AC 2012-3783: STUDENT LEARNING OUTCOMES FROM AN ENVIRONMENTAL ENGINEERING SUMMER RESEARCH PROGRAM

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Student Learning Outcomes from an Environmental Engineering Summer Research Program

Abstract

Intensive summer research programs have the opportunity to help students achieve a wide variety of learning outcomes, while also deepening their interest in graduate school and increasing their overall confidence. This research explored the learning outcomes from an NSF-funded Research Experience for Undergraduates (REU) site in environmental engineering at the University of Colorado Boulder. The ten-week REU site included lab, field, and modeling projects on the quality and treatment of water, soil, and air. The REU site successfully attracted an over-representation of female and minority participants. Among the 2011 students there was a statistically significant gain in the likelihood that the students would pursue an MS degree based on pre- and post- survey ratings. Students' self-ratings of knowledge and skills related to ABET outcomes and other topics showed significant improvement in 22 of 26 areas, based on Likert-scale responses on pre- and post- surveys. The self-rated confidence in personal ability to execute various tasks did not show significant gains on the post survey for 12 of 13 items. For post-survey items that asked about gains due to the program, some items showed statistically significant differences in responses based on race/ethnicity, previous research experience, year (freshman/sophomores vs. juniors/seniors), and major. The data indicated that students from all demographics could benefit from the research experience. Mentoring varied widely between individual students, projects, and years which appeared to have significant impacts on the students' responses. The paper concludes with recommendations for other REU sites to consider.

Background

Intensive summer research programs for undergraduate students have a long history. The National Science Foundation (NSF) endorses such programs via the Research Experiences for Undergraduates (REU) site grants, which began in 1987.[1] Prior to the REU program the NSF funded Undergraduate Research Participation (URP) grants from 1958 to 1979.[1] Most of the students who participated in the URP program worked on research at their home institution for a full calendar year in their junior or senior year.[1] The REU program changed the URP model in order to encourage student participants from outside the awarded institution and target students typically under-represented in science and engineering (i.e. females and minorities).[1] This paper will focus on REU sites rather than supplements to individual NSF grants.

The NSF's REU program as a whole is very diverse. The NSF funds REU sites in all 50 states across science, engineering, and math disciplines.[2] An award search on the NSF website using the search terms "REU site" AND "environmental" AND "engineering" in active and expired awards yielded 125 results that matched these criteria.[3] These REU sites had start dates ranging from 1988 to 2011, represented 37 states, and crossed multiple NSF organizations, such as 62 grants from Engineering Education and Centers (EEC); 15 from the Division of Biological Infrastructure (DBI); 12 from the Division of Earth Sciences (EAR), 8 from the Division of Chemistry (CHE), and 3 from Chemical, Bioengineering, Environmental, and Transport Systems (CBET) in the Engineering Division. Some of the REU sites are partnerships between multiple institutions and include international components (i.e. Ghana, China, South Africa). Some examples of different environmental engineering REU site models are provided in Table 1; the list is not intended to be exhaustive but rather to provide examples. Most REU sites have a theme that is more specific than environmental engineering. Today most sites are awarded for a period of three years, a typical size is ten undergraduate participants per summer, and the site may be renewed upon a successful proposal if the proposal targets significantly different themes or other elements (i.e. Clarkson's REU via PIs Powers, Grimberg, Rogers, 1998 to present).

Table 1. Examples of REU sites focused on Environmental Engineering[3]

REU name	Location	PI	Start Year	# weeks	Website URL
REU Site: Nanotechnology for Health, Energy and the Environment	SUNY at Stony Brook	Halada	2011	10	www.stonybrook.edu/cie/For%20Departments/Application.pdf
REU Site: Advancing Sustainable Systems and Environmental Technologies to Serve Humanity (ASSETs to Serve Humanity)	Clarkson	Rogers	2011	10	www.clarkson.edu/reu/
REU Site: Assessment and Sustainable Management of Ecosystem Services	U of Arkansas	Matlock	2011	10	www.ecoreu.uark.edu/
REU Site: Tackling Some of the Grand Challenges of Engineering	Purdue	Hua	2010	10	engineering.purdue.edu/EEE/Research/REU
REU Site in Environmental Engineering	U of Colorado	Bielefeldt	2010	10	spot.colorado.edu/~bielefel/REU.html
REU Site: Tampa Interdisciplinary Environmental Research (TIER)	U South Florida	Trotz	2010	10	www.reu-tier.net/
Research Experience for Undergraduates in Sustainable Infrastructure Technology	U of Oklahoma	Strevett	2009	8	www.ou.edu/coe/cees/audience/undergrad_students/reu.html
Research Experiences in Pollution Prevention	Rowan U	Jahan	2001	7	www.rowan.edu/colleges/engineering/clinics/reu0406/

A stated goal of the REU program is to increase diversity in STEM.

