# AC 2011-811: GRADUATE STUDENTS MENTORING UNDERGRADUATE RESEARCHERS ON A LARGE-SCALE EXPERIMENTAL RESEARCH PROJECT - A CASE STUDY

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# Graduate Students Mentoring Undergraduate Researchers on a Large-Scale Experimental Research Project - A Case Study

## Abstract

The paper describes our strategies and experiences in recruiting, training, advising, and mentoring five undergraduate student researchers for a large-scale experimental research project. Specific discussions focus on the development of student learning outcomes and the establishment of a recruiting program. For this project, graduate student leaders served as the primary mentors to the undergraduate researchers. In the paper, we discuss how the graduate students prepared for their roles as research mentors. The principal investigators worked with the graduate student leaders to provide advice and training on topics such as teamwork, project management, communication, feedback, and student learning. Details of this approach are described in the paper. The paper also includes a discussion of the methods used to assess the undergraduate students' project experiences. Examples are provided of different work products prepared by the undergraduates. Also provided are the results of a post-employment assessment survey, which was developed by the graduate student leaders and a principal investigator. The survey results indicate that the undergraduate student research experiences have been challenging and rewarding. The survey results also provide valuable feedback for the graduate student leaders. At the mid-point of the project, the graduate students are using the feedback to develop specific recommendations for managing the research project and mentoring undergraduates in the future. The recommendations are summarized in the paper.

## Introduction

During the past two years, five civil and architectural engineering students have worked as undergraduate student researchers on project sponsored by the National Science Foundation (NSF). The research investigation is ongoing and focuses on centrifuge modeling of soil-foundation-structure interaction during earthquakes. Due to the scope of the project, graduate students are serving as the primary mentors to the undergraduates as they complete their research appointments.

In this paper, we describe our strategies and experiences in recruiting, training, advising, and mentoring undergraduate student researchers for this laboratory-based research project. We also discuss the methods used to prepare the graduate students for their roles as research mentors. As part of this project, the principal investigators worked with the graduate students to provide advice and training on topics such as teamwork, project management, communication, feedback, and student learning, which has helped to foster effective mentor-mentee relationships.

We conclude the paper by discussing different ways in which we assessed the undergraduate students' project experiences. We provide examples of different work products prepared by the undergraduates and present the results of post-employment assessment surveys, which were developed by graduate student leaders and a principal investigator. The assessment results are discussed in the paper, along with recommendations for continued mentoring of undergraduate students associated with this ongoing project.

## Background

The subject research project, titled "NEESR-SG: Seismic Performance Assessment in Dense Urban Environments," represents a collaboration between six universities and organizations, including the University of California, Berkeley (lead institution), the University of California, San Diego, the University of California, Davis, the University at Buffalo, the Consortium of Universities for Research in Earthquake Engineering (CUREE) , and California Polytechnic State University (Cal Poly), San Luis Obispo, a predominantly undergraduate institution. The research team supporting this project is relatively large and includes six investigators, a post-doctoral researcher, six graduate students (to date), and five equipment technicians on staff at the Network for Earthquake Engineering Simulation (NEES) equipment site at the University of California, Davis. These personnel, along with the undergraduate research assistants from Cal Poly, have been working on this project for over two years. The project ends in September 2012.

The research involves the use of both centrifuge experiments and analytical modeling to investigate soil-foundation-structure interaction effects occurring in dense urban areas during earthquakes. In support of this project, undergraduate students have participated primarily in the centrifuge modeling aspect of the research. Six centrifuge experiments are planned for this project, with three completed to date. As research assistants, the undergraduates' primary tasks include calibrating and placing model instrumentation, constructing the models, helping to conduct the centrifuge tests, documenting experimental activities, and reducing and analyzing test results. Overall, the project brings together many different facets of geotechnical, structural, and earthquake engineering, including foundation design, structural dynamics, ground motion selection and processing, and site response analysis. The advanced nature of the research requires the undergraduates to be at the junior-level (at least) in their degree program.

The undergraduate student research appointments have lasted from eight to ten weeks. Work has taken place at Davis, which has required the students to travel and secure temporary housing. Four of the five undergraduates participating on this project completed their work during the summer. One student completed his work in fall, which allowed him to extend a separate Cal Poly summer research appointment from three to six months.

The project is well suited for undergraduate students as the learning experience involves hands-on laboratory work, which is often appealing to students seeking to apply learned engineering skills. Also, the centrifuge represents a complex and powerful research tool that elicits "wows" from undergraduates unaccustomed to the equipment typically available at large research-oriented (i.e., R1) institutions. Students recruited for this project have been genuinely excited about participating. They have also been eager to work on a diverse research team that includes several graduate students. Although Cal Poly offers seminars and workshops to describe graduate school to its undergraduates, the opportunity to work directly with a team of graduate student mentors provides a more worthwhile and educational experience.

