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Hands-on Earthquake Engineering Curriculum for the Virtual Classroom

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Abstract

During Summer 2021, five week-long virtual earthquake engineering sessions were offered in the Cal Poly Engineering Possibilities in College (EPIC) summer program. Typically, this is a residential program comprised of faculty-led workshops in various engineering fields to provide pre-college experiences to students, particularly from underrepresented backgrounds. The challenge posed by remote learning, due to the global pandemic, was to continue providing educationally effective hands-on activities. To accomplish this, the instructor team designed, fabricated, and shipped over 120 mail-home engineering kits for students to assemble a shake table, build and retrofit a structural model, as well as collect and analyze data with a low-cost accelerometer. These activities were paired with lectures to help students understand earthquake hazard, seismic design of buildings and instrumentation among other topics. Given the virtual setting, particular attention was given in lectures to provide multiple opportunities and modes that students could engage. Student feedback collected on the last day of each week-long session highlighted students' high level of interest and enjoyment of the hands-on activities. This earthquake engineering lab piloted in the EPIC program shows one solution to increasing accessibility of outreach activities to students in locations that are geographically remote from EERI regional and student chapters.

Introduction to Cal Poly EPIC Summer Program

For over a decade, multiple week-long sessions of the Engineering Possibilities in College (EPIC) residential summer program have been offered to expose middle and high school students to different engineering fields through hands-on workshops, panel discussions, and tours led by Cal Poly faculty and students. The workshop topics range from the design of wearable devices to rocketry. One of the core missions of EPIC has been to provide opportunities to students from underrepresented backgrounds to learn about and cultivate an interest in engineering, serving as a pipeline for their potential future university studies and career in this arena. Engagement of a diverse population of students has been possible through relationships developed with the Migrant Education Program (MEP) as well as Advancement Via Individual Determination (AVID) [1].

In 2020-21, the EPIC program transitioned to a virtual mode in response the global pandemic. This provided educators with the challenge and opportunity to re-envision the in-person workshop format to a remote experience that maintained the project-based learning approach along with the direct

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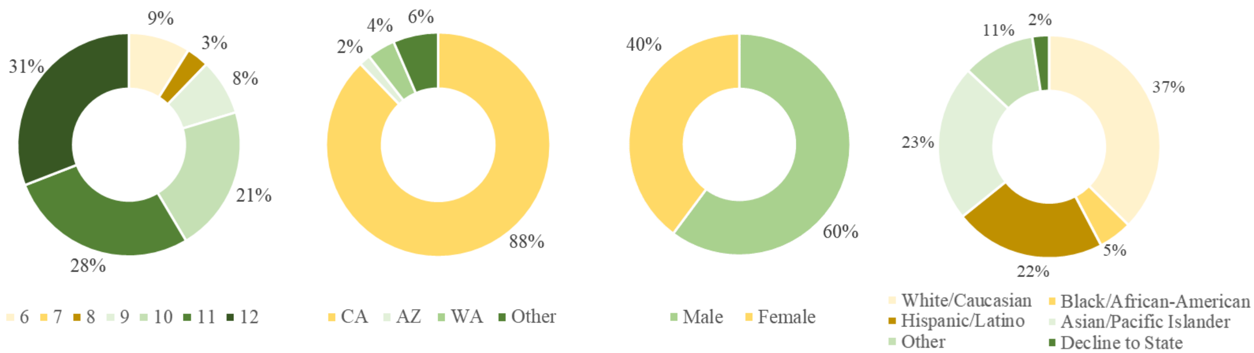
interaction between participants and Cal Poly faculty/students. It was for Summer 2021 that the authors developed the week-long earthquake engineering (EE) curriculum described in the remainder of this paper. The five offerings of the EE session totaled 123 students from 11 U.S. states in 6th-12th grades representing a diverse gender and racial/ethnic background per Figure 1.



a) Grade Level b) State of Residence c) Gender d) Race/Ethnicity

Figure 1. Student demographics.