> *"The REU program is a major contributor to the NSF goal of developing a diverse, internationally competitive, and globally-engaged science and engineering workforce. NSF is particularly interested in increasing the numbers of women, underrepresented minorities, and persons with disabilities in research. REU projects are strongly encouraged to involve students who are members of these groups."* [4]

However, it is difficult to find demographic information compiled across REU sites. Each PI is required to report the student participant demographics to the NSF in annual and final reports. In a 1990 report on the first three years of the then-new REU program, the NSF summarized these statistics.[1] On the ~450 site awards and supplements involving ~8,000 students [the supplement students were subtracted], the NSF reported that ~43% of the participants were female and 10% were underrepresented groups, although this percentage had increased from 7% in FY1987 to 13% in FY1989. An SRI study in 2003 among REU sites reported 53% female and 39% under-represented minority (URM) participants.[5] A more recent study focused only on grants from the Directorate for Biological Sciences (BIO).[6] Their study analyzed data from 2006 to 2009, with 62-64% female participants and 43-49% underrepresented minorities (which increased over time). These percentages were higher than the likely pool of biology students – of the 2006 bachelor's degree recipients, 59.8% were awarded to women[7] and 15% to URM[8]. More specific to environmental engineering, Grimberg et al.[9] reported that from 1998 to 2005 the REU Site Program in Environmental Science and Engineering participants were ~53% women and 10% URM.

Beyond the stated goal of the REU program to help attract and retain students in STEM, including careers in teaching and education research, these programs can help students achieve a wide variety of learning outcomes. Some of these learning outcomes clearly map to the ABET criterion C "A-K" outcomes; such as b "the ability to design and conduct experiments, and analyze and interpret data".[10] Other outcomes may also be achieved to varying degrees depending on the structure and activities associated with a particular REU site. For example, the Clarkson REU likely improved students' knowledge of sustainability[9], which is a desired outcome in both the Environmental Engineering Body of Knowledge[11] and the Civil Engineering Body of Knowledge[12].

Kardash[13] found that for 13 learning outcomes primarily related to research skills (i.e. design an experiment or theoretical test of the hypothesis; observe and collect data), students' self-ratings increased significantly for 12 outcomes. Students' self-ratings were compared to their faculty mentors' end-of-program ratings of the 14 outcomes; significantly higher student ratings were only found for three outcomes (understand the importance of controls in research, statistically analyze data, relate results to the "bigger picture" in your field).

Beyond knowledge and skills outcomes, Seymour et al.[14] reported that summer research programs could also lead to a variety of personal outcomes, such as increased self-esteem and self-confidence. There were also changes in attitudes toward learning and career aspirations among some students. Their study used student-interview methods using questions derived from an extensive review of 54 different studies of undergraduate research.

The goal of this study was to evaluate the student learning outcomes that resulted from an REU site focused on environmental engineering. These outcomes were evaluated using multiple methods. First, three types of self-evaluations by students were used: (1) ratings of knowledge on a Likert-scale using pre- and post- surveys and analyzing gains; (2) students' level of agreement with statements about learning gains that resulted from the REU program using a Likert-scale on the end-of-summer post survey; (3) students' open ended response to the question "What was the most valuable aspect of your summer REU experience for you?"

Student self-ratings were explored to determine if these ratings differed based on demographic variables such as gender, URM status, years of college completed, or major. The second method was to use direct evidence of students' knowledge based on their written research reports and oral presentation slides. These research artifacts were evaluated using rubrics. Third, a survey was conducted of faculty mentors of REU students. The outcomes from the second and third methods were compared to students' self-ratings in an attempt to verify their validity. An additional goal of this paper is to provide information on the site itself which may help others to develop and offer quality undergraduate research opportunities for students.

University of Colorado Boulder REU Site

This research explored the learning outcomes from an NSF-funded Research Experience for Undergraduates (REU) site in Environmental Engineering. The University of Colorado Boulder (CU) has had three similar sites funded, with Professor JoAnn Silverstein serving as the PI for the first 5-year site and Angela Bielefeldt serving as the PI for the next two 3-year sites. The ten-week REU site included a range of lab, field, and modeling projects that spanned topics on the quality and treatment of water, soil, or air. In around January of each year, the research projects available for students in the upcoming summer were posted to the REU website, along with application materials. Email announcements of the program were sent to colleagues and via list serves such as the Association of Environmental Engineering and Science Professors (AEESP) and the Environmental Engineering Division of the American Society for Engineering Education (ASEE). Students from a wide variety of disciplines were invited to apply.

The application required that students submit basic information (year in college, major, GPA, previous research experience, gender, race/ethnicity), formal transcripts, two letters of recommendation, and a statement describing their interest in the specific research projects available for the summer. Completed applications were logged into a spreadsheet. The project PI selected about four to ten top students interested in each research project, and forwarded these applicant files to the relevant faculty research mentor. The mentors each used different criteria to select preferred students (as will be described further below); for example, some mentors desired more seasoned researchers while others wanted to mentor more junior students. In some cases, the criteria would vary with project constraints, such as the availability of graduate student mentors for the project. The mentors then contacted students by phone and/or email, and eventually selected a student to extend an offer. These offers were sent by email and students generally had two weeks to accept or decline.