## Learning Outcomes

For this project, we recognized that an undergraduate student research appointment represented an opportunity to provide a structured learning experience. As such, the principal investigators worked with the graduate student mentors to articulate a list of important learning outcomes. Specifying what the undergraduates were expected to learn as a result of this experience helped the team define the work assignments and develop an assessment plan. This upfront work also helped the graduate students to better understand their roles as mentors.

The principal learning outcomes for the undergraduate researchers fit into three broad categories:

- Conduct and document a research experiment;
- Function effectively on a multi-disciplinary research team; and
- Summarize both the technical and experiential aspects of the research experience.

These learning outcomes are summarized in Table 1 along with performance metrics and learning opportunities. We defined performance metrics as specific skills or abilities that we expected our students to demonstrate by the end of the research appointment. Learning opportunities represented tasks or activities completed by the undergraduate students, which helped them to achieve the learning outcomes. These tasks and activities also provided opportunities for the research team to assess the performance of the undergraduate students and graduate student mentors. Each of the undergraduate students participating on this project completed many, if not all, of the tasks and activities listed in Table 1.

## Recruiting Program

### *Minimum Qualifications*

Prior to recruiting undergraduate student researchers for this project, the principal investigators and graduate student mentors identified the essential attributes of potential candidates. These attributes, or minimum qualifications, included: at least junior-level knowledge and experience in geotechnical engineering and/or structural design; laboratory work experience gained through school or summer employment (or both); above average academic performance; strong communication skills; team experience; and comfort with travel and temporary relocation during the duration of the appointment. With these minimum qualifications in mind, we then developed a plan for marketing the research positions and evaluating candidates.

### *Application and Evaluation Processes*

In our announcements of the available undergraduate research positions, we instructed potential candidates to first e-mail a letter of interest requesting an application. We required this first step for three reasons: (1) we wanted to assess the students' written communication skills and professionalism; (2) we wanted to impress upon the students the formal nature of the solicitation; and (3) we wanted to assess, in real time, the effectiveness of our marketing efforts. Once a student submitted his/her letter of interest, we then e-mailed an application. The application included questions for name, major, class level, overall grade point average, and applicable course work (course number, name, and grade). We also asked the students to submit a current resume and to prepare a 300-word statement describing why he/she was interested in the position. In this statement, students were encouraged to discuss future goals and/or similar past project experiences, as they related to the research opportunity.

**Table 1 - Undergraduate Student Learning Outcomes, Performance Metrics, and Learning Opportunities**

| Learning Outcomes | Performance Metrics - Demonstrate the ability to… | Learning Opportunities |
|---|---|---|
| Conduct and document a research experiment | Calibrate, install, and troubleshoot instrumentation<br>Construct soil and structural models for the centrifuge<br>Collect and analyze experimental test data<br>Document and report experimental test results | Photograph experimental activities; prepare design drawings; design or modify test equipment; work in the machine shop; work in the centrifuge; work in the control room; prepare charts and graphs; prepare and analyze test videos |
| Function effectively on a multi-disciplinary research team | Behave in a professional and respectful manner<br>Accept and analyze feedback on work performance<br>Articulate critical path issues associated with the centrifuge test<br>Evaluate different communication styles<br>Apply active listening techniques | Participate in team meetings and conference calls; manage project sub-tasks and design work with help from technical staff; complete a communications style survey; maintain open communication with the graduate student mentors; participate in after work social activities |
| Summarize both the technical and experiential aspects of the research experience | List the primary objectives of the research project<br>Describe the principal findings of the research project<br>List the attributes of a successful graduate student<br>Describe a typical work day for a graduate student<br>Write an effective technical paper or report<br>Compose and deliver an effective oral presentation | Complete pre-assignment "homework" problems; ask questions; speak to student groups at home institution; assist with recruiting of future research team members; co-author technical papers; co-author project summary reports; prepare research posters for conferences or workshops; prepare design drawings; prepare purpose statements for graduate school applications |

We developed a scoring rubric to assess the student applications. As shown in Table 2, the scoring system equally weighted grade point average, work experience, applicable coursework, written communication skills, and leadership. We ranked the applicants according to their final aggregate score, and we used this ranking as a basis for inviting students to in-person, one-on-one interviews. We assessed a student's performance during the interview in a more general manner. The interview questions allowed the applicants to elaborate more on their goals for the future, laboratory experiences, and past experience. During the interviews, we specifically noted the students' strengths (and weaknesses) in relation to oral and interpersonal communication skills. We made offers to the highest ranked candidate(s) based on our final assessments.

