# An example of effective mentoring for research centers

C.E. Bronner, D.W. Wilson, K. Ziotopoulou, K.M. Darby, A. Sturm, A.J. Raymond, R.W. Boulanger, & J.T. DeJong
*University of California, Davis, California, United States*

D.M. Moug
*Portland State University, Portland, Oregon, United States*

J.D. Bronner
*GeoEngineers, Redmond, Washington, United States*

ABSTRACT: Engineering center research faculty and staff value the importance of performing educational outreach and mentoring graduate students. However, these activities are often less structured than research projects, which leads to variable and less effective results. The geotechnical group at the University of California, Davis (UC Davis), which includes research faculty and staff at the Center for Geotechnical Modeling and the Center for Bio-mediated and Bio-inspired Geotechnics, developed a Ladder Mentoring Model (LMM) for mentoring graduate students in academic environments to enrich graduate student development while minimizing additional demands on center personnel. The LMM is a combination of several existing mentoring models and relies on six core principles where the outcome is students receiving guidance from a variety of mentors with different areas and levels of expertise or experience. This paper provides a brief overview of the UC Davis LMM and describes how it is integrated into three critical areas of graduate student development: technical training, professional skills, and educational outreach.

## 1 INTRODUCTION

Training graduate students is often a central objective for engineering research centers. Traditional models for training graduate students provide limited exposure to researchers other than faculty and staff related to their thesis project. There is often minimal development of non-research skills needed for successful academic careers, such as teaching, networking, and communication skills.

Center personnel, however, have several other responsibilities including training visiting researchers on center equipment, preparing for and performing experiments, maintaining center equipment, and developing researchers. While center research experiments are meticulously designed and orchestrated, a lack of structure often exists in mentoring and educational outreach activities. Despite recognizing the importance of these latter activities to prepare future engineers and scientists and broaden participation of underrepresented groups in STEM disciplines, center researchers may feel burdened with other demands that produce timelier, more concrete results.

To improve graduate student mentoring and educational outreach effectiveness in research centers without excessive additional demands on personnel, a restructuring of these activities is needed. This paper presents a model for organizing mentoring and outreach activities to produce researchers with the technical expertise, networks of collaborators, ability to communicate to all audiences, and other professional skills that can help them achieve their career goals. After a brief overview of common mentoring practices, an overview of the UC Davis Ladder Mentoring Model (LMM) is presented along with its six core principles. The following three sections provide examples of how the LMM is applied with six core principles at UC Davis in three different areas: technical training, professional skills development, and educational outreach. The paper concludes with ideas for transferring and tailoring UC Davis's LMM model to other institutions.

## 2 MENTORING IN ACADEMIC ENVIRONMENTS

Table 1 summarizes the different types of mentoring models used in academic environments (Hanover 2014, Lee et al. 2015). The primary differences between the models include the distance in expertise between the mentor and mentee, the number of mentors, the combined breadth of expertise a mentee receives, and the amount of agency a mentee has in the mentoring process.

Table 1: Common mentoring paradigms used in academia (sources: Hanover Research 2014, Lee et al. 2015)

| *Mentoring Model* | *Example* |
|---|---|
| *Traditional one-on-one mentoring*: Mentor seen as distributer of advice/help | Faculty advisor (mentor) guides graduate student (mentee) through the academic job search process |
| *Peer mentoring*: Mentoring between two or more individuals who are considered peers or have similar status | Graduate student (mentor) trains another graduate student (mentee) on how to set up a centrifuge test |
| *Group/collective mentoring:* Combination of traditional and peer mentoring | Faculty member (mentor) coaches their graduate group (mentees) on giving research presentations; students may also guide peers |
| *Mutual mentoring*: Mentoring relationships that include a wide variety of mentors and focus on specific areas of experience and expertise. Assumes that no single individual possesses all expertise that an individual needs | An assistant faculty member (mentee) mentored by a network of individuals (mentors) that may include peers, senior faculty, administrators, etc. |
| *Reverse mentoring:* The mentor in this role is often in the role of the mentee in other situations between these two individuals | Graduate student (mentor) guides a faculty member (mentee) through a new analytical approach |
| *Mentoring up:* Similar to a traditional mentoring model, however the mentee is proactive in determining the help they need and seeking it out | Graduate student (mentee) asks faculty advisor (mentor) for help on how to develop their professional network |

### 2.1 *UC Davis Ladder Mentoring Model*

Geotechnical faculty at UC Davis encourage students to act as both mentees and mentors and to work in a collaborative environment. Often, students are mentored in research by near-peers who are just a few steps up the ladder from them (e.g., another graduate student who is one- or two-years ahead of them). Over time, the program has also developed structures that have integrated the LMM into the academic, professional development, and outreach training that graduate students receive. Through the LMM, graduate students obtain many of the benefits of traditional, peer, group, mutual, and reverse mentoring models, while practicing the pro-activeness from the mentoring up model.

Recently, the UC Davis team has started studying the LMM to evaluate its benefits and to share lessons learned with other institutions. It is posited that the model works due to the integration of the following six core principles into graduate student training in research, professional development, and educational outreach activities. Examples of how these principles are applied are provided in the next three sections.

1. Providing a sustainable structure with clear expectations
2. Tailoring mentoring to needs of the individual
3. Leveraging resources generously
4. Promoting an inclusive culture
5. Encouraging consistent assessment
6. Building networks that expand beyond the borders of the institution

The three organizations in Table 2 provide structure, vision, and resources for the sustainable implementation of the six LMM principles. The Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) and Center for Geotechnical Modeling (CGM) are research centers, whereas the Geotechnical Graduate Student Society (GGSS) is a student organization. Many individuals in the UC Davis geotechnical group are connected to one or more of these organizations.