Within the program itself, students were expected to live on-campus in dormitories; some exceptions were made for local participants. The students attended various orientation and research-related seminars in the first week (program expectations, overview of all research projects, responsible conduct of research, lab safety, literature research). A written research proposal was due at the end of the first week. This proposal described the independent project that each student planned to execute over the summer, including a literature review, research hypotheses, experimental plan and methods. During the rest of the summer there was typically one group seminar scheduled each week. Most of these seminars were 1-hour lectures by faculty on various topics (such as environmental policy, environmental ethics, sustainability, air pollution, etc.), a panel of graduate students (to discuss applications, scholarships, graduate school experiences), or 2-hour tours at local research laboratories (such as the National Oceanic and Atmospheric Association, National Center for Atmospheric Research, the United States Geological Survey, or National Renewable Energy Laboratory). The research experience culminated with a research symposium where each student gave a 15-minute presentation with powerpoint slides. The students were also required to submit a final written report. Students were encouraged to work with their mentors to submit a conference abstract, and limited funds were provided to support student travel to present their REU research.

Participants

The basic demographics of the student applicants for each grant cycle are summarized in Table 1. In the first year of each grant period (2000, 2006, and 2010) the NSF provided fairly late notice that the grant was awarded, so applicant numbers were lower and as such a higher number of students from the host institution were selected to participate in the program (data not shown). The percentage of female applicants was higher than the U.S. nationwide average percentage of female students who graduated with B.S. degrees in environmental engineering of ~43%.[15] The percentage of under-represented minority students was similar to the national average for engineering overall of 12.7%.[15] The URM student applicants were primarily Hispanic (36 of 46 URM applicants in 2006-2011). The increase in applicants from non PhD-granting universities is presumed to be due to recruiting targeted to the ASEE list serve (which was not done in the 2000-2004 grant cycle).

Table 1. Demographics of Applicants to the CU Environmental Engineering REU Site

Years	# students	Average GPA	% female	% URM	% non PhD schools	% non host school	% Fr/ So / Jr / Sr	% CEE/E/S majors
2002-2004	105	N/A	53	*13**	7	92	22/ 49 / (29)	NA
2006-2008	194	3.5	55	9	38	91	5/ 34 / 51 / 10	48/29/23
2010-2011	179	3.4	54	16	31	88	4/ 33 / 44 / 19	54/29/16

N/A = data not available; CEE = civil and/or environmental engineering, E = other engineering, S = science majors (chemistry, physics, environmental science, biology, geology)
** included Asians*

There was generally good success in encouraging the selected students to participate. The characteristics of the students who were made an offer to participate but declined are summarized in Table 2 (data from the 2000-2004 REU program are not available). The students who declined generally stated that they had chosen to participate in another REU program, due to research topic preference or other reasons. The declining participants were over-represented in demographically desirable groups (high GPA, minority, non-PhD, non host school). Improved success in 2010/2011 was presumably due to more timely offers and/or better recruiting discussions on the phone by faculty research mentors.

Table 2. Demographics of Students who Declined the Offer to Participate

Years	# students	Average GPA	% female	% URM	% non PhD schools	% non host school	% Fr/ So / Jr / Sr	% CEE/E/S majors
'06-'08	16	3.6	56	31	44	100	6 / 31 / 63 / 0	69/6/25
'10-'11	4	3.9	50	75	50	100	0/ 25 / 50 / 25	25/25/50

The demographics of the student participants in the Environmental Engineering REU Site are summarized in Table 3. The participant demographics were over-represented compared to the applicant pool for females (54%) and minorities (~9-18%/grant cycle). The majority of the URM students were Hispanic (5 of 8 in 2000-2004, 3 of 5 in 2006-2008, 8 of 8 in 2010-2011). The majority of the student participants were majoring in environmental and/or civil engineering, with a number of students from other engineering majors (primarily chemical, but also mechanical and biological) and sciences (chemistry, physics, environmental science, biology, geology).

Table 3. Demographics of Participants in Environmental Engineering REU Site

Years	# students	Average GPA	% female	% URM	% non PhD school	% non host school	% Fr / So / Jr / Sr	% CEE/E/S majors
2000-2004	39	NA	79	21	13	79	0 / 26 / (64)	74/13/13
2006-2008	30	3.5	73	17	33	90	0 / 50 / 43 / 7	53/17/30
2010-2011	19	3.6	79	42	37	76	5 / 32 / 37 / 26	47/32/21

Assessment Methods

Extensive student pre- and post- surveys to evaluate the REU site were initiated in 2006. The student surveys included demographic questions, open-ended questions, ranking questions, and a number of Likert-based questions. A summary of the survey instrument is shown in Table 4. Students were encouraged to complete the surveys as a requirement for the program, but could opt out (via the informed consent process) or skip specific questions. The post survey seemed overly long, which seemed to lead to a decrease in response quality, as indicated by lower variation in responses between questions and a high percentage of seemingly inaccurate responses on a reverse worded item (that was a direct negative wording of a previously positive worded survey item).

The Likert-based questions were largely based on ABET skills, types of technical knowledge desired by the faculty mentors, and undergraduate research outcomes in STEM documented by Seymour et al.[14]. The pre- and post- surveys included Likert-based questions where students rated their knowledge, abilities, and likelihood of pursuing MS and PhD degrees (scale 0 = none to 4=excellent).