Program Curriculum

The curriculum was inspired by problem-solving tasks in the Earthquake Engineering Research Institute (EERI) Seismic Design Competition and content in outreach modules produced by School Earthquake Safety Initiative (SESI) [2,3]. The instructional objectives of the week-long summer program were to spend one hour of lecture each day introducing EE concepts interspersed with questions and discussion, followed by an hour for students to work on a hands-on activity in break-out rooms with instructors. These activities formed a project highlighting the engineering design process: (i) assemble a shake-table, (ii) design, construct, instrument, test, and analyze a basswood structural model, (iii) retrofit and retest the model, and (iv) present to the class on their decision process and original/retrofitted structure's performance. The curriculum schedule is presented in Table 1.

Table 1. Curriculum Schedule.

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00-9:00	Icebreakers	Icebreakers	Icebreakers	Icebreakers	Icebreakers
9:00-10:00 Engineering Lecture	• Vulnerability and resiliency • Fault rupture • Seismic Waves • Classifying buildings • Capacity vs demand	• Structural and ground motion • Modeling mass and stiffness • Natural frequency and period • Recording earthquakes	• Recording and analyzing structure motion • Different types of sensors • Finding response spectra at students' homes	• Isolation systems: friction pendulums and lead rubber bearings • Damping systems: tuned mass, friction, and viscous dampers	• Student feedback about course • Student presentations of structure, collected data, and lessons learned • Teacher presentations about structural engineering and experiences in the department
10:00-11:00 Engineering Activity	• Discuss project overview, items in kit, and design parameters • Work on basswood structure	• Demonstrate shake table construction process • Campers build their own shake tables	• Install sensor software • Mount sensor on structure • Record structure motion	• Design and install seismic upgrade(s) to structure • Record motion of structure with retrofits	
11:00-12:00 Coding Lab	• Data types • Operators • Booleans • If-else statements	• Functions • For loops • While loops	• Import/install libraries • Line plot • Import data to plot	• Accessing USGS earthquake data • Mapping geospatial data	College Readiness Presentation

Students in each EE session had access to a Google Classroom where lecture slides, tutorial videos for hands-on activities and homework were posted. This tool was also used send reminders of daily office hours as well as EPIC activities like engineering panels with current and past Cal Poly students.

Mail-Home Engineering Kit

Preparing physical materials for the summer program started in Spring 2021 and included prototyping and sourcing the components of a mail-home engineering kit for students to participate in the hands-on activities. The shake table was patterned after an out-of-stock Tinker Crate educational subscription box [4] and low-cost accelerometers were purchased from Wit Motion [5]. Other custom-formed parts (constructed of basswood, cardboard, craft foam, etc.) for the shake table, structural members, base isolation, damping devices, and accelerometer mount were drafted in Rhino and laser-cut using equipment in the Cal Poly Digital Fabrication Lab. The kit materials, shown in Figure 2, were hand-packed and shipped to each student's home. The budget for each kit including shipping and taxes was around $60 USD, with nearly half of that cost being the sensor.

a) Footing Parts b) Motor Parts c) Retrofit Parts d) Sensor e) Shake Table

Figure 2. Engineering Kit Materials.
(Note: not all parts shown due to space limitations)

Lecture Materials

Following the engineering kit creation, the lecture content for this virtual summer program was prepared. In this process, there was an intentional use of a variety of mediums to actively engage students and avoid further "Zoom fatigue" from over a year of online schooling.

A number of instances where students contribute (verbally, in the chat box, or via video/screenshare):

- *Project or Homework Update:* at start of class, students share progress on their projects, or building case studies they explored for homework to prepare for a topic in the day's class
- *Discussion Questions*: questions aim to have students share their personal experience with earthquakes, the built environment, or knowledge from their past science classes
- *Draw Together*: in a break-out room facilitated by an instructor, teams of students work together to draw on a building the type of damage they expect to see after an earthquake
- *Software Tools/Websites*: after being introduced to the ATC Hazards Tool [6], students share the seismic parameter S_{DS} at their home and see who has the highest/lowest values
- *Spirit Points*: concurrent summer sessions were in a competition which encouraged students to photograph/videotape their project work and share it with EPIC program staff

