crowd-source data. This could include early warning smartphone applications, the USGS “Did You Feel It?”, or ATC Hazard Tool (the latter two are described in more depth in *Inquiry Methods to Promote Student Engagement*). It is not necessary during class time to

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00-9:00	Icebreakers	Icebreakers	Icebreakers	Icebreakers	Icebreakers
9:00-10:00 Engineering Lecture	<ul style="list-style-type: none"> Vulnerability and resiliency Fault rupture Seismic Waves Classifying buildings Capacity vs demand 	<ul style="list-style-type: none"> Structural and ground motion Modeling mass and stiffness Natural frequency and period Recording earthquakes 	<ul style="list-style-type: none"> Recording and analyzing structure motion Different types of sensors Finding response spectra at students' homes 	<ul style="list-style-type: none"> Isolation systems: friction pendulums and lead rubber bearings Damping systems: tuned mass, friction, and viscous dampers 	<ul style="list-style-type: none"> Student feedback about course Student presentations of structure, collected data, and lessons learned
10:00-11:00 Engineering Activity	<ul style="list-style-type: none"> Discuss project overview, items in kit, and design parameters Work on basswood structure 	<ul style="list-style-type: none"> Demonstrate shake table construction process Campers build their own shake tables 	<ul style="list-style-type: none"> Install sensor software Mount sensor on structure Record structure motion 	<ul style="list-style-type: none"> Design and install seismic upgrade(s) to structure Record motion of structure with retrofits 	<ul style="list-style-type: none"> Teacher presentations about structural engineering and experiences in the department
11:00-12:00 Coding Lab	<ul style="list-style-type: none"> Data types Operators Booleans If-else statements 	<ul style="list-style-type: none"> Functions For loops While loops 	<ul style="list-style-type: none"> Import/install libraries Line plot Import data to plot 	<ul style="list-style-type: none"> Accessing USGS earthquake data Mapping geospatial data 	College Readiness Presentation

Table 1. Weekly Schedule

demonstrate how to use each application. A screenshot with application name or link and brief verbal description is often sufficient for interested students to go investigate on their own.

Storytelling: When instructors share anecdotes about their own or peers' earthquake engineering contributions in industry, research, and reconnaissance. An example was one of the student instructors talking about a site visit to the SoFi Stadium near Los Angeles, CA with a Cal Poly alumni employed by the construction management firm on the job. The instructor was able to talk about and show images of the various unique top-of-column isolators that were implemented in the project, and other complexities that structural engineers had undertaken on the project. The faculty instructor had recently had a presenter from the project's structural engineering firm in her graduate course (another Cal Poly alumnus) and could add further details to the discussion. Communicating curriculum concepts via personal experiences can generate student enthusiasm and a feeling that they are also connected to the story.

Activity Tutorial Videos & Documents

For each of the daily hands-on activities, the instructors led the students through what materials from the kit would be used and steps to executing the task. This included sharing their video or their screen as they demonstrated the tasks. In addition to this live demonstration, they also developed supplementary written and video instructions to make the experience accessible to all students. Some concerns were that with the virtual setting there can be internet interruptions or other distractions at home, compounded with the fact that even in an in-person setting students learn and can complete tasks at different speeds. The tutorials proved to be a valuable time as campers reported their use for various reasons, when they wanted to: move more rapidly through an activity and did not need much help; pause, replay, or zoom in on the screen; and revisit material while working on homework. The tutorial videos were recorded using Zoom and ranged between 25 minutes to 1 hour and 25 minutes, while the documents generally were 1-3 pages in length with some including timestamps referring to the associated video.