There were also surveys given at the end of the summer to the faculty mentors of the REU students and other mentors (i.e. graduate students, post-doctoral researchers). The types of questions on these surveys are summarized in Table 4. Some items likely have very similar responses from year-to-year for the same individuals (i.e. selection criteria, why participate) while other responses would be specific to the student-project experience in a given year. Some of these questions were similar to those used by Russel[16].

Table 4. Survey Instruments From the CU REU Site (2006-2011)

Survey Target	Type of Questions (number of items)	Examples
REU student participants - pre	Demographics (5 items) Why selected this REU (3 items) Goals (3 open ended) Rate level of knowledge (16 5-pt Likert items) Rate current ability on ABET outcomes (10 Likert items) How confident are you that you can…. (13 items rated from 1 to 100; 2010-2011 only) Rate likelihood pursue MS / PhD (2 Likert items)	What is the main thing that you hope to gain by participating in the REU program this summer?
REU student participants - post	Open ended questions on experience (13 items) Rate seminars / tours (~9 items, Likert) Rate level of knowledge (16 Likert items) Rate ability on ABET outcomes (10 Likert items) How confident are you that you can…. (13 items rated from 1 to 100; 2010-2011 only) Rate likelihood pursue MS / PhD (2 Likert items) Potential increased confidence/knowledge/mentoring outcomes (90 5-point Likert items) Demographics (6 items)	What did you like the most about your particular project? What was the most valuable aspect of your summer REU experience for you? My research experience increased my confidence
Faculty Mentors – post	Criteria used to select student mentees (rank up to 10 items) Perception of student activities (10 Likert items) Satisfaction / benefits of research outcomes (8 Likert items) Mentoring characteristics (3 items) Future contact plans (6 Likert items) Various why participate statements (7 items)	Rate the level of involvement your REU student had in the following aspects / likelihood of the various outcomes listed. Were you satisfied with the quality of your REU student(s)?
Additional mentors (i.e. graduate students)	Perception of student activities (10 Likert items) Satisfaction / benefits of research outcomes (8 Likert items) Mentoring characteristics (3 items) Future contact plans (6 Likert items) Various why participate statements (7 items)	Some questions similar to Russell[16]

In addition to the self-reported knowledge and/or learning gains experienced by students, the written research reports and powerpoint slides were reviewed for direct evidence of students' knowledge. A rubric was developed for each deliverable, and items were scored.

Results: Undergraduate Student Interns

Pre-Survey

On the pre-survey, 72% of the students in 2010-2011 indicated that they first learned of our program was via an email from a faculty member at their home university compared to only 41% in 2006-2008; this increase may have been due to improved faculty contacts of the PI over time. The other primary way that students learned about our REU program was the NSF REU website (17% of students in 2010-2011; 38% in 2006-2008). Verbally, some students also indicated that they had talked with alumni of our program or another REU program and therefore checked out the NSF REU website. This indicates that asking faculty at similar programs to announce your research opportunity to their students can be a powerful recruiting tool.

On the pre-survey students noted that the most important motivating factors for participation were to clarify career interests and learn about an interesting topic, followed by preparing for graduate school or a professional career and desire to create new knowledge, followed by benefit society and resume enhancement (students from 2006-2011). The greatest motivators for the minority students were somewhat different: learn about an interesting topic followed by preparing for graduate school, clarify career interest, create new knowledge, resume enhancement, and benefit society. Therefore, programs might consider different program design and/or publicity to attract different kinds of students.

On the pre-survey, the students rated their knowledge/ability on ten of the ABET criterion C "A-K" outcomes[10] using a 5 point Likert scale (0=none to 4=excellent). The highest rated items were an ability to engage in life long learning, function on multi-disciplinary teams, and written communication (which averaged 3.2 to 3.3 each) while the lowest rated items were design, design and conduct experiments, and use the techniques, skills, and modern engineering tools necessary for engineering practice (which averaged 1.9 to 2.0 each). Of these items, minorities rated themselves higher on ability to apply knowledge of math, science and engineering and the ability to identify, formulate and solve engineering problems, but lower on written communication (t-test, 2 tail, heteroscedastic, $p<0.05$). Gender differences were only found for two items: males rated themselves higher in ability to analyze and interpret data and oral communication (t-test, 2 tail, heteroscedastic, $p<0.05$). Somewhat surprisingly, the number of years of college completed only impacted a single item: the ability to design a system, component, or process was rated higher by students with three or more years of college completed versus students with only one or two years of college completed (t-test, 2 tail, heteroscedastic, $p<0.05$).

The pre-survey also asked students to rate their level of knowledge of 16 topics, using a Likert scale of 0 = none, 1 = minimal, 2 = fair, 3 = good, 4 = excellent. There were 48 responses. The highest rated items on the pre-survey were lab safety, the global need for environmental engineering, and sustainability (averaged 2.7 to 2.9). The lowest rated items on the pre-survey were numerical simulation, acid mine drainage, and research and graduate student funding (average ratings 0.9 to 1.3). There were not statistically significant differences in any of the topic ratings based on minority race/ethnicity or years of college completed. Four topics were rated higher by male students (research methods and data QA/QC, experimental design, responsible conduct of research, and lab safety; 0.5 to 0.7 higher; significant based on t-test $p<0.05$) and one item was rated higher by female students (environmental ethics, 0.8 higher, significant based on t-test $p=0.02$). The gender differences in the self ratings of knowledge are not surprising, and supported by the literature that women often under-rate their own abilities[17]. The transcripts of the female students and their overall GPA (average 3.5 from 2006-2011) would indicate that actual abilities were likely similar regardless of gender but that the females under-rated themselves.