A few examples instructors built into the lecture slides (aside from photographs and figures):

- *Videos:* recordings from recent/local earthquakes, researchers discussing sensors in Los Angeles tall buildings, shake table tests at Cal Poly and E-Defense Facility
- *Animations:* types of seismic waves, simulation of ground motion propagation, building vulnerabilities like a soft story mechanism, function of base isolators and damping devices
- *Physical models*: Mola model to examine various lateral force resisting systems [7]
- *Software Tools/Websites*: early warning smartphone applications that students can access
- *Storytelling*: instructors share anecdotes about their own or peers' earthquake engineering contributions in industry, research, and reconnaissance

There was also a significant portion of lecture time invested in teaching students how to implement the Wit Motion sensor via Bluetooth or USB-C on a laptop (this required Parallels [8] for Mac), Physics Toolbox Accelerometer for Android [9], or Accelerometer by Dreamarc for iPhone [10]. This instruction included collecting data, formatting it in Google sheets, and plotting it in Python coding language using the online platform Replit [11]. The Wit Motion sensors were provided and Replit was used for universal accessibility since not all students might have personal laptops or smartphones, but at least a school district issued laptop without download privileges. However, surprisingly, a survey conducted in the EE program showed nearly 98% of students had smartphone access.

Student Engagement & Feedback

On the last day of each week-long session, students were surveyed on the earthquake engineering summer program. Most students had strong positive feedback on constructing their structures and shake tables as well as plotting the acceleration data from their sensor. While many students did not have any suggested improvements, a few in earlier weeks did request focusing more on the hands-on activities over lectures, to which the instructors responded by modifying the curriculum. Students also expressed interest in having more time in the engineering lab to learn the material and develop their structures. This was affirming commentary, particularly given the virtual nature of the experience.

Another measure of success with this virtual engineering lab observed by the instructor team and EPIC staff was in the student thoughtfulness in their final presentations. On the last day they all showed off various brainstorming sketches for their original and retrofit designs, ran a real-time shake table test of their structure, discussed challenges they overcame in construction, and presented data collected with the accelerometer (sometimes for multiple retrofits to select the best performing option), see Figure 3.

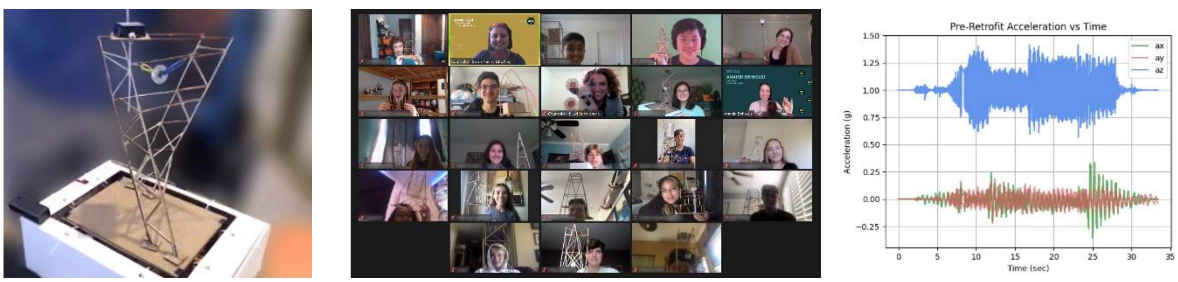


Figure 3. Sample Project Deliverables.

Conclusions

The effective execution of virtual earthquake engineering summer sessions in Summer 2021, as part of the Cal Poly EPIC program, demonstrates the possibilities for EERI members to conduct remote outreach to K-12 students that lack direct access to a regional or student chapter. The development of an inexpensive mail-home engineering kit (with construction materials and an accelerometer) proved to be critical to these sessions' success since students most appreciated and learned from the hands-on activities. The hands-on component was coupled with lectures of varied and engaging content to provide background knowledge on what generates earthquake hazard and how structural engineers design buildings and infrastructure to insure the seismic resiliency of our communities. For educators or practitioners that are interested, the lecture and engineering kit materials are available upon request.

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