Table 2: UC Davis geotechnical organizations

| *Organization* | *Purpose* |
|---|---|
| CBBG | Transforms geotechnical practice by developing technologies that leverage natural biogeochemical processes or leveraging principles/functions/forms from natural analogs (i.e., bio-inspired), resulting in more efficient and sustainable solutions |
| CGM | Provides access to geotechnical modeling facilities to enable major advances in the ability to predict and improve the performance of soil and soil-structure systems affected by natural hazards |
| GGSS | Promotes scholarship, service, leadership, and social events to foster collaboration within the UC Davis geotechnical group |

*Abbreviations: CBBG = Center for Bio-mediated and Bio-inspired Geotechnics; CGM = Center for Geotechnical Modeling; GGSS = Geotechnical Graduate Student Society

## 3 TECHNICAL TRAINING

The Center for Geotechnical Modeling (CGM) serves as a resource in the National Science Foundation's Natural Hazards Engineering Research Infrastructure program (NHERI). The facility hosts researchers from across the US and provides the technical training and oversight necessary to maintain a high standard of research quality. Currently 15 students are actively working across six projects at the CGM, including six non-UC Davis students. Typically, about 10 to 15 researchers per year will rotate through the testing facility for short durations.

New researchers start with varying skill levels, academic backgrounds, and hands-on mechanical expertise. Table 3 describes types of CGM researchers and their typical characteristics, including the amount of time they spend at the CGM.

The CGM follows an apprenticeship model to introduce new researchers to centrifuge testing. CGM staff train new users on methods directly through annual workshops and hands-on equipment training at the start of a researcher's time on site. However, new users can still be confused even after a lesson on what to do.

The apprenticeship model grew naturally from the mutual benefits gained by experienced users needing extra assistants and new users needing practice to support their training. Apprenticeship is formally integrated into current CGM operating protocols.

Table 3: Typical needs of different types of CGM researchers

| *Researcher Type* | *Typical Duration* | *Mentoring/ Training Need* | *Ability to Mentor* |
|---|---|---|---|
| Undergraduate student from UC Davis | 10 weeks to 2 years | Very high; transitioning to medium/high | Medium |
| Visiting undergraduate students | 6 to 10 weeks | Very high | Low |
| UC Davis graduate students & post-docs | 10 weeks to 6 years | Medium to high; transitioning to low or medium | High |
| Visiting graduate students & post-docs | 2 to 6 week intervals over 1 to 3 years | Often high initially; transitioning to low or medium | High |
| Visiting research faculty | 2 weeks to 1 year | Depends on experience | High |

### 3.1 *CGM Apprenticeship Model*

At the CGM, researchers are responsible for their entire physical model test program (Fig. 1). New researchers must learn physical modeling techniques, sensor and data acquisition procedures, as well develop an engineering design of their research application. Researchers, acting as project managers, learn to supervise assistant researchers, productively direct staff, work with outside vendors, and manage non-personnel resources. Given the high cost of experiments on the 9 m centrifuge, both in terms of fees and consumed effort, projects cannot afford to let new researchers learn by failure in their first experiment. Thus, new researchers serve as apprentices to experienced researchers on other models/projects to learn how to run a centrifuge test.

The apprenticeship model requires new researchers to assist an experienced researcher during an experiment. The mentee is encouraged to participate in the experiment from beginning to end so that they can learn the entire process before becoming responsible for their own test. CGM staff still provide training on equipment, but focus primarily on personal and equipment safety. Apprentices "learn while doing" within a safe, supervised environment.

Figure 1. A typical experiment on the 9m centrifuge at UC Davis includes 1500 kg of soil, over 100 sensors, in-flight characterization using cone penetrometers, and multiple simulated earthquake events. Experienced researchers may spend two months building, testing, and excavating such a model. New researchers learn through apprenticeships important centrifuge modeling techniques such as how to place soils, how to calibrate sensors, how to place and log sensors during model construction, how to design a test protocol, and how to manage their test schedule and facility resources, before attempting to lead an experiment.

The apprenticeship model benefits both the mentee and the mentor. The mentee gains the experience and training required to design their future experiment. The mentor gains the advantage of having an extra set of hands and eyes. The CGM expects all researchers to serve as both mentees and mentors, so that all can gain experience and receive the benefit of outside help.

### 3.2 *Role of CGM*

The CGM has institutionalized the expectation for the apprenticeship model by incorporating the practice into facility use rates. Projects are charged a base fee for sending a "new lead researcher" to the CGM. New lead researchers require additional orientation, training, and interaction, which consumes effort of the CGM staff. Credits against this fee are given when the researcher has the tools to be self-sufficient in order to pass on the effort savings for the center. For example, half the fee is returned if the new lead researcher has served a full apprenticeship at the CGM. Further credits are given for other forms of formal training such as attending the annual centrifuge users' workshop and taking courses in signal conditioning.

The CGM also has a fee for "basic researcher support" intended to recover costs of CGM staff providing the extra set of helping hands when a project only sends one researcher to perform a test. Credits are given if a project provides their own assistance, such as through mentoring other users.

The well-documented apprenticeship model together with the fee structure and credit incentives have proven effective in getting 100% participation by project teams from UC Davis and near 100% by external users. External teams have an added burden of paying travel costs, which reduces their apprenticeship participation rate. When possible, external teams apprentice on the 1m centrifuge, where mentees can participate from beginning to end over a shorter time. The CGM has implemented parallel operating protocols across the 1m and 9m centrifuge so that procedural training is consistent, which has improved the apprenticeship participation of external research teams.