Starting in 2010 the students also rated their confidence to perform different tasks on a scale of 1 to 100. On the pre-survey the males had a significantly higher confidence in 10 of the 13 items (based on 2-tailed, heteroscedastic t-test, $p<0.02$). There were no items with statistically significant differences in responses based on race/ethnicity, and only 1 item was significantly higher rated by students with fewer years of college completed (ability to work effectively with others on a team rated as 97 by students with two or fewer years of college completed compared to 89 by students with three or more years of college completed). The gender differences in self ratings of confidence are not surprising, and supported by the literature[17]. The female students were likely similarly competent, but merely under-rate their own abilities.

On the pre-survey the self-rated likelihood that the students would pursue an MS degree averaged 3.5 (range 2 to 4 on 0 to 4 Likert scale) and the likelihood that they would pursue a PhD degree averaged 2.3 (range 1 to 4).

Comparison of Pre- and Post- Ratings

To determine impacts of the summer REU research and program experience, the most direct method was to compare the pre- and post- ratings for identical survey items. Comparing the pre- and post- ratings of the ABET outcomes using unpaired two-tailed t-tests, 8 items had statistically significant gains ($p<0.05$); see Figure 1. Although the differences appear small, the students were only rating these abilities on a 5-point Likert scale (0=none, 1=minimal, 2=fair, 3=good, 4=excellent). The largest gain was in the ability to design and conduct experiments (pre=2.02), which is fully consistent with the goals of a mentored, independent research experience. Somewhat larger gains in the ability to analyze and interpret data were expected, but this skill have a much higher initial rating by the students (average pre=2.67).

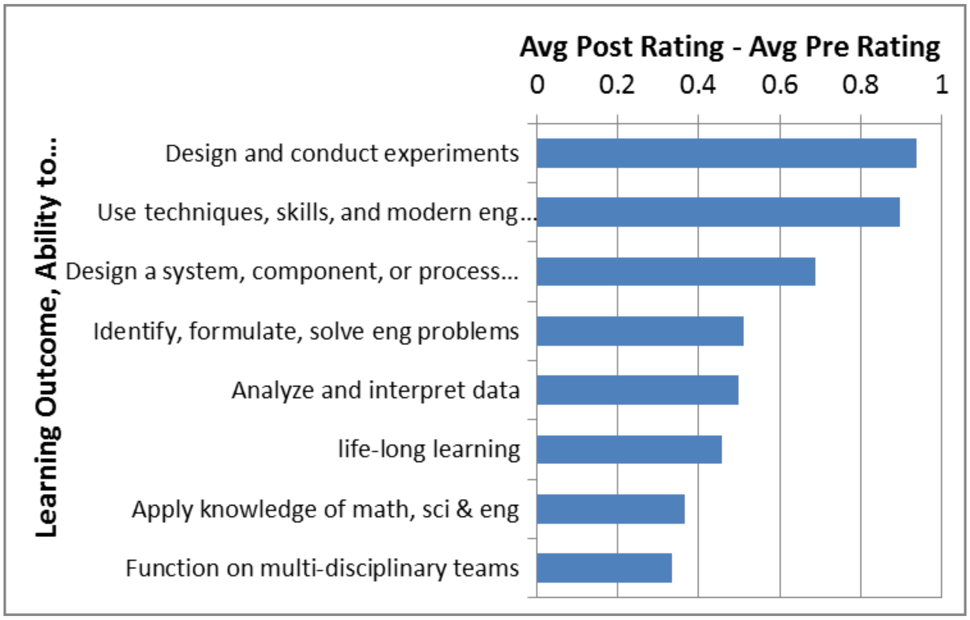

Figure 1. Increased in students' average self-rated abilities on the post – pre survey (n=48)

The REU student interns used modern equipment and computer software in their research activities, which predictably increased their self-perceived ability to use the techniques and modern engineering tools necessary for engineering practice. The system design result was somewhat unexpected, but students often designed laboratory experimental apparatus and/or were cognizant of how their research results could improve the design of existing systems to minimize negative environmental and/or human health impacts. Design ability was also the lowest rated item on the pre-survey at 1.91. The ability to engage in life-long learning was the highest rated item on the post survey, averaging 3.8. Written and oral communication did not show gains (difference 0.1). This indicates that the single formal oral presentation at the end of the program and the two significant written deliverables (proposal and final report) were not perceived by the students to increase their skill in these areas.

For the 16 knowledge outcomes rated on a 5-point Likert scale, unpaired two-tailed t-tests were conducted to compare the 48 pre and post responses (student responses were anonymous, and therefore could not be paired). The post scores were higher for 14 of the items, with $p<0.05$. Figure 2 shows the difference in the average post – pre scores for the knowledge items that were statistically significantly different. The largest gains ($\geq$1.0) occurred in knowledge of research / graduate student funding (there was a seminar on this, and it was a very low rated item on the pre survey), experimental design, and research methods / data QA/QC. It is good that two of the significant gain areas were directly related to research. Many of the environmental engineering topics (i.e. air pollution) were not researched by all students, but the students learned about these topics from each other via the cohort experience and/or the seminar series.