Programming Lectures

Very briefly, since this falls outside of the typical scope of structural designers conducting outreach, the Python coding lab was intended to introduce students to the relevance of programming for structural engineers involved in seismic design. During those four hours of instruction, students were introduced to the basics of variable assignment, conditional and looping statements, and plotting. This was to enable them to plot and compare the tri-axial acceleration data collected from their original and retrofitted structures tested on the shake

table. As a further topic of interest, they were taught how to access the US Geological Survey (USGS) earthquakes map to download a data set with a given geographic, date, and magnitude range and be able to create their own map visual summarizing the metadata from these events. The instructors assumed there would be some students using a school district supplied Chromebook which they would not have administrator's privileges to download software, and so Python was taught in a cloud-based environment called Replit. Contact the authors for further details on coding lab material and content.

Google Classroom

Google Classroom was used as the learning management system to enable instructor interaction with each week of campers. It was used to provide them with learning materials, reminders, and a portal to interact with instructors and EPIC staff. The shell of a classroom and student enrollment was set up by EPIC staff, they also loaded all items except bullet points 2-3 below. The weekly Google Classroom was organized into the following seven sections:

- Week Schedule: Document indicating the activities throughout the week with Zoom meeting links
- Designing Structures for Earthquakes Lab: Each of the five days had presentation slides, an activity tutorial document and video, as well as a homework document (Day 2 also had software preparation tutorials)
- Coding Lab: Each of the four days had presentation slides, coding activity description document, tutorial document, and solution (most days also included example code and/or sample data)
- Spirit Points: Presentation and document explaining the point system for this team competition
- Tech Support – How to's: Material on using Google Classroom and Zoom
- Cal Poly Engineering: Presentation on engineering majors, document with links to virtual campus tours, and pre-camp survey
- Camp Guidelines: Documents on expected student etiquette and the three-strike policy

The stream feature of Google Classroom (like a news feed or announcements board) was used by instructors daily to remind students about attending afternoon office hours, filling out surveys, completing necessary preparations and homework before coming to engineering lab the following day, logging spirit points, and generally communicating in a positive and enthusiastic manner to encourage student engagement in camp all week.

Inquiry Methods to Promote Student Engagement

To maintain student engagement in the daily one-hour lecture portion of the camp it was important to integrate a variety of inquiry methods that were responsive to the fact that:

- At the start of the week none of the students knew each other or the instructors, and it was necessary to build rapport to establish a safe learning space where they felt comfortable to share ideas.
- A single class cohort ranged in age, prior academic experience, and background such that using primarily traditional hand-raising to ask/answer questions might result in a small group dominating the conversation.
- Students had already experienced nearly a year of online learning and were at risk of “Zoom fatigue”, where with their cameras off they might completely disengage; this was addressed by having frequent and different manners of checking in with the entire class.
- These young learners have an intuitive understanding of the built environment as observant end-users, and their lived experiences should be leveraged as an opportunity for them to teach their peers when possible.
- As an optional educational summer program selected by students, their parents, and/or the academic (AVID/MEP) advisors, students entered with varying levels of motivation; to meet this reality, the goal with development of inquiry methods was to facilitate a fun exploration of earthquake engineering for all.

In the remainder of this section, a selection of the inquiry approaches used during the virtual EPIC summer camp are described with concrete examples of how they were specifically implemented for earthquake engineering topics. Commentary is also provided on how to transition these approaches to the in-person classroom, if the method was heavily dependent on a functionality in Zoom. For readers interested in how to effectively use traditional approaches of hand-raising or cold-calling for fostering an inclusive classroom (addressing the concern raised in the second bullet point above), the authors recommend reviewing and applying guidance from Sherrington (2021).