The CGM use fees are located on the CGM website under the "information for users" area. https://cgm.engr.ucdavis.edu/information-for-users/

### 3.3 *Connection to the LMM*

The apprenticeship model for training researchers in centrifuge techniques aligns with the LMM framework and its six core principles as described below.

*Providing a sustainable structure with clear expectations:* The centrifuge test pricing incentives provide the primary structure for the success of the apprenticeship model. This structure offers users a price incentive to participate both as a mentee and as a mentor, and has helped the apprenticeship model of training to become "the norm" at the CGM.

*Tailoring mentoring to needs of the individual*: The model allows researchers to be paired with individuals who are their near-peers with respect to the experiment they will be performing. Researchers actively work with someone performing experiments using similar techniques to those they need to learn in addition to general training. As external researchers have additional housing costs, the CGM implemented parallel operating protocols for both the 9m and 1m centrifuge to allow researchers to train on either centrifuge. This flexibility reinforces the structure by making the program feasible for internal and external researchers.

The graduate students involved in mentoring develop advising skills, which is particularly important for those who plan to enter academia or serve in leadership roles. The high number of mentees a CGM graduate student mentors provides them more opportunity to develop their teaching style. Table 4 provides an example of doctoral student's mentoring experiences.

*Leveraging resources generously:* Leveraging of resources occurs between UC Davis and visiting centrifuge researchers. Through the apprenticeship program, a researcher is provided a necessary assistant at no cost, while another researcher receives training in centrifuge methods and a credit towards the cost of their centrifuge tests. The two projects benefit from reduced costs and the CGM staff can better utilize their expertise in center operation and technical research advancement.

*Promoting an inclusive culture:* The apprenticeship model provides the opportunity to involve researchers from a broad range of backgrounds, abilities, expertise, and development levels. For example, the apprenticeship model allows for the inclusion of undergraduates in centrifuge research. Typically, undergraduates are not able to commit the time or flexible schedule needed to participate in centrifuge experiments. They can, however, offer valuable assistance as the third member of a centrifuge team while gaining valuable research experience. Provision of the primary assistance by the apprenticeship program produces more opportunities for undergraduates to work as an extra assistant when their schedule permits.

*Encouraging consistent assessment:* The CGM has a stated performance goal of developing its members for the future workforce. Objectives toward this goal include providing ladder mentoring toward the development of independent researchers, engaging researchers in education and outreach activities (EOT) (to be discussed later), and providing technical training on all facets of geotechnical centrifuge testing. Progress is assessed by tracking the percentage of teams with ladder-mentored lead or assistant researchers (target >90%, actual 10 of 11 since 2016), percentage of users engaged in EOT (target >50%, actual >75% since 2016), and through user satisfaction surveys (target > 90% of users satisfied or very satisfied with training, actual surveying has been informal to date). Our user surveys to date have indicated strong support for the apprenticeship model, but also a consistent desire for improved documentation.

The UC Davis geotechnical group is now working to improve and expand assessment of the ladder mentoring program across all activities in an effort to better quantify its impact on preparing its members for the twenty-first century workforce.

*Building networks that expand beyond the borders of the institution:* The CBBG and CGM both include participation by researchers across the US. These activities give users valuable opportunities to work with people from diverse institutions and academic backgrounds (Fig. 2). Anecdotal observations indicate that knowledge, beyond centrifuge testing skills, is being broadly disseminated and wide-reaching networks are being developed.

### 3.4 *Example: Experience of a Graduate Student*

To demonstrate the potential impact of the apprenticeship model, Table 4 highlights the centrifuge-related mentoring experiences of a graduate student participating in both the CGM and CBBG, Kathleen Darby. Her research included centrifuge tests over a period of five years. As Ms. Darby progressed through her graduate work, she worked with 17 different researchers (three faculty, one visiting scholar, one post-doc, nine graduate students, four undergraduate students) from eight different institutions covering a range of research roles, as described in the table.

Due to the CGM's apprenticeship model, Ms. Darby's contact with researchers at several institutions allowed her to gain and distribute centrifuge-related skills beyond the boundaries of the CGM. She received mentorship from researchers within and outside of UC Davis, including initially serving as an apprentice under a visiting graduate student. As a graduate student, she mentored undergraduate and graduate students from seven different institutions, including several who apprenticed with her or were supervised by her.

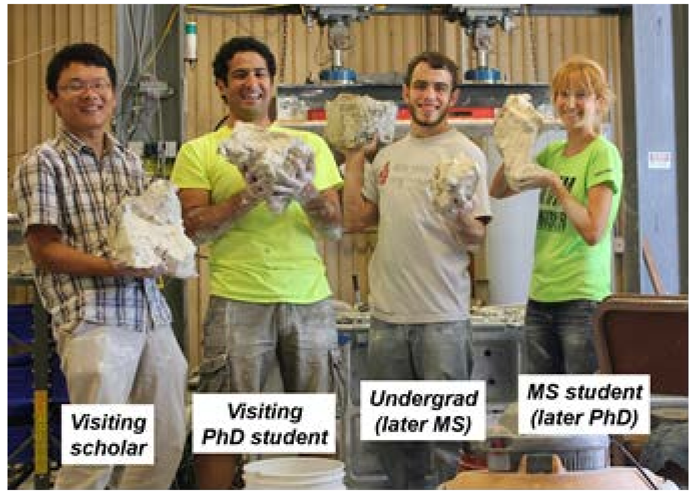


Figure 2. Ladder mentoring in practice. Visiting PhD student Mohammad K. (VaTech) led an experiment looking at ground improvement using soil cement. He mentored three engineers during the test and benefited from the depth of support available for a complicated test. Dr. Wang, a visiting scholar, gained experience in how to perform centrifuge testing that he would take back to his new centrifuge in China. Kate D., as an MS student, apprenticed during the experiment so that she could lead her own tests on the 1m centrifuge and eventually the 9m centrifuge as a PhD student. Daniel C. gained valuable research experience as an undergraduate and ultimately decided to further pursue his education as an MS student.