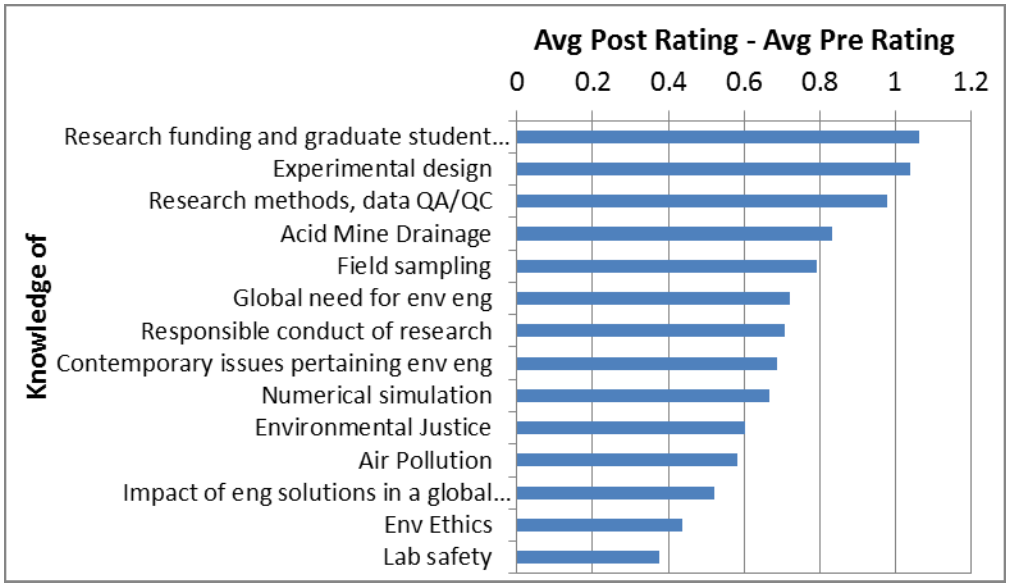

Figure 2. Difference in the average rating of knowledge on post survey – pre survey (n=48)

Knowledge of sustainability and environmental policy did not increase significantly (0.1 and 0.3 on a Likert scale). However, for the sub-cohort in 2010-2011 when there was a 1-hour seminar on environmental policy, there was a significant gain for this topic (pre average 1.5, post average 2.2, p-value 0.01). This result indicates that the weekly seminar series can be designed to achieve specific learning objectives.

For the self-rated confidence to perform different tasks (scale 1 to 100) in 2010-2011, there were small average gains in all of the confidence areas (2 to 16 points of 100). The confidence gain was only statistically significant for "*confidence in ability to design and implement the best measurement approach possible for your study of some aspect of environmental engineering*." Gender differences were significant ($p<0.02$) on only 5 of the post-survey confidence items.

Across all students (n=46 pre, n=49 post), there was not a significant difference in the likelihood to pursue an MS degree or PhD degree on the post and pre surveys (averaged 3.5 and 2.3, respectively; where 0 = none, 1 = minimal, 2=fair, 3=good, 4=excellent). However, among the 2011 students there was a statistically significant gain in the likelihood that the students would pursue an MS degree. Looking in detail at the 13 URM students (2006-2011), the pre versus post interest in an MS and PhD remained about the same (average 3.7/3.6 and 2.5/2.5, respectively). While most students had a higher interest in MS degrees (35 students on the pre survey, 40 students on the post survey), a few students had greater interest in a PhD (2/3 students on the pre/post survey; 2 were non-engineering majors). This result was disappointing, but not surprising given the initially very high rating for MS interest, and the fact that REU applicants are typically already fairly interested in research. A similar lack of increase in students' intent to pursue graduate studies was also found in a 2004 study on a structural engineering REU site.[18] Among their three years of cohorts, intent to pursue an M.S. degree in structural engineering or a closely related discipline decreased in 2 to the 3 years (range on post survey 3.3 to 4.6 on a 1 to 5 Likert scale).[18] Students' intent to complete a PhD dropped in all 3 years (-0.1 to -0.75). [18]

Post Survey Gains and Impacts

The post-survey asked the students to rate their *gains* in various confidence and knowledge areas (scale 1= not a benefit/strongly disagree, 3 = neutral, 5=strong benefit/strongly agree). The average across all 80 of the increased/positive benefit items was 4.1. The most highly ranked items on average are summarized in Table 5.

Table 5. Gains by the REU students that were Rated on Average as 4.3 to 4.5 on the Post Survey

Category of questions	Item
My research experience increased / improved my:	Confidence Confidence in ability to do research Ability to present research findings in graphs and tables Understanding of the research process Understanding of how engineers and scientists work on real problems Self-esteem
My research experience:	Helped me establish a mentoring relationship with faculty Clarified/confirmed my level of interest in graduate school
My research experience contributed to gains in the application of the following knowledge and skills:	Critical thinking and problem-solving skills related to research Critical thinking/problem solving skills, in general
My research experience resulted in:	Greater understanding in depth Ability to work independently Willingness to take responsibility for the project
(miscellaneous statements)	I felt that I became part of a learning community Through my experience I bonded with faculty I bonded with other students in the lab

None of the 11 specific knowledge areas (chemistry, microbiology, etc.) had average ratings over 3.3, but this is not surprising given the broad diversity of research topics. All of the 11 items were rated as 5 by at least one student; the highest rated areas were chemistry, costs/potential benefits of environmental engineering, and drinking water; the lowest rated areas were soils and wastewater.