3-2-1 Questions: This approach works well for questions with multiple correct, short answers. Students are directed to type an answer to the question into the public Zoom chatbox and wait until the instructor finishes a 3-2-1 countdown to press enter to display their response. There is a level of excitement the moment the chatbox is flooded, and the instructor begins to read off student answers out loud, highlighting trends as well as unique submissions and providing context to correct answers. Students can also read through their peers’ contributions and feel affirmed by coming up with similar answers or proud of an answer no one else thought of. This is

a method of energizing and engaging the whole class is most effective when used only a couple times in a one-hour session to maintain its novelty. It is also best when the instructor frames the activity by first posing the question and giving an example answer with an explanation. After reading out the student answers, if some critical responses appear to be missing, the instructor can pose targeted questions to help students uncover rather than be told those answers. Finally, a lecture slide should be shown with an array of correct answers (in graphics or text) that provides closure to the question and reinforces student understanding. For an in-person classroom, this could be accomplished via an interface like Poll Everywhere where student respond with their cellphone on the 3-2-1 countdown and their answers can be projected on a PowerPoint slide for sharing.

Example: After defining the terms vulnerability and resiliency, the students were queried “What are some systems that might be affected by earthquakes?” For the middle school group, an instructor gave the example of rail transportation and told a personal anecdote about an Amtrak train delay she experienced during inspections that took hours after the 2019 Ridgecrest, CA Earthquake while she was traveling from the Los Angeles area to San Luis Obispo. She provided global context by describing that Japanese bullet train lines are instrumented for earthquakes and designed to trigger the emergency breaks to halt traffic and allow for inspections to identify issues like displaced tracks for rider and equipment safety. Then the students were challenged to answer the same question, their responses included systems like internet, roadways, and hospitals. If, for instance, no students mentioned water systems then the instructor could ask students about their morning routine which includes teeth brushing and often requires use of municipal water, to help them arrive at this answer.

Share an Experience: This is appropriate when posing a question intended to encourage students to engage in peer-storytelling about their own lived experience. This can serve as a topic-relevant icebreaker where the class can get to know each other better and begin developing rapport early on. Moreover, it allows the student to serve as the expert while communicating about an event and responding to follow up questions from instructors or other students, without needing to have certain pre-existing technical knowledge about scientific principles or engineering systems. Still, the instructor should have the awareness that not all students will have the same shared experience and so they should also frame the question in a way that is inclusive of all students by allowing them to share second-hand exposure to the life event via their family members, friends, news or popular media. There are a few types of follow up comment that instructors can provide to these anecdotes to validate a student’s experience, promote learning with additional information on

the event, or clarify examples from media (from non-experts or fictional shows/movies).

Example: Prior to the instructors beginning to present any technical content in the camp, the students were asked “Have you ever felt an earthquake? Where were you? What did it feel like?” Students answered in a combination of modes – typing in the Zoom chatbox or by raising their hands to speak. Being that most students were from California and Washington they either had felt an earthquake or could share a story passed on to them from a parent of a time before they were born. In one instance, a high school student in a rural area of the California-Nevada area recounted the 2021 Antelope Valley, CA earthquake he had experienced in just the week prior, captivating the other students’ attention to hear more and in real-time the instructors were able to bring up the associated USGS “Did You Feel It?” (DFYI). This led to an anecdote on how an instructor had contributed DFYI data immediately after the 2020 Alleghany County, NC while she was visiting family in North Carolina during the prior year’s summer break. The discussion concluded with encouraging students contribute to the USGS DFYI after an event, so that they too could be part of a crowd-sourced dataset to describe earthquake impact!

Homework Report Out: For the first two days of camp, the homework was to continue the hands-on activity started in the engineering lab that day. The beginning of lecture the next day would open with students updating their progress to the group through the chatbox, oral report, and/or showing the physical deliverable on the Zoom camera screen. All students were motivated to participate in the latter because they were in competition for “Spirit Points” with other EPIC camp lab sections and one of the highest point value items was taking a daily group selfie (screenshot of the Zoom classroom with all the students) where they hold up their projects, see Figure 1. Through a combination of these intermediate project reporting approaches instructors could identify students that needed more assistance on a past deliverable or a unique solution worthy of kudos that others could learn from. For homework on the third day of camp, students identified case study buildings that implemented innovative seismic systems to investigate and then educate their peers on what they had discovered. This is another method of positioning the student as the expert, giving them control of the classroom to guide how the conversation on the topic progressed. The instructors followed up and were able to reference student examples in their pre-prepared lecture on an array of seismic systems. The last homework assignment was to prepare to present the project they had been working on all week, this is shared in detail in the *Outcomes* section of this paper.