## 4 PROFESSIONAL SKILLS DEVELOPMENT

The UC Davis geotechnical graduate program typically consists of about 30 graduate students and six full-time faculty, serving as their graduate advisors. A traditional mentoring system where knowledge transfer occurs only from faculty member to student would lead to limitations on mentoring in professional skills, such as restrictions based on faculty time constraints and variability based on an advisor's individual sense of importance for specific skills. Expansion of a mentoring system to include knowledge transfer between peers and research staff increases development of and feedback on professional skills.

At UC Davis, the Geotechnical Graduate Student Society (GGSS) provides an additional structure for graduate student professional development. The GGSS program actively fosters leadership, outreach, and mentorship skills in its members, making them better qualified and well-rounded to graduate to professional or academic careers. The organization's practices align with the LMM core principles and expand support originally provided through geotechnical faculty members and the CGM.

Table 4: Centrifuge Mentoring Experience of Kathleen Darby

| *Mentor or Mentee* | *Position and Affiliation** | *Year* | *Role* | *Primary motivation in mentorship* |
|---|---|---|---|---|
| R. Boulanger | Faculty | 2014-2018 | PhD Advisor | Lead research project |
| J. DeJong | Faculty | 2014-2018 | Mentor | Co-lead research project |
| D. Wilson | Faculty | 2014-2018 | Mentor | Train students on test methods |
| Jackee A. | GS | 2014 | Mentor | Transfer knowledge on NEEShub and data analysis |
| Mohammad K. | GS at VT | 2014, 2017 | Mentor | Gain assistance, train Kate and Jaclyn on test methods |
| Jaclyn B. | GS | 2014, 2016 | Peer Mentee | Co-apprentice under Mohammad. Co-lead 1m centrifuge tests |
| Daniel C. | UG | 2014 | Peer Mentee | CGM UG employment. Experience research and assist researchers |
| Yunlong W. | VS from CEA | 2015 | Apprentice | Learn UC Davis test methods |
| Maggie E. | GS at OSU | 2016 | Apprentice | Learn 9m test methods |
| Maddie H. | UG | 2016 | Mentee / Assistant | CGM UG employment. Experience research and assist researchers |
| Mohammad K. | Postdoc | 2017 | Assistant | Reciprocate assistance on test |
| Dexter H. | UG at MSU | 2017 | Mentee | NHERI REU to experience research |
| Gabby H. | GS (CBBG) | 2017 | Mentee / Apprentice | Gabby, Caitlyn, Alex, and Greg: Learn general 1m test methods and specific research protocols for their projects |
| Caitlyn H. | GS at ASU (CBBG) | 2017 | Mentee / Apprentice | |
| Alex S. | GS | 2017 | Mentee / Apprentice | |
| Greg S. | GS | 2017 | Mentee / Apprentice | |
| Jiarui C. | GS at UIUC | 2018 | Apprentice | Jiarui and Soham: Learn centrifuge testing methods (shared project) |
| Soham B. | GS at UV | 2018 | Apprentice | |

* Institutional affiliation is UC Davis unless otherwise listed. Abbreviations: ASU = Arizona State University; MSU = Morgan State University; OSU = Oregon State University; UCD = UC Davis; UIUC = University of Illinois – Urbana-Champaign; UV = University of Vermont; VT = Virginia Tech; CEA = China Earthquake Authority; GS = graduate student; UG – undergraduate student; VS = visiting scholar; REU = Research Experience for Undergraduates.

### 4.1 *Geotechnical Graduate Student Society*

In 2007, the UC Davis geotechnical engineering faculty members guided the graduate students in initiating the GGSS to formalize and focus the activities used to develop the professional skills of graduate students. The goal of the GGSS is to promote scholarship, service, leadership, and social events for the geotechnical group at UC Davis. The intention is to foster community and collaboration, and provide opportunities to promote graduate student education and professional development.

The GGSS is governed by a board consisting of six officers: President, Treasurer, Seminar Coordinator, Social Events Coordinator, Field Trip Coordinator, and Outreach Coordinator. Each officer has clearly defined responsibilities and opportunities. For example, the seminar coordinator recruits and hosts seminar speakers, which allows them to develop a professional network that they can leverage for employment opportunities as they near graduation. The GGSS board is mentored by the faculty advisor.

Faculty members rotate the responsibility of GGSS faculty advisor so that the workload is fairly distributed. The faculty advisor provides historical context and advice to the students as they navigate their new roles. While the faculty advisor will always be a critical role, the GGSS board retains continuity of some members from year to year and draws on advice from past officers. The officers are usually established senior graduate students who in turn serve as mentors to junior officers and new GGSS members. New officers are elected in April and current officers end their terms the following June to ensure there is training time for new officers.

The GGSS organizes a variety of events including a weekly seminar series, field trips, educational outreach activities, and social outings, which diversifies the expertise and experiences to which graduate students are exposed. The largest GGSS event is the annual Round Table where about 80 geotechnical professionals from government and industry are invited to a full day of student presentations, poster sessions, panel discussions, and closing social. The goal of the Round Table is to foster connections between UC Davis researchers and leading professionals by providing opportunities for open conversations, exposure and feedback on current research, exchanges or collaborations, and connections among future colleagues.

### 4.2 *Role of CGM*

The CGM supports the goals of the GGSS by providing connections and institutional knowledge. Networking opportunities include interacting with visiting scholars at the CGM, utilizing the growing network of professional contacts when planning GGSS field trips and seminars, and connecting GGSS members with long-term educational contacts for outreach events.