**Table 2 - Scoring Rubric for Assessing Student Applications**

| Scoring Category | Scoring (0 to 3 points ) and Qualifying Characteristics | | | |
|---|---|---|---|---|
| | 0 pt | 1 pt | 2 pt | 3 pt |
| Grade Point Average (GPA) | < 2.50 | 2.50 to 2.99 | 3.0 to 3.49 | 3.50 to 4.0 |
| Work and Laboratory Experience | No applicable work or laboratory experience. | Worked up to one summer (3 months) on an engineering-related assignment | Worked 3 to 6 months on engineering- and laboratory-related assignments. | Worked 6 or more months on engineering- and laboratory-related assignments. |
| Applicable Coursework | Enrolled in sophomore-level engineering classes (or below). | Enrolled in junior-level geotechnical and/or structural design courses. | Completed junior-level geotechnical and/or structural design courses. | Completed advanced electives in geotechnics and/or structures. |
| Written Communication Skills (Statement, Resume, and E-mails) | Goals not articulated in the interest statement. Submittals are laden with grammatical errors and formatting inconsistencies. E-mails and resume are not professionally prepared. | Goals not clearly articulated in interest statement. Writings include examples of spelling, punctuation, and sentence structure errors. Resume missing some important elements. | Goals mentioned in interest statement with some support. Writings proofed with few spelling, punctuation, and sentence structure errors. Resume prepared well, but could be more persuasive. | Goals clearly articulated in interest statement and well supported. Writings professional and well proofed with no errors. Resume is very well organized and persuasive. |
| Leadership Experience | No mention of professional organizations, social clubs, or project teams. | Member of local professional organizations, social clubs, or project teams. | Leadership position held for an organization or project team related to major. | Multiple leadership positions held for different activities related to major |

*Marketing Approaches*

We believed it was important to vary our marketing approach when recruiting students for this project so that we could reach the largest audience possible. Particular effort was exerted to recruit underrepresented and underserved undergraduate students. Given the busy nature of everyone's schedules, the goal in marketing the positions was to limit the effort while maximizing the impact. To achieve this goal, we tried several different marketing approaches:

- Short 5- to 10-minute presentations (by a principal investigator) during student chapter meetings of the American Society of Civil Engineers (ASCE), Society of Women Engineers (SWE), and Society of Hispanic Professional Engineers (SHPE);
- Website job postings and e-mail announcements through these same student professional organizations;
- Short 1- to 2-minute announcements (by a principal investigator) in geotechnical, structural, foundation, and earthquake engineering courses;
- Mass e-mail announcements to junior- and senior-level students enrolled in civil, architectural, and mechanical engineering degree programs; and
- Technical presentations and testimonials (by past undergraduate student participants) in courses and during ASCE student chapter meetings.

In developing presentations, announcements, and e-mails, every effort was made to keep the message positive. Photographs of undergraduates working on the project (and their testimonials) were used whenever possible. The marketing messages clearly articulated potential benefits to the students and the learning outcomes associated with the appointment.

During our most recent recruitment (for the third centrifuge experiment), we solicited over sixty letters of interest. Eventually, thirty-two students submitted applications and interview requests. Six of these students were interviewed for the project, and two were eventually hired. In examining these results (and the qualifications of those students eventually hired), we felt that we achieved our recruiting goal, realizing great benefit with minimal cost. We plan to use similar approaches when recruiting undergraduates during the second half of this project.

## Mentoring Strategies

*Undergraduates*

The members of the research team agreed on a list of key objectives when devising the strategy for mentoring the undergraduate students. These objectives included the following:

- Prepare the undergraduates to be successful team contributors;
- Assign varied tasks;
- Encourage questions;
- Provide regular feedback; and
- Reduce distractions and stress.

These objectives are summarized in Table 3 along with the approaches used to meet these objectives and enhance the undergraduate students' research experience.