Example: With the homework on the third day, students were tasked with selecting a building that employs a seismic response control system. On the assignment sheet students

were given a list of two base isolation and four damping approaches as well as six different buildings. These were not necessarily a one-to-one match of building to system, but simply to provide some examples if the students were not clear on what types of case studies they were searching for. Once students selected a system to research, they were to find a building they found interesting that utilized it. The term “interesting” was described in the assignment sheet as: a location the student had travelled before; a unique form, construction, or occupancy type; or a place that they wanted to visit someday. They were to take notes and report to their classmates on the building name, location, seismic response control system, form, construction material, occupancy, and why they chose the building/system. Some of the high school students found articles or websites that they shared on the Zoom screen, so they could show visuals of the systems that are often hidden within the interior or foundations of the building. One example case study that a student selected near their hometown was the Apple Headquarters in Cupertino, CA that utilized a triple friction pendulum bearing base isolation. They found an article with an animation of how the system worked and indicated that out of the base isolated buildings they had reviewed, it was the scale (mile in circumference), shape (circular spaceship), and client’s sector (globally renowned software company) that fascinated them.



Figure 1. Homework Check In

Use a Tool, Compare Results: This activity is important to introduce students to the fact that there are many resources structural engineers can use to get parameters necessary to calculate structural demands on buildings resulting from naturally occurring weather or geologic phenomena like wind, snow, tornado, earthquakes, and tsunamis. These values vary significantly in a geo-spatial sense across the entire globe. An instructor can share that in the past one of the primary references to get this information would be the print maps found in a lengthy and costly document published by the American Society of Civil Engineers (ASCE 7), but now there are free, public online tools that make this process more accessible and rapid for anyone. A few of the organizations

that host these tools include ASCE, Applied Technology Council (ATC), Structural Engineers Association of California (SEAOC), and USGS. An instructor can select one tool and demonstrate how the interface has a familiar feel to Google Maps, which many of the students have been exposed to, as well as brief explanation for how to determine the input criteria and the important outputs to proceed with determining demands. This brief online activity serves as an important step to demystify for the students how engineers determine loads for structures around the country.

Example: Introduction of the ATC Hazards by Location website followed a discussion of earthquake spectra and how the design acceleration is utilized to determine seismic force. First the instructor explained how to input an example to find the seismic parameters of the Architectural Engineering building on Cal Poly’s campus. This included showing students how to select the appropriate reference document (ASCE 7-16), risk category assuming a 1-2 story free-standing residential structure (Category II), and default site class (Class D). There are over 20 variables that appear in the resulting report, so the comparison point students were directed to look at was the S_{DS} value which defines the plateau region of the design response spectrum. Then each student independently looked up this parameter for their home address and in the public chatbox typed their city and state with the S_{DS} value so their classmates could see it. The activity was framed as a competition of who had the lowest and highest S_{DS} values, with the instructor reading off many of the submitted responses commenting on trends, minima, and maxima. Being that many students lived in California and Washington the data was relatively tightly spaced, so the instructors also put results for their hometowns in North Carolina and Colorado to provide a contrast. The ATC Hazard tool also enabled everyone to quickly check their ASCE 7-16 Risk Category II wind speed and observe that the locations with lower S_{DS} value could have a higher wind speed and consequently higher wind loading than locations with high S_{DS} value. This opened the discussion for the engineers examining multiple loading cases to determine which controls.