The institutional history provided by the CGM was instrumental for the GGSS when developing its educational outreach program as it could build off the center's previous experience and existing connections. Graduate students learned whom to contact and which activities had been the most successful.

### 4.3 *Connection to the LLM*

GGSS mentoring relationships strongly rely on characteristics of the mutual mentoring, peer mentoring, and mentoring up models. The GGSS structure relies on the six core principles in the LMM to provide effective professional skills development for graduate students.

*Providing a sustainable structure with clear expectations:* The GGSS provides a structure, outlined in its bylaws, with clear roles and responsibilities of officers. The election process and officer overlap period provide continuity for the organization and minimize the possibility of knowledge loss when students graduate.

Geotechnical faculty and current graduate students set a clear expectation that all graduate students in the group should be active participants in the GGSS. If students are not attending seminars, their faculty advisor is responsible for strongly encouraging their attendance, often through a reminder of the benefit they are missing out on. The importance of participation in the GGSS is highlighted from their first day on campus; prospective graduate student campus visits include attendance at a GGSS organized activities such as the Round Table event or a weekly seminar.

*Tailoring mentoring to needs of the individual:* Students in the UC Davis geotechnical group vary based on their experiences, career ambitions, and desired professional skills. The GGSS offers a variety of involvement levels, which requires students proactively decide how much they can or want to contribute and gain from the GGSS at a given time in their graduate study.

As a baseline, all students are expected to attend the weekly seminars and the Annual Round Table, which together provide essential exposure to professional practice and opportunities for networking. Note that all seminar speakers are taken to lunch by a group of two to four GGSS members, so all students have opportunities for establishing personal connections with various professionals during the year. In addition, GGSS members can participate in some combination of the field trips and outreach events held throughout the year, with that mix varying from year to year. For example, an MS/PhD student may only have time to participate in one or two outreach events in their first year (due to class workload), may participate more heavily for the next year or two, and then participate less frequently in the last year or two depending on other commitments or roles they assume. The same MS/PhD student may serve in an officer role (e.g., seminar coordinator) in their second or third year, followed by a second officer role (e.g., president) in the fourth or fifth year.

Additionally, the GGSS structure allows students to work on specific professional skills that they want to improve. For example, a student who has difficulty communicating their research to non-technical audiences may choose to participate in outreach activities to practice these skills. Another student who struggles in professional networking situations may become the seminar coordinator to hone these skills in a supportive environment.

*Leveraging resources generously:* Both the CGM and CBBG have responsibilities related to the professional development of graduate students. By these centers supporting the GGSS and encouraging their students to be active members, they leverage the enthusiasm of graduate students and provide a structured approach to professional development.

The GGSS, CGM, and CBBG also leverage resources for providing professional development. The Round Table event provides the majority of the funds for GGSS activities; the event's success is partially due to the reputation of the CGM and research faculty. CBBG resources (e.g., webinars) for supporting professional development of its students are often shared with other GGSS members. The CBBG also provides funding resources to support the outreach activities of the GGSS; these activities are further discussed in Section 5.

*Promoting an inclusive culture:* GGSS members actively recruit new graduate students as members. Their commitment to inclusivity is demonstrated by the policy in their bylaws that automatically makes any registered UC Davis geotechnical graduate student a voting member of the GGSS. The GGSS also has a practice of inviting visiting students and scholars to participate in GGSS activities as honorary members while they are in Davis.

The culture of inclusion is demonstrated through diverse leadership in the GGSS. Nationally, 20% of civil engineering graduate degrees are earned by women. Currently, 50% of the GGSS officers are women and 33% are underrepresented minorities. Three of the past seven presidents have been women. These statistics indicate that women and other underrepresented groups in engineering are supported and actively participating in the GGSS. GGSS students further stress the importance of inclusion by including presentations on topics such as inclusion in engineering education and impostor phenomenon in their seminar program.

*Encouraging consistent assessment:* After every large GGSS event, students host a debriefing session to identify strengths, weaknesses, and opportunities for improvement. Feedback on weekly seminars and social events is provided during quarterly GGSS board meetings. This consistent assessment followed by action to address concerns leads to ever-improving, high-quality events. For larger events, surveys are distributed to collect participant feedback and include their input in the debriefing meetings.

*Building networks that expand beyond the borders of the institution:* The GGSS members have helped expand the influence of the UC Davis geotechnical program beyond the institution's borders. Due to the GGSS's success at UC Davis, CBBG faculty and students used the GGSS as the model when designing the engineering research center's Student Leadership Council (SLC). The SLC consists of graduate student and undergraduate student representatives from all CBBG partner institutions: Arizona State University, Georgia Institute of Technology, New Mexico State University, and UC Davis. To help establish similar expectations and a culture of inclusion in the SLC, UC Davis students, Michael Gomez and Alena Raymond, served as the president for the first and second years of the center, respectively. Additional plans for expansion include collaborating with GGSS alumni now working at other universities to help establish a similar graduate student organization at their universities.

The professional network for UC Davis researchers has expanded through positive interactions of geotechnical professionals with students during seminars, field trips, professional and K-12 outreach activities, and the Round Table event. This reputation has helped a large percentage of students secure jobs before graduating; about 90% of master's students are hired by companies who attend the Round Table.

### 4.4 *Example: Round Table Event*

The GGSS's Annual Round Table event foster connections between leading geotechnical professionals and UC Davis faculty and graduate students by providing opportunities for open conversations, exposure and feedback on current research, exchanges or collaborations, and connections among future colleagues. During the event, geotechnical graduate students present their research to professionals from industry, consulting firms, and government organizations through poster and oral presentations. The event also includes an industry panel discussion and social activities.