**Table 3 - Key Objectives of the Undergraduate Student Mentoring Strategy**

| Objective | Approach |
| --- | --- |
| Prepare the undergraduates to be successful team contributors | Assign readings and problem sets prior to the undergraduates traveling to Davis. Provide feedback on solutions to problems sets and answer questions. Articulate Learning Outcomes for the assignment and introduce the undergraduates to the other members of the research team. Emphasize the importance of open communication and provide tips on best practices. |
| Assign varied tasks | Prepare a "technical rotation" for the undergraduates to follow while working at the centrifuge facility to help ensure a more varied and interesting experience. Identify the undergraduates' strengths and areas in which they may need to improve. Address the Performance Metrics outlined under Learning Outcomes. |
| Encourage questions | Maintain a low-threat atmosphere. Maintain open communication. Understand that individuals have different personalities and different ways in which they communicate. Treat the work assignment as a learning experience for the undergraduates and frequently ask them questions. |
| Provide regular feedback | Use varied means of communication (phone, e-mail, text messaging) to maintain regular contact with undergraduates. Involve the undergraduates in team meetings and conference calls. Train team members on giving and accepting feedback. Clearly define the student-mentor relationship. |
| Reduce distractions and stress | Limit the undergraduates' administrative responsibilities (related to payroll paperwork, travel paperwork, lodging arrangements, etc.). Provide the undergraduates with a living space that includes a kitchen and other important amenities. Invite the undergraduates to after work social activities. Allow for at least one mini- vacation during the work assignment. |

*Graduate Students*

The members of the research team agreed on a list of key objectives when devising the strategy for mentoring the graduate students. In "mentoring the mentors," the principal investigators wanted to prepare the graduate students for success as they undertook the task of working with the undergraduates. The mentoring objectives included the following:

- Articulate learning outcomes;
- Provide teacher training;
- Provide leadership training;
- Trust them; and
- Provide regular feedback.

These objectives are summarized in Table 4 along with the approaches used to meet these objectives and enhance the graduate students' mentoring experience.

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**Table 4 - Key Objectives of the Graduate Student Mentoring Strategy**

| Objective | Approach |
|---|---|
| Articulate learning outcomes | Encourage graduate student participation in the development (and refinement) of the Learning Outcomes. Provide the graduate students with the Learning Outcomes and remind the students of their importance. Involve the graduate students in the assessment of project outcomes and student performance. |
| Provide teacher training | Provide the graduate students with reading materials and presentations related to effective teaching methods. Provide specific training and tips on developing learning objectives, employing different questioning techniques, understanding learning styles, and developing interpersonal rapport. |
| Provide leadership training | Provide the graduate students with reading materials and presentations related to project management and leadership. Provide specific training and tips on interpersonal communication, communication styles, effective meetings, providing (and receiving) feedback, and teamwork. |
| Trust them | Maintain open communication. Encourage the graduate students to take ownership of the mentoring program. Solicit regular feedback on the performance of the team members, in relation to mentoring. Understand that failures, although not desired, can serve as learning opportunities. |
| Provide regular feedback | Ensure that the principal investigators are available and open to questions. Use varied means of communication. Hold regular meetings with the graduate students to discuss mentor-related issues. Train team members on giving and accepting feedback. Clearly define the student-mentor relationship. |

*Teacher and Leadership Training*

An important part of the strategy to mentor the graduate students was to provide them with the training and tools to successfully educate and lead the undergraduate researchers. The research team accomplished this goal, in part, by having one of the principal investigators available to meet with the graduate students on these issues and answer questions. Moreover, the graduate students were provided with reading materials and guides on leadership and teaching.

The research team found several references to be valuable in providing straightforward guidance on project management and leadership.[1,2,3,4] The graduate students were provided copies of these texts (and associated notes) and were encouraged to read specific sections on project management, interpersonal communication, active listening, giving and accepting feedback, organizing and running effective meetings, and negotiation. The graduate students were then encouraged to conduct their own research and seek out additional references on these and related topics. There are countless project management and leadership texts and training guides available in the literature, including many valuable electronic resources.

The research team took a similar approach in providing teacher training for the graduate student mentors. The graduate students were provided with references on teaching best-practices. These references taught the graduate students how to develop learning objectives, employ different questioning techniques, understand different learning styles, and develop interpersonal rapport.[3] As with project management and leadership, there are many teaching references available in the literature, which are not listed herein.

Early in the project, the research team recognized that encouraging effective communication between the undergraduates and graduate student mentors would be key to the success of the project and the achievement of the Learning Outcomes; therefore, this topic was emphasized in the graduate student training. One way to become a better communicator and team member is to understand that people have distinct, preferred, and predictable ways of communicating. Personality assessment exercises, such as the well-known Myers-Briggs method, can help team members to understand one another and improve communication. Similar methods exist whereby the individuals assess their own "communication styles," which are based primarily on the degree to which the individual is assertive and outgoing.[4,5]

Farley and Donaldson[5] identify four predominant communication styles with the following names: "medic" (amiable, harmony seeker), "cheerleader" (expressive, excitement seeker), "computer" (analytical, detail seeker), and "steamroller" (driver, results seeker). Each style has different strengths and blind spots, but no style is considered better than another. A person's predominant style is determined by completing a self-assessment survey, which takes about fifteen minutes. The chart on Figure 1 lists the important characteristics of the four possible communication styles.