Statistical differences ($p<0.05$) were found in the post-survey "gain" ratings between non-Hispanic whites vs. URM (22 items), freshman+sophomores vs. juniors+seniors (13 items), students with minimal vs. extensive previous research experience (14 items), and civil+ environmental engineering majors compared to non-engineering majors (5 items). No gender differences were found.

Results: Student Abilities: Direct Evidence

Scoring rubrics are often used for programs to demonstrate the achievement of various learning outcomes for ABET[19] and other purposes. The rubrics rate ability, but not gains in ability due to the REU program. Due to the high quality of the applicants and advanced nature of many of the students (juniors and seniors), the REU students likely entered the program with significant skills in many areas. However, many of the students required coaching on experimental design issues (controls, replicates) and significant guidance on statistical methods to analyze data.

The results from the rubric analysis of the final written reports and oral presentation slides from the REU students are shown below in Tables 6 and 7, respectively. A simple 4-step rubric was used for the written report evaluation (1=minimal or no evidence of the ability, 2=some evidence, 3 = good, 4 = excellent, similar to expectations for graduating M.S. students). The outcomes map to Kardash[13]. Only a three-step rubric was used for the presentation slides, because analysis of an oral presentation based only on slides may give an incomplete representation of the overall oral presentation. [Student outcomes from 2010 and 2011 were evaluated. Analysis of all available reports and slides across all years has not yet been completed. Inter-rater reliability has not yet been determined.]

The analysis of the student written reports indicated that the strongest area was literature citation, likely due to the early summer effort devoted to the research proposals and library training on literature searches (the average number of cited references in the final reports was 16). Other strong outcomes (with average scores above 3) were: ability to observe and collect data, evidence that research addressed a contemporary challenge in environmental engineering, and interpretation of the data. The weakest areas were the articulation of research hypotheses (the majority of the reports made no mention of a hypothesis) and even the specific research questions being explored were often not clearly stated.

Table 6. Number of student written reports scored in each of the four rubric categories

Outcome Evident	**1**	**2**	**3**	**4**
Evidence of contemporary challenge in environmental engrg	0	2	9	3
Relevant literature cited	0	2	2	10
Specific research question articulated	1	6	7	0
Research hypothesis articulated	9	2	3	0
Evidence of appropriate controls	0	6	8	0
ability to observe and collect data	0	0	13	1
Statistically analyze data	1	8	2	3
interpret data by relating to research question / hypothesis	0	2	10	2
Ability to relate results to the bigger picture in environmental engineering	2	5	7	0

Further analysis will be conducted in the future to analyze the content of the research proposals to determine if those are predictors of the content quality of the final report. An observation has been that once the proposals are done many students immerse in laboratory work and data collection, and leave insufficient time to digest what the data mean and conduct appropriate statistical analysis of their findings. As they immerse in the details the students may also lose sight of the bigger driver for their research and the initial goals and objectives. It is the responsibility of the mentors to coach students on the process of data interpretation. Some students work on finalizing their reports after the end of the REU program, via email correspondence with their advisors. Future work will also be conducted in an attempt to correlate the quality of the final report with eventual publication or conference presentation of the results.

Table 7. Number of student presentation slides scored in each of the three rubric categories

Outcome Evident	**1**	**2**	**3**
Research need (big picture) clear	0	3	14
Specific research question &/or hypothesis articulated	2	3	12
Research methods described	0	5	12
Research data shown; presented in tables and figures	1	0	16
Statistical analysis of data evident (i.e. error bars, t-tests, regression)	5	8	4
Data interpreted, particularly in regards to research objectives	1	4	12
Visual quality of slides (i.e. adequate text size, interest)	0	7	10

The analysis of the student presentation slides indicated that the strongest areas were: presenting the big picture motivation for the research and generating/presenting data, while the weakest area was statistical analysis of the data. The level of input from the research advisors on the presentation slides and practicing the oral presentation varied (some appeared to give no assistance while others gave detailed feedback on draft slides and practice presentations).

There was some correlation between the written reports and oral presentations in demonstrating achievement of learning outcomes. The strongest correlation was in the statistical analysis of the data (correlation coefficient 0.74), with stronger evidence of the statistics in the written reports (average 2.5) versus the presentation slides (average 1.9). There was a weaker correlation in the articulation of research objectives (correlation coefficient 0.47). Interestingly, the students did a better job articulating research objectives in the presentation slides (average 2.8) compared to the written reports (average 2.4).