Round Table guests provide gifts that go to an account overseen by the civil and environmental engineering department, but controlled by the GGSS, and those funds support the GGSS activities throughout the year. These generous gifts reflect the fact the community has embraced the Round Table as an event they look forward to, they like to support the broader educational experience of graduate students, and they like the personal connections that lead to either hires or connections with future colleagues.

GGSS students plan and run all portions of the Round Table, which requires students to interact with professionals, plan out all logistics for the event, and develop an engaging program. Each year the GGSS President leads the event, however successful implementation requires a coordinated effort from all GGSS members. In their first year at UC Davis, students' participation at a minimum includes creating an abstract and poster presentation, informal conversations with professionals, and observations of their senior GGSS peers. By their second year, students will take on more responsibilities and may eventually lead the event or give one of the keynote presentations. Table 5 provides a potential Round Table path for GGSS members over their academic journey.

Table 6 lists examples of ladder mentoring interactions that occur during the preparation and implementation of the Round Table.

Table 5: Different levels of GGSS member participation during Round Table

| *Level of Involvement* | *Description of Mentoring* | *Role* |
|---|---|---|
| First year graduate student | Mentoring focuses primarily on preparing individuals to present their research to a professional audience in a clear and engaging manner, including through their design of a research poster. Mentoring comes from faculty advisors and fellow GGSS students. *Students make minimal contributions to larger planning efforts, mainly observing their peers.* | Mentee |
| 2+ years as graduate student | With respect to interactions with industry and poster preparation, students transition from mentee to mentor roles. Students receive mentoring from faculty advisors and fellow GGSS students on poster and/or oral presentations.*Students make minimal contributions to larger planning efforts, mainly observing their peers.* | Mentee & Mentor |
| GGSS Officer | Mentored by GGSS faculty advisor and provides mentoring to junior GGSS officers and members. *Students contribute to larger planning efforts, such as program design and implementation and contacting professionals* | Mentee & Mentor |
| GGSS President | Mentored by GGSS faculty advisor and provides mentoring to junior GGSS officers and members. *Student is responsible for the event.* | Mentee & Mentor |

Table 6: Mentoring interactions initiated due to Round Table

| *Mentoring Interactions at Round Table* |
|---|
| *Prior to Event* |
| • GGSS past/senior officers mentor new officers on logistical processes involved, as well as how to handle moments of stress (near-peer mentoring) |
| • GGSS faculty advisor mentors GGSS president through check-in meetings and advising on logistics, especially those related to industry (traditional mentoring) |
| • GGSS senior members mentor new members on preparing research posters and how to interact with industry (near-peer mentoring) |
| • GGSS members give feedback to each other on their posters and presentations (peer mentoring) |
| *During & Post Event* |
| • Industry members and faculty members provide feedback and advice to graduate students on their research projects (form of mutual mentoring) – potentially forming new research contacts |
| • Faculty and GGSS members provide constructive feedback to each other on Round Table execution – strengths, weaknesses, opportunities (form of collective mentoring) |

## 5 EDUCATIONAL OUTREACH

In addition to the technical training and professional development of graduate students, the mission of engineering research centers often includes providing service to the profession in the form of educational outreach activities. Despite good intentions, outreach activities are often ad hoc and their impact is seldom assessed. Funding agencies, such as the US National Science Foundation (NSF), are increasing the burden of evidence for demonstrating the impact of outreach efforts. Throughout its history, the CGM has and continues to provide hands-on tours of facilities to K to 12 students (US primary and secondary school levels, typical ages 5-17). Over time, these outreach events have added structure by rotating attendees through discrete stations, each led by a volunteer geotechnical graduate student. After its establishment, the GGSS took over the organization of outreach activities at the CGM. The post-activity assessment of outreach events includes discussion of what worked and what did not after each tour, but does not include assessment of activity learning outcomes.

In 2015, the UC Davis geotechnical group began transitioning to a more strategic approach to educational outreach due to three factors: the start of the CBBG, the hiring of a department faculty member with expertise in assessment, and the creation of a GGSS outreach officer position. One program in development is a graduate-level engineering education course in which students design educational activities to be implemented in annual outreach activities performed by the GGSS.

### 5.1 *History of UC Davis Geotechnical Engineering Outreach Program*

Before the GGSS began, CGM faculty, staff, and students developed relationships with local secondary schools and invited them on tours of CGM facilities (Fig. 3). They developed a series of modules for participants to rotate through. Modules are tailored to the needs of the participants, and more formal presentations on geotechnical earthquake engineering can be included. The most successful modules include significant physical interaction, while a tour of the 9m centrifuge can impress students simply with its scale.

Figure 3. Kathleen Darby (center) leading an outreach module during a tour by middle school students during one of her experiments on the 1m centrifuge. Jaclyn B. (peer/mentee) and Mohammad K. (mentor/visiting graduate student) also participated in this tour event.

Current modules include a shake table where participants build structures with K'nex, a create your own earthquake station where participants jump on an instrumented pad, a CGM module explaining the centrifuge and how it works, a CBBG module with bio-cemented sands, and a liquefaction module where users liquefy soil in a bucket to induce foundation failures.

With the creation of the GGSS, the students took over organizing the outreach events with the assistance of CGM staff. In 2014, the GGSS created an officer position for outreach coordinator. The result of these efforts was a time-efficient outreach system where new geotechnical students were trained on how to run different stations as they became involved in research. The participation in the activities provided opportunities for students to communicate technical topics to an audience with no or limited understanding of engineering. The direct interaction with K to 12 educators also exposes the graduate students to the curricular requirements of K to 12 education in the US.