We encouraged our team members to complete the self-assessment survey and determine their preferred communication style. We then provided this information to the research team. Most of the team members were found to have preferred a communication style corresponding to that of a "computer." The graduate student mentors were then given training to help them better understand that people have predictable and preferred patterns of behaving and communicating. The mentors were given advice and practice exercises on how to communicate with persons having communication styles that are different from their own.

**High Responsiveness / Very Outgoing**

| Low Assertiveness / Less Forceful | | High Assertiveness / Very Forceful |
|---|---|---|
| **MEDIC (AMIABLE)** | **CHEERLEADER (EXPRESSIVE)** | |
| Slow at taking action and making decisions | Spontaneous actions and decisions | |
| Likes close, personal relationships | Likes involvement | |
| Dislikes interpersonal conflict | Dislikes being alone | |
| Supports and "actively" listens to others | Exaggerates and generalizes | |
| Works to develop self-direction | Jumps from one activity to another | |
| Works slowly and cohesively with others | Works quickly and excitingly with others | |
| Seeks security and belongingness | Seeks esteem and belongingness | |
| Easily gains support from others | Tends to dream and inspire others | |
| Good counseling skills | Good persuasive skills | |
| **COMPUTER (ANALYTICAL)** | **STEAMROLLER (DRIVER)** | |
| Thorough actions and decisions | Firm actions and decisions | |
| Likes organization and structure | Likes control | |
| Dislikes over-involvement with others | Dislikes inaction | |
| Asks many questions and wants specific details | Low tolerance for feelings, attitudes, or advice | |
| Prefers objective, task-oriented activities | Prefers maximum freedom | |
| Likes an intellectual work environment | Strong manager of self and others | |
| Wants to be right | Cool and independent | |
| Relies on data collection | Competitive with others | |
| Works slowly, precisely alone | Works quickly and impressively alone | |
| Seeks security and self-actualization | Seeks esteem and self-actualization | |
| Good problem-solving skills | Good administrative skills | |

**Low Responsiveness / Not Very Outgoing**

**Figure 1 - Characteristics of Farley and Donaldson's four communication styles (adapted from Hunsaker and Alessandra[4])**

**Program Participants**

The research team has completed three of six planned centrifuge experiments, to date. For these tests, the team recruited five undergraduate student researchers from Cal Poly. This group of undergraduates included two women, four civil engineering majors, one architectural engineering major, two students interested in geotechnical engineering, two students interested in structural engineering, and one student interested in all areas of civil engineering.

Summarized in Table 5 are the qualifications of these students. Qualifications are defined in terms of class level (or academic background prior to beginning the assignment), overall grade point average, work and laboratory experience, applicable coursework, writing skills, and leadership experience. We previously defined assessment scores for these categories in Table 2. Please note that we list the undergraduate students anonymously and in random order in Table 5.

**Table 5 - Qualifications and Assessment Scores for the Undergraduate Participants**

| Student ID | Class Level | Grade Point Average (GPA) | Work and Laboratory Experience | Applicable Coursework | Writing Skills | Leadership Experience |
|---|---|---|---|---|---|---|
| Student1 | JR | 3 pt | 2 pt | 2 pt | 2 pt | 3 pt |
| Student2 | SR | 2 pt | 1 pt | 3 pt | 2 pt | 2 pt |
| Student3 | SR | 2 pt | 2 pt | 3 pt | 2 pt | 3 pt |
| Student4 | JR | 2 pt | 1 pt | 2 pt | 3 pt | 2 pt |
| Student5 | SR | 2 pt | 3 pt | 3 pt | 3 pt | 3 pt |

Summarized in Table 6 are short-term career goals for the five undergraduate students, as understood before and after the completion of the research appointment. The students' short-term career goals are presented in a different order from the data presented in Table 5. We shuffled the presentation order to preserve the anonymity of the student participants.

**Table 6 - Short-Term Career Goals for the Undergraduate Student Participants**

| Short-Term Career Goals (before the research appointment) | Short-Term Career Goals (after completing the research appointment) |
|---|---|
| Private consulting or graduate school (M.S.) | Graduate school (M.S.) |
| Private consulting | Graduate school (M.S.) |
| Private consulting | Private consulting or graduate school (M.S.) |
| Private consulting | Private consulting |
| Public works or graduate school (M.S.) | Graduate school (Ph.D.) |

During the first three centrifuge tests of this project, we varied (slightly) the research experiences for the undergraduates. To a limited extent, we experimented with our approach to mentoring the undergraduates to assess which methods worked (and did not work). For example, three of the five of the undergraduates were assigned reading materials and problem sets on geotechnical, structural, and earthquake engineering concepts prior to beginning their work at Davis. Three of the five undergraduates were given the opportunity to work extensively with the centrifuge test data and results. Two of the five undergraduates continued to work at the centrifuge facility for over a week after the test was concluded, helping with report preparation and data analyses. In addition, for one of the centrifuge tests, we recruited two undergraduates to work together as research assistants.