Draw Together: This teamwork activity is particularly attractive for younger students to utilize conversation, sketching, and writing to document qualitative predictions of how a system responds to a hazard event. The Zoom interface has two functionalities critical for this virtual activity. The first is breakout rooms which enables the class to be divided into smaller groups, each with a dedicated instructor to moderate and ensure that ideas are solicited from all participants. The instructor also has the important role of helping translate students’ descriptions into the equivalent engineering terms. The other useful Zoom feature is the annotation toolbar which makes it possible for each camper to contribute to a shared PowerPoint slide that contains the problem statement and

image. Using this the students can draw lines and shapes as well as adding text boxes with notes. If they run into any issues, they are encouraged to verbally share their ideas or type in the chatbox, so the instructor can add it for them. When the 10-15 minutes of allotted time for the activity has concluded, the breakout rooms are closed and the class comes together to share. An instructor wraps up this activity by remarking on how student predictions compare to observations from experimental testing, computer simulation, or real events. This same activity could be accomplished in-person by laminating several large copies of the problem statement and image, placing it on a table, and having students work together using whiteboard markers to annotate. The “draw together” concept could also be extended to 3-D with a small-scale building model that can be drawn on or otherwise manipulated to show predicted earthquake damage.

Example: The middle school students were initially shown a picture of a historic landmark Rios-Caledonia Adobe located in San Miguel, CA and briefly introduced to the concern in the San Luis Obispo area with numerous adobe mud brick dwellings and Spanish mission buildings that are still in active use and vulnerable to earthquakes (if left un-retrofitted). Then the students were given a simplified sketch of the building type, told to assume that it was unmodified from its initial condition when built in the 1800s, and asked to respond to the question “What would this house look like after an earthquake?” One group submission is shown in Figure 2 which demonstrates the students’ intuition about the seismic performance, correctly identifying concerns of: heavy clay roof tiles either falling off or the entire roof system collapsing, cracks in the walls particularly near penetrations like windows and doors or even walls collapsing in the out-of-plane direction. They considered non-structural damage including the shattering of glass windows and toppling of large outdoor items. If the students finish early, an instructor can begin to pose questions on aspects that may have been overlooked like interior contents. The sketching and group discussion provide variety to the many other student engagement approaches that involve speaking/listening or typing/reading in the chatbox.

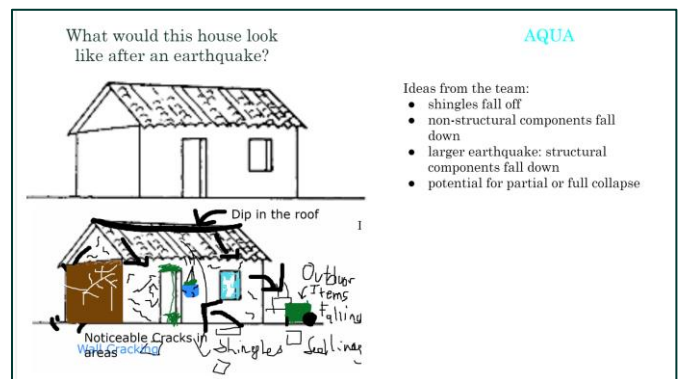


Figure 2. Draw Together Example

Student Outcomes

Final Presentations

On the final day of camp, each of the students got to share on the project they had been working on throughout the week, two examples are shown in Figure 3. Their presentations included discussion of:

- **Design Process:** discuss structural precedents reference in their design, show sketches of the original and retrofitted buildings, comment on trial and iteration of construction
- **Shake Table Testing:** show the other students how their final building performed when subjected to shaking
- **Analysis:** share qualitative observations of the difference between the original and retrofitted building (and if they had time, plots to quantify)
- **Instructor questions:** what part of your project are you most proud of? what was the most interesting thing you learned?

Reflection on Student Learning

At the beginning of the summer, the instructor team had been concerned that students might check-out from the camp with disinterest in participating in another Zoom activity or become overwhelmed with the many new skills and tasks being asked of them. Yet it seemed that the lecturing, live and supplementary tutorials, and office hours provided sufficient interest and support that in the presentations at the end of each week, week, every student had a thoughtful project to present with a concerted effort at each stage in the process, though some did have complications or ran out of time to collect data with their sensor and were unable to present graphs. In the following paragraphs are a few assessments of positive outcomes observed by the instructors through the student presentations.