The geotechnical group, however, did see a need for more intentional outreach that maximized impact without exhausting CGM staff and GGSS students. In 2015, the funding of the CBBG increased external demands for inclusive educational outreach and assessments of outreach efforts. This change coincided with the department hiring of a faculty member with an expertise in pedagogy and assessment.

Early steps have included the design of a two-course sequence for engineering graduate students in *Engineering Education Design (*discussed in section 5.4), intentional targeting of outreach activities to where they will have the most value, and developing tools for assessing outreach.

### 5.2 *Role of CGM*

As noted earlier, the CGM was the catalyst for early outreach efforts. Most connections with educators occurred organically. For example, one CGM development engineer, Tom Kohnke, initiated a now annual visit from a local high school where his daughter was attending. CGM personnel and students developed the first versions of the educational modules, and the facility attracted groups to UC Davis. The CGM currently support GGSS graduate students by providing access to the facility for tours and providing maintenance on outreach equipment (e.g., the shake table).

### 5.3 *Connection to the LMM*

Aligning the educational outreach program with the LMM maintains the sustainability of the program and trains graduate students to communicate their research to non-technical audiences.

*Providing a sustainable structure with clear expectations:* The structure for the outreach efforts are provided by the three geotechnical organizations and the UC Davis Civil and Environmental Engineering Department (Table 7). One of the most important factors is the expectation that graduate students participate in educational outreach, which allows more outreach to occur than if it were performed only by center personnel.

Table 7: Contributions to UC Davis geotechnical educational outreach

| *Organization* | *Structure provided* |
|---|---|
| CGM | Access to physical facility; institutional memory; technical support for demos |
| CBBG | Funded education-focused project; graduate course in engineering education; expectation of CBBG students to participate in two events per year |
| GGSS | Annual outreach coordinator; supply of volunteers |
| Department | Supporting tenure-track faculty hire in civil engineering education |

*Tailoring mentoring to needs of the individual:* As with other GGSS activities, the level of involvement in educational outreach activities is flexible. Students with minimal interest may only participate in a couple of outreach events each year and receive basic training from more experienced GGSS members. However, students with a strong interest in outreach or teaching may enroll in the graduate course sequence and serve as GGSS outreach coordinator. More active students will have multiple mentors coaching them, including both geotechnical engineering faculty and a faculty member with expertise in engineering education.

*Leveraging resources generously:* For outreach programs and associated mentoring interactions to be sustainable, they must leverage funding, equipment, space, time, and expertise. The CGM and CBBG both contribute funding related to outreach activities. The CGM primarily funds equipment maintenance, some supplies, and contributes staff effort. The CBBG funds workshops, undergraduate assistants to help design and organize outreach events, and new module development, and provides faculty support.

Expertise is leveraged in the design of modules and training of graduate students. Modules depend on the technical expertise of the geotechnical graduate students and faculty and the engineering education expertise of an environmental engineering faculty member. By finding someone with an educational design and assessment background, the geotechnical group can more efficiently train their students and assess the impact of their activities. The CGM provides expertise and support in maintaining the equipment used for outreach and providing a facility for on-campus outreach activities.

Both the CGM and CBBG are required to perform educational outreach and contribute to broadening participation of underrepresented groups in geotechnical engineering. By working together and with the GGSS and pooling resources, different types of expertise are exchanged and activities are more strategically designed with respect to time and impact.

*Promoting an inclusive culture:* All three organizations are committed to an inclusive culture, both for participants in the outreach activities and for the graduate students, staff, and faculty involved.

Outreach activities typically are targeted at populations underrepresented in engineering, including students who are female, from an underrepresented minority or ethnicity, from low-income families, have a disability, or who would be the first in their family to go to a four-year university or graduate school. Examples of inclusive actions include partnering with schools where many students come from low-socioeconomic backgrounds and a one-week sustainable engineering academy designed for girls entering grades seven to nine.

Outreach activities are an opportunity for students to see role models with similar backgrounds to their own, and to envision themselves in similar roles. For example, in California, where approximately 50% of elementary students are Hispanic or Latino, it is important that some of our participating graduate students are Hispanic or Latino. The diverse group of geotechnical graduate students allows students to find someone who shares some characteristics with them. Currently 75% of UC Davis CBBG graduate students are female and 25% are Hispanic or Latino. The US averages for civil engineering graduate students are 24% and 12%, respectively (National Science Foundation 2017). Additionally, some of our outreach activities highlight the impact of less-known female civil engineers (e.g., Emily Roebling) to provide historical role models.

Recognizing and valuing the different areas of expertise needed for effective outreach, graduate students receive mentoring from each other, faculty, and secondary teachers in how to integrate the culture of inclusion into their educational modules. Examples of inclusive designs include designing flexible lesson components or challenges that can be increased or decreased in complexity and incorporating best practices for inclusive teaching in both the design and implementation of the module.

*Encouraging consistent assessment:* As with research experiments, assessment and evaluation are necessary to understand the results and make improvements. Assessment data has been collected from outreach participants through observations, surveys, and engineering assignments. For example, some of the modules ask participants to answer questions before and after the activity to determine if the learning outcomes are reached. In addition to these methods, assessment of secondary teacher feedback was collected through discussions on specific modules and on overcoming barriers to productive collaborations between the university and secondary schools. Graduate students are assessed in the engineering education course through reflection assignments and the process they use to design their educational module.

Through the assessment process there have been numerous lessons learned. Evaluation based on assessment data from the Sustainable Engineering Academy for Girls led to a modified recruitment plan, increasing the ages targeted, changing the duration from four to five days, adjusting the target number of participants to 15, and modifying educational modules for future implementations. The increased target age group was observed to be appropriate as students had the fundamental math skills desired for some activities (e.g., a Life Cycle Assessment activity). The older students also had a larger attention span and were all highly interested in science.