**Assessment**

*Student Qualifications*

The data summarized in Table 5 illustrate that the research team was successful in recruiting highly qualified undergraduate participants, which reflects well on the recruitment program established for this project. All of the undergraduates had grade point averages greater than 3.1 prior to beginning their research assignments. The current average grade point average for senior-level undergraduate students in the Cal Poly Civil Engineering Program is approximately 2.9. In addition, each of the undergraduate participants had completed at least one summer job in engineering and/or construction management prior to beginning their research work. Also, nearly all of the students demonstrated moderate to high levels of participation in co-curricular activities and leadership.

*Short-Term Career Goals*

Short-term career goals for the undergraduate participants are summarized Table 6. Prior to beginning their research assignments, the short-term career goals for two of the undergraduate participants included graduate school as a potential option (at the M.S. level). Graduate school (at the M.S. or Ph.D. level) is now a short-term goal for four of the undergraduate participants. At this time, four students have graduated from Cal Poly with their B.S. engineering degrees. Three students currently have graduate school applications under review at numerous research-oriented universities. One student is currently working for a private engineering firm and has decided to work for two to three years before considering graduate school. Expressing interest in attending graduate school was not considered a requirement for the undergraduate research position. We are pleased that the research experience seems to be generating more interest in graduate school as a short-term option in their careers.

*Student Work Products*

To effectively meet the ambitious work scope and schedule outlined in the original research proposal, it was necessary to bolster the "on-site" research team with undergraduate researchers. To date, undergraduate students have worked intently alongside the principal investigators and graduate students, and the project is currently on schedule. The fact that the research team has completed three centrifuge experiments (as proposed) and collected valuable research data is evidence of quality undergraduate student work. The undergraduates have proved to be productive team members, thanks to their exceptional qualifications, pre-assignment preparation provided by the investigators and graduate students, and on-site mentoring provided by the graduate students.

The centrifuge experiments are considered to be "products" of this research project. Additional undergraduate student tasks that led to specific work products included: design and fabrication of instruments used successfully during the centrifuge testing; preparation of two- and three-dimensional CAD drawings of the centrifuge models for interpreting and describing experimental test results; photo and video documentation of centrifuge test activities for describing test results; preparation of data reports and technical papers summarizing test procedures and results; and preparation of oral presentations for summarizing experimental results and recruiting research team members. To date, all undergraduates have served as co-authors on conference papers, and two undergraduates have presented research findings at a graduate student poster session held during a recent research conference. As part of a "media competition" held during this same conference, two of the undergraduates were awarded prizes for photos and CAD drawings depicting important aspects of the centrifuge testing.

*Exit Survey Results*

We recently surveyed all of the undergraduate participants with regard to their experiences on this project. Each student was surveyed after completion of their research appointment. Survey responses were kept anonymous, and the undergraduates were encouraged to comment freely on their experiences.

In the first part of the survey, the undergraduates answered fifteen poll questions by indicating the degree to which they agreed (or disagreed) with a given statement. The survey incorporated the following scale: 1=Strongly Disagree; 2=Disagree; 3=Neither Agree or Disagree; 4=Agree; and 5=Strongly Agree. Table 7 shows the fifteen statements and the average responses for the five participants. Overall, the majority of the responses to the poll questions were "agree" or "strongly agree." In only one case (Question #6) did a student respond with an answer of "disagree." For the statement “The research team members provided me with useful and constructive feedback regarding my performance,” a student disagreed and noted a specific instance where a communication breakdown that occurred between him/her and one of the research team members. No answers of "strongly disagree" were provided to any of the questions.