Design Precedents: the students cited inspiration from structures ranging from high-voltage powerline towers, geodesic domes, the Freedom Tower in New York City, De Young Museum in San Francisco, Manchester Grand Hyatt Hotel in San Diego, to the fictional world with Avenger's Tower in Marvel's Cinematic Universe. This demonstrates students engaged in independent learning to seek out examples of interesting structural forms and studying them to inform their own design

Construction: the students commented on identifying and solved constructability issues related to adhesive set-times and unique structural geometries. Some found household items (yarn, golf ball, keys, tape, half a can of soda) to utilize for their retrofits in addition to materials that came in the kit, and one student even got additional wood because her sketch was

taller and more complex than the basswood that had been included. This illustrates their ability to problem solve and to seek out other materials to realize their creative design vision, including sloshing soda dampers.

Iterative Seismic Design: a few students had conducted a parametric study of different retrofit approaches compared to their original structure and plotted all the data to comment on which approach they believed was the most effective in reducing accelerations. Others made insightful comments about vulnerabilities that they noticed when they subjected their retrofitted structures to shaking, like uplift of the building when implementing their base isolation system, and how they worked to resolve that. These are examples of thinking with an engineering mindset.

Presentation: several students had prepared PowerPoint slide sets of the design process, which had not been required. Some had even taken video recordings of each shake table test at each stage of modifying their building to share with the class and reflect on how the performance changed. They were demonstrating skills of carefully documenting their test series and communicating their findings to peers.

Conclusions & Lessons Learned

Reflecting on the quality of student work as conveyed in their final day presentations, the instructor team was impressed by student engagement and output. It was affirming that the countless hours of kit prototyping, fabrication, packing as well as earthquake engineering curriculum development generated positive outcomes. The final version of the camp is the product of the instructor team debriefing nearly each day for the first few weeks of camp to refine engineering class materials, yet there are still two major opportunities for improvement.

One is revisiting the coding class materials and the cloud-based coding interface students were directed to use. Most of the students had little prior experience with coding; moreover, they did not have time to go through all the examples and try to work through the assignments during camp time. A further complication was that Replit often took a very long time to download the libraries that students would need to use for tasks like reading datafiles and plotting. Lag times were significant on high-use days or due to internet instabilities, which meant students had difficulties keeping up with the coding examples. On a positive note, many did indicate they found the programming topics interesting, and were able to modify the sample code provided by the instructors to plot their acceleration data from shake table tests.

The second area of improvement is that the kit delivery method as very time intensive. Two of the instructors with help from student shop personnel worked countless hours on laser-

cutting, followed by packing boxes with help from other EPIC staff and ARCE student volunteers. A fortunate occurrence this quarter was that the team had complete ownership of three laser cutters for the duration of the project and were permitted to occupy an entire ARCE lecture classroom for a month to stage all the kit parts for shipping. Some solutions for this concern could be working with the Cal Poly Industrial Technology and Packaging Program who may be able to provide some support in fabrication and packing efficiency or outsourcing the operation to a manufacturer using external funding. Another challenge was acquisition of the large quantity of sensors which each cost nearly half of a kit's budget. Alternatives could be surveying students before an outreach program to establish does not have access to a smartphone to only buy the necessary number of sensors, working directly with a supplier who can more easily facilitate the batch sale of sensors with partial/full donation, or investigating use of sensor chips.

The hope is that this program can be replicated in some manner through other outreach programs including those where the engineer/educator is geographically distant from the students and connects with them remotely. Interested readers should contact the faculty author for access to a folder that has all the lecture presentations, video and document tutorials, kit materials lists and fabrication drawings, etc.