The recruitment strategy, based on conversations with middle school teachers, was modified in 2017 to have teachers nominate students for participation. Students came from five different schools and three different grades. Students were more racially and ethnically diverse than in 2016; 33.3% of students in the 2017 cohort were from underrepresented minorities and two of the students had disabilities.

As graduate students work with faculty in the assessment phase, they are mentored in the iterative process that is required when designing instructional activities. Graduate students also learn of the great impact of non-technical factors on the success of educational activities (e.g., the length of student's attention span, emotional needs of students, and preparing for sometimes random remarks/questions from students).

*Building networks that expand beyond the borders of the institution:* Through CBBG partner institutions, best practices and lessons learned are exchanged with respect to outreach design and implementation. That network also allows for an expanded library of educational modules.

While the CGM already had a network of secondary teachers, the revised outreach program has expanded the network and provided the teachers agency. They now are mentors and mentees in the overall LMM of the geotechnical group. By providing interactions during the academic year, hopefully these relationships will be strengthened and sustained. One mechanism for maintain relationships with secondary teachers is through the development of K to 12 educational modules.

### 5.4 *Development of Educational Modules*

A two-course sequence in *Engineering Education Design* was designed for graduate engineering students to offer guidance in intentional engineering educational design. The first course introduces students to engineering education topics (e.g., student learning outcomes (SLOs) and assessment, types of learning and communication styles, active learning strategies, project-based learning, and creating inclusive environments).

In the second course, students design educational outreach modules related to their research that target specific age groups, align SLOs with state or national education standards, and include SLO assessment strategies. After developing a draft of their modules, students pilot their designs for a sample target audience. In the past, pilot events have included a public outreach event and a one-week engineering academy for secondary school girls. The course has been offered twice, with plans to offer it annually.

It is necessary that students designing educational modules for elementary and secondary school levels receive feedback from teachers at these levels, as they are most knowledgeable on what would work and what is most important to cover in their classrooms. To provide this input, secondary school teachers participated in a one-week summer workshop in 2016 and 2017.

The workshop format included one to two graduate students teaching their educational modules each day followed by discussion on those modules. Other workshop activities introduced participants to the topics of engineering, civil engineering, geotechnical engineering, sustainability, and underrepresented groups in engineering (especially women). At the end of each day, facilitated discussions with teachers led to: 1) developing strategies for integrating workshop activities and content into lesson plans, 2) strategizing methods for involving underrepresented groups in outreach activities, 3) identifying potential partnerships between UC Davis and local schools, and 4) obtaining feedback for graduate students on the modules they presented.

The workshops achieved three main outcomes: 1) graduate students increased teachers' confidence to teach engineering in their classrooms, 2) teachers provided practical feedback on the modules designed by the graduate students, and 3) partnerships between teachers and the geotechnical group were nurtured. After incorporating feedback from teachers, graduate students revised their modules for future implementations.

Current modules are in the iterative revision and testing phase familiar to most engineers. Although some students have graduated, the modules remain part of the GGSS/CBBG/CGM library of activities. When the final educational modules are complete, they will be submitted to TeachEngineering (https://www.teachengineering.org/), a web-based digital library of standards-based engineering K to 12 curricula.

After evaluating activities from the past two years, an adjustment has been made to encourage more continuous interactions with secondary teachers (e.g., student visits to UC Davis, teachers attending some of the classes in the improved graduate student course, visits to science classes in the teachers' schools, teachers providing direct feedback on modules during the graduate course). One improvement implemented is a Google Form created in which teachers can submit requests for borrowing outreach equipment, touring UC Davis facilities including the CGM, and having undergraduate and graduate students visit their classrooms. There have also been improvements to assessing outreach activities and their impacts. For example, an online outreach form that the GGSS outreach coordinator fills out after each event maintains a record of all information needed for reporting to NSF and observations about the activity's implementation (e.g., features that could be improved).

## 6 SUMMARY AND FUTURE WORK

The Ladder Mentoring Model presented herein has provided a formal structuring of mentoring and outreach activities toward producing researchers with the technical expertise, networks of collaborators, ability to communicate to all audiences, and other professional skills that can help them achieve their career goals. While the specific mechanisms vary, the three different programs described herein address the six core principles of our LMM (Table 8).

Table 8: Summary of LLM Core Principles integration into the UC Davis geotechnical program

| *Principle* | *Implementation in UC Davis Geotechnical Group* |
|---|---|
| Providing a sustainable structure with clear expectations | Each program has multiple structures that provide clear roles or expectations |
| Tailoring mentoring to needs of the individual | Flexible options for participation depending on interests and needs of individuals |
| Leveraging resources generously | Financial, time, space, and expertise resources are leveraged |
| Promoting an inclusive culture | Common focus on increasing access to broaden participation |
| Encouraging consistent assessment | Assessment occurs in all activities and is increasing in rigor with time |
| Building networks that expand beyond the borders of the institution | Partners include other academic institutions and personnel, industry partners, secondary education teachers, etc. |

The results in Table 8 are an initial effort to characterize the LMM at UC Davis. However, CGM and CBBG researchers continue to investigate impacts and perceptions of the LMM through surveys and interviews of current and past geotechnical engineering graduate students. The goal of these studies is to evaluate how and why the LMM model has been successful at UC Davis. Factors under investigation include quantifying mentoring interactions, understanding graduate student participation in program activities, and student perception of mentoring activities.

Future work will include piloting the LMM framework beyond UC Davis. GGSS alumni are now in faculty positions at other universities and we are making plans with them to pilot programs featuring the core principles at their institutions.

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