**Table 7 - Poll Questions Included on the Undergraduate Student Survey**

| | Statement | Average Score (out of 5) |
|---|---|---|
| **Instructions: Please read the following statements and indicate the degree to which you agree or disagree with them, using the following scale: 1=Strongly Disagree; 2=Disagree; 3=Neither Agree or Disagree; 4=Agree; and 5=Strongly Agree.** | | |
| 1 | "Coursework at Cal Poly prepared me for working on this research assignment." | 4.0 |
| 2 | "Co-curricular and project activities at Cal Poly prepared me for working on this research assignment." | 4.2 |
| 3 | "The research team (e.g. graduate students and investigators) prepared me for working on this research assignment." | 4.2 |
| 4 | "The research team members clearly communicated project goals, objectives, and strategies." | 4.4 |
| 5 | "The research team members clearly communicated tasks and assignments." | 4.4 |
| 6 | "The research team members provided me with useful and constructive feedback regarding my performance." | 4.0 |
| 7 | "There was a feeling of teamwork and cooperation on this project." | 4.8 |
| 8 | "The research team members treated me in a respectful and professional manner." | 4.8 |
| 9 | "The work environment at the Davis centrifuge facility is safe and well-maintained." | 4.8 |
| 10 | "Overall, work on this project represented a challenging experience." | 4.8 |
| 11 | "Overall, work on this project represented an enjoyable experience." | 4.8 |
| 12 | "Being given tasks at different project sites (i.e. UCD, UCSD) makes this research assignment more valuable and rewarding." | 4.4 |
| 13 | "Prior to this assignment, I was considering graduate school as an option after graduating from Cal Poly." | 4.6 |
| 14 | "Because of this assignment, I am more seriously considering graduate school as an option after graduating from Cal Poly." | 4.6 |
| 15 | "I would recommend this research assignment to a friend." | 4.6 |

In the second part of the survey, the undergraduates provided written answers to ten open-ended questions. These questions are listed in Table 8. We strongly encouraged the undergraduates to provide constructive feedback in response to these questions, and we provided them enough time (over a week) to formulate detailed answers. Listing all of the undergraduate students' written comments is beyond the scope of this paper. We were generally pleased with the level of detail in the undergraduate students' feedback. Select student responses are included below.

**Table 8 - Open-Ended Questions included on the Undergraduate Student Survey**

| | Question |
|---|---|
| **Instructions:** | **Please take some time to provide feedback on the following open-ended questions.** |
| 1 | With hindsight being 20:20, what changes would you have made to the centrifuge test you worked on in order to improve it? |
| 2 | Given your newfound centrifuge testing knowledge and experience, what would you change for future tests at the U.C. Davis facility to improve the experience for researchers and/or improve the quality of the research? |
| 3 | Do you feel you were adequately prepared for working on this research assignment? Please explain. |
| 4 | Required reading assignments prior to beginning work at the research facility? Problem sets and homework? Online training? An on-site orientation session prior to starting work? On-the-job-training? Please explain how you would prefer to be prepared for work on this research project. |
| 5 | What part(s) of this assignment were the most appealing/enjoyable? Please explain. |
| 6 | Were there parts of this assignment that were unappealing/aggravating? Please explain. |
| 7 | What (if anything) did you learn about yourself while working on this assignment? |
| 8 | What (if anything) did you learn about graduate research and/or graduate school by working on this assignment? Did this assignment influence your view of attending graduate school in the future? Please explain. |
| 9 | What suggestions would you give to future students in your position, prior to them starting their research assignments? |
| 10 | What aspects of this research assignment might be improved to provide a rewarding and enjoyable experience for future undergraduate researchers? |

The opportunity to work with state-of-the-art research equipment at a research-oriented institution was appealing to all of the students. Responses to open-ended Question #5 included:

> *"My favorite part of the assignment was constructing the models. I enjoyed helping with designing and machining the parts, from the flags to the instrumentation rack. Working with people who can joke around made the whole assignment even better; it helped ease any tension and stress."*

> *"The most enjoyable was building the model. I enjoyed my time in Davis constructing the model and my time in San Diego applying strain gages to the structures. Both sites gave me the opportunity to see graduate life at those universities."*

We were encouraged by the undergraduate student responses to open-ended Question #8, which focused specifically on graduate school. Sample responses included:

> *"I didn't have much of a clue about what graduate school was like before, so it's fair to say I learned everything. What kind of a commitment it is, what research can be like, what working in close conjunction with professors is like, etc. Before hand, graduate school was something I merely considered doing upon graduation; now it is my main focus."*

> *"I planned on attending grad school before this project, but my work here reaffirmed my plans. I had not previously been exposed to research, so seeing how experiments are conducted was very eye-opening. I was also blown away by the depth of knowledge possessed by both the graduate students and PIs. It presents a high target for me to aim for."*

> *"The students we worked with treated it as a full time job and took a lot of pride in their project. This was an aspect of the project that I did not expect. I also learned how much problem solving is involved in the daily life of a graduate student."*

Student responses to the open-ended questions aided us in the assessment of the different mentoring approaches. For example, the following responses contributed directly to recommendations described in the following section of this paper.