Acknowledgements

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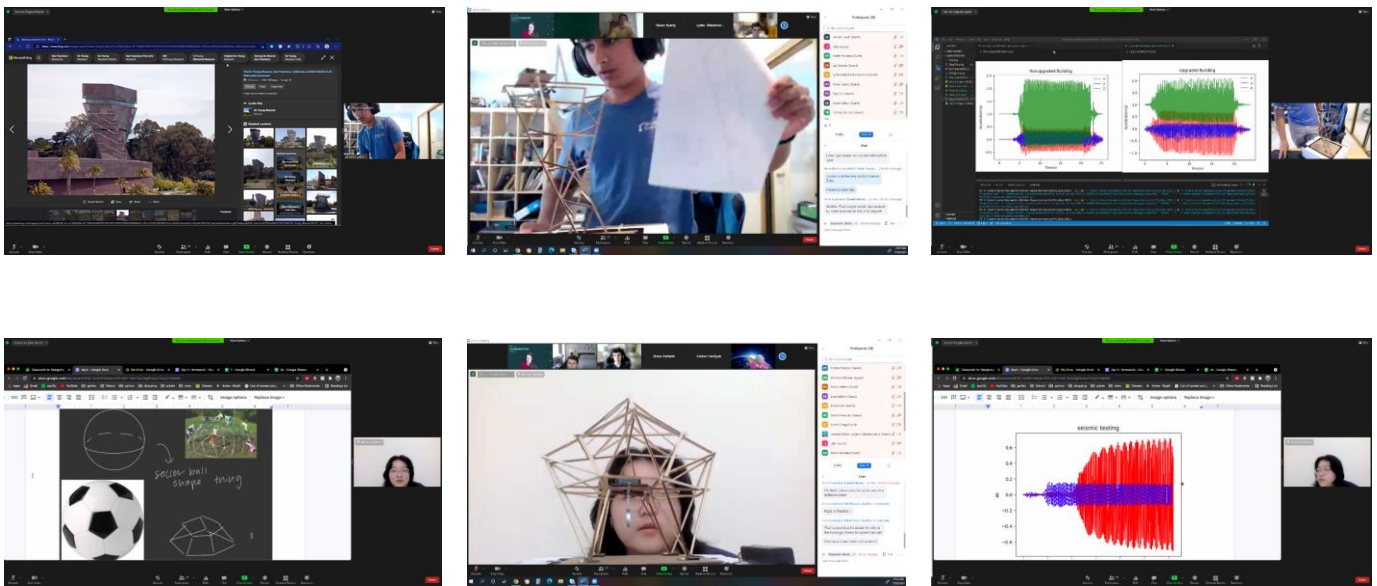


Figure 3. Final Presentations

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Definitions

Advanced Via Individual Determination (AVID): a federally funded in-school academic support program for 7th-12th graders. Its mission is to close the opportunity gap for college and career readiness, particularly among students from minority, rural, low-income, and without a college-going tradition in their family, as well as those in the “academic middle” who desire to complete college.

Migrant Education Program (MEP): a federally funded program to support the education of elementary and secondary school age children of parent or guardians who is a migratory worker in the agricultural, dairy, lumber, or fishing industries. The program supports high-quality programs during the school year and summer periods to specifically address unique needs of migratory children including educational disruption, cultural and language barriers, etc.

Appendix: Job Posting for Student Instructor

Cal Poly EPIC Summer Camp Teaching Assistant Job Posting

Interested in a paid summer opportunity to help develop a fun, project-based summer camp for middle and high school students to learn about earthquake engineering?!

Send resume to ARCE faculty Anahid Behrouzi at behrouzi@calpoly.edu by Fri, March 5 to apply

What I will be doing?

For this summer, we are looking for one undergrad or grad student to help create curriculum content, develop a hands-on kit (think [Tinker Crate](#)) and serve as a teaching assistant for a virtual summer camp through the [Cal Poly EPIC program](#). The week-long project will involve constructing a low-cost shake-table; a small-scale earthquake-resilient building; virtual broadcasting of tests in our seismic lab; and virtual tours of our CAED labs, Poly Canyon, and/or downtown SLO focusing on earthquake testing, design, and performance.