The following response was given for open-ended Question #3, which asked if the student felt adequately prepared for the research appointment:

> *"Yes and no. I felt like I understood the basis behind the centrifuge and its uses in regards to modeling soils. Additionally, my educational background had taught me the principles behind structural dynamics, but when it came to testing the model, I felt like I understood very little about the earthquake aspect of the project. More instruction about earthquakes and their properties would have been helpful prior to going to Davis."*

In addition, the following response was given for open-ended Question #4, which asked the student how he/she would prefer to be prepared for work on the project:

> *"I think focused reading assignments would have better prepared me for this project. I did a lot of reading on centrifuge testing which was helpful, but little on foundation and building dynamics, which turned out to be more critical. With such a large group it is easy for one or two people to "skate-by" with out fully understanding what was happening, but more reading and possibly some problem sets may have forced me to learn more about the research topics than the testing methods."*

As another example, the following response was given for open-ended Question #10, which asked the student to comment on ways in which the research experience could be improved:

> *"I would have liked to been more involved with the data for the test. I felt like I had spent two months working on preparing the model for the test, but I never had the opportunity to see what it meant. At the end of the test, we cleaned everything up, and I immediately went back to San Luis Obispo."*

Overall, the responses to the open-ended questions were positive and provided valuable suggestions for improvement. We were encouraged by the fact that the student responses tended to be even more positive for the most recent centrifuge experiment, which indicated improvement over time in our ability to lead and mentor undergraduate research assistants. We are currently using the survey results and student feedback to enhance and improve future experiences for our undergraduate researchers. Graduate student mentors will use this survey information as a guide during the remaining two years of this project. Specific recommendations concluded from the survey results are presented in the following section of this paper. Based on the value derived during this study, we encourage all investigators working with undergraduate and/or graduate student researchers to consider using their own post-employment surveys.

**Recommendations**

Based on feedback provided by the principal investigators, the graduate student mentors, and the undergraduate student researchers (from the surveys), we developed a list of recommendations for improving the undergraduate student research experience. The research team has already acted on some of these recommendations, which are reproduced for the benefit of the readership. The remaining recommendations will be implemented during the final two years of the project.

The recommendations are as follows:

- Involve the undergraduate student researchers in the project as early as possible. Assign readings to acquaint them with the project objectives and important earthquake engineering principles. Assign problem-solving exercises that help them to be productive team members when on site. Provide copies of data reports, conference papers, and photo logs from previous centrifuge tests to acquaint them with project specifics.

- Survey the undergraduate student assistants on their engineering abilities and interests (strengths and weaknesses) prior to them beginning work. Use the results of these surveys to customize the research experience for each individual.
- Before the students begin working on the project, clearly define the work conditions at the research facility, identify and introduce the research team members, describe the project management structure, and define expectations regarding work performance.
- Provide regular feedback (positive and corrective) on student work performance. Provide advice on giving and receiving feedback to all team members.
- Schedule a work week after every test where the graduate and undergraduate student researchers remain at the research site to reflect on the project. The objectives of this work week are to write the data report, upload the data to the project server and website, and wrap up other loose ends. As part of this process, the undergraduate students should learn the skills necessary for reducing and interpreting the test data.
- When possible, seek opportunities for undergraduates to work together on a centrifuge test. Each student brings with him/her a valuable and unique skill set. Having more undergraduates adds to the research team's expertise. In addition, undergraduate student pairs have the opportunity to mentor one another and are less likely to be intimidated in the new work environment.

**Conclusions**

Our experiences show that undergraduate student researchers can serve as productive team members on a large-scale experimental research project. These students can also provide valuable insight to important research questions and be trusted with complex tasks. However, there must a commitment by the entire research team (including investigators, graduate students, and technicians) to prepare these undergraduate students for their appointments. We summarized specific strategies for recruiting, training, and mentoring the undergraduate researchers. We believe these strategies prepared the students for successful completion of their work assignments and broadened their perspectives of experimental research and graduate education.

We also provided training for graduate students who served as mentors for the undergraduates. Providing structured mentoring opportunities for the graduate students helped them to develop important communication, project management, leadership, and teaching skills. These opportunities also prepared the graduate students for work in university positions where quality teaching, proactive advising, and careful research are so important. We recommend that investigators advising student researchers (especially undergraduates) consider implementing their own mentoring programs, given the benefits outlined in this paper.

In developing any mentoring program, communication is key. This was especially the case on this project, which included a research team of six investigators, a post-doctoral researcher, six graduate students (to date), and five equipment technicians. Introducing the team members to exercises and/or activities related to effective interpersonal communication will help prepare the student researchers for success during their appointments.

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