Who will I be working with?

ARCE faculty Anahid Behrouzi and ARCE alumni Nicole Buck, PhD Candidate at Univ of Auckland
Staff directors and other student employees of EPIC Program

When will I be working?

Mix of virtual and in-person: 5+ hrs/week in Spring 2021 quarter (may include weekend work)
Mix of virtual and in-person: 22.5 hrs/week June 14 – July 23 (hours generally 7:30am-12pm)

What are the required qualifications?

Enthusiasm to teach engineering to a diverse group of students
Attention to detail and ability to work collaboratively
ARCE 371 and ARCE 412/354 (before Spring 2021)
Videorecording and editing
Laser cutting (or willingness to learn)
Python (or similar) programming

What are the desired qualifications?

Past teaching or educational outreach experience
ARCE 483 (before/during Spring 2021)
Recording/analyzing data from accelerometers
Conversational or fluent in Spanish

What is the salary/benefits?

\$ 14-15/hour (undergrad student), \$19-20/hour (grad student)
Opportunity to inspire younger students to pursue an engineering career
Curriculum development and teaching experience
Co-author conference paper about the curriculum and kit (optional)

Appendix: Shake Table Kit Parts Sheet

Shake Table Kit Parts Sheet

Welcome to EPIC! This parts sheet includes an image and quantity number for every part included in your engineering shake table kit.

1 x DC Motor 	1 x Battery Pack with AA battery 	1 x Spinner Base 	1 x Washer 	1 x Gear 	1 x Craft Stick 	2 x Spinner Adhesive (square) 
1 x Spinner Adhesive (rectangle) 	2 x Motor Adhesive 	1 x Battery Pack Adhesive 	2 x Wire Adhesive 	15 x Zip Ties & 12 x Rubber Bands 	6 x Footing Squares 	10 x Footing Connectors 
12 x Metal Brads 	1 x Ruler 	4 x Binder Clips 	6 x Paperclips 	3x Washers 	4 x Ball Bearings 	8 x Ball Bearing Donuts 
4 x Metal Springs 	8 x Chipboard Squares 	8 x Foam Squares 	16 x Chipboard Rectangles 	6 x Coffee Stirrers 	8 x Chipboard Gusset Plate 	4 x Foam Gusset Plate (small) 
4 x Foam Gusset Plate (large) 	1 x Accelerometer 	1 x Accelerometer Mount 	1 x USB Cable 	20 x Balsa Wood Sticks 	1 x Shake Table Platen 	1 x Structure Base 
2 x Vellum Paper 	1 x Tablecloth 	2 x Syringes 	3 x Large Rubber Bands 	1 x Piece of Sandpaper 	1 x Gorilla Super Glue 	1 x Shake Table 

Shake Table Kit Parts Sheet

Some of the smaller items listed on the parts sheet are grouped in bags based the activity for a particular day. Below are photos of each bag as well as a list of their contents.

Day 1: Shake Table Fabrication



- DC motor with lead wires
- battery pack with lead wires and one AA battery inside
- spinner base
- metal washer
- plastic gear
- mini craft stick
- spinner adhesive (square)
- spinner adhesive (rectangle)
- motor adhesive
- battery pack adhesive
- wire adhesive
- zip ties
- small rubber bands

Day 2: Structure Fabrication



- footing squares
- footing connectors
- metal brads
- ruler
- binder clips
- paper clips

Day 3: Structure Retrofit



- metal washers
- ball bearings
- ball bearing donuts
- springs
- chipboard squares
- foam squares with holes
- chipboard rectangles
- coffee stirrers
- chipboard gusset plates
- foam gusset plates (small)
- foam gusset plates (large)

Day 4: Data Collection



- accelerometer
- accelerometer mount
- USB cable