Another direct measure of research quality includes the dissemination of the REU students' research results at conferences and in peer reviewed manuscripts. Table 8 summarizes the research outputs from the REU students, including technical reports delivered to funding agencies, conference presentations (with or without associated proceedings papers), and peer-reviewed journal papers with REU students as co-authors. In some cases, multiple REU students' data were combined into a single publication, so the data below indicates student numbers rather than the number of papers. Also note that in some cases the same student co-authored both a conference paper and a journal article.

Table 8. Dissemination of REU Student Research Results

	Number of REU interns who co-authored a:			% of cohort involved in 1 or more dissemination venues
Cohort Year	Technical Report	Conference Paper or Presentation	Peer-Reviewed Journal Paper	
2000-2004	1	5	2	21
2006	1	3	2	50
2007	0	3	3	50
2008	0	2	1	30
2010	1	3	1	44
2011	0	4	0	40

Over the first five year grant, only eight such outcomes occurred in total from all 39 participants. By comparison, of the 39 participants from 2006-2011 there have already been 25 reports/ presentations/journal papers (which is expected to rise due to the time lag in publications). It is believed that this gain was due to a combination of improved mentoring, requiring students to write a final research paper, and providing travel funds for the REU students to present their research at conferences. For the 2011 cohort, four faculty indicated that the students were "extremely likely" to be included as co-authors on future peer-reviewed publications.

Results: Faculty Mentors

Surveys were also administered to faculty mentors and additional mentors (post-doctoral researchers, graduate students). Overall, the faculty mentors were "satisfied" to "very satisfied" with their REU students. The faculty mentors were asked to rank the importance of ten different factors in selecting student interns for the REU program. Faculty may choose not to rate an item if they do not use the criteria in their selection process. These ratings have varied by year for some of the same faculty, presumably due in part to the complexity of the specific summer project, availability to mentor, quality or availability of graduate student / post doctoral mentors, etc. The rankings were translated into scores from "highest ranking" = 10 on down, with zero assigned for items not rated. In this paper, only data from 2010 and 2011 is summarized below.

The highest rated criterion was "student interest in my research topic" with an average rating of 9.1. The second most important criteria on average was the technical background of the student was relevant to the project, with an average score of 7.6; but the scores from individual faculty ranged from 10 to 2. Items with the greatest disparity in ratings were GPA (average 6.2+3.0, range 0 to 10), a student with previous research experience (score of 0 to 9, average 4.2+3.6), student from an under-represented group (average 6.8+2.6, scores 0 to 10), and the student stated an interest in future graduate school (average 4.3 + 3.3, range 0 to 8).

One goal of the REU program is to inspire students to pursue graduate studies. Therefore, including students who have not yet made up their mind to go to graduate school is an appropriate goal for the site. Only 2 of the 14 responses indicated a greater preference to select a student without previous research experience. This is disappointing since NSF states that a goal of the REU program is to expose students to a research experience. Despite the variability in the faculty preference for under-represented students, the average score for this criterion made it the 3rd highest rated item. This is important since increasing diversity is a stated goal of the NSF REU program. The variability in the GPA criteria may reflect our historical success for anyone with a GPA above 3.0, and little correlation between student success on the research project and GPA.

The faculty survey on the increased abilities in the undergraduate students due to the summer research experience was administered in spring 2012. Faculty rated the gains on a Likert scale from 1 (none) to 5 (a very significant amount) or U (unknown, not observed). Nine responses were received. The highest rated outcomes, with averages score of 4 or higher, were: analyze and interpret data, modern engineering tools, design and conduct experiments, and knowledge of math/science/engineering. The lowest rated items, with average scores of 3.1 or lower, were: sustainability, ethics and professional responsibility, and system design.

The average faculty gain ratings were grouped into high (4.0 or higher), medium (3.4 to 3.9), and low (2.8 to 3.2) ranges. The differences in the students' self ratings on the post and pre surveys were also grouped into three ranges (no gain = not significantly different; medium gain 0.33 – 0.52; high gain 0.69 to 0.94). Comparisons of the learning outcomes that fell into these faculty and student categories are shown in Table 9. Seven of the 15 outcomes have the same general ratings by students and faculty (highlighted in yellow). Compared to student self-evaluations, the faculty under-rated the benefit to students' design abilities, ethics, societal impact, and contemporary issues knowledge. Faculty over-rated the benefits to written communication, oral communication, ability to analyze and interpret data, and knowledge of math/science/ engineering. However, the faculty were reporting typical results from mentoring multiple REU students. In addition, not all of the faculty mentors completed the survey. The results provide interesting insight into which ABET-related learning outcomes can be realistically achieved in a fairly typical REU program.

Table 9. Comparison of Learning Outcomes from the REU: faculty vs. student results

		Faculty Rated Gain		
		Low	Medium	High
Students Post – Pre Ratings	No Gain	Public policy impacts Sustainability	Written communication Oral communication	
	Medium Gain	Societal impact Ethics	Solve engrg problems Multi-disciplinary teams Lifelong learning	Analyze & interpret data Math, science, engineering
	Large Gain	Design a system…	Contemporary issues	Modern engineering tools Design, conduct experiments

Graduate School Outcomes

One of the goals of the REU program is to encourage students to attend graduate school. The program has had fairly good success in this regard, with data as of the December 2011 alumni survey shown below. Overall, a higher percentage of students not from the host institution have added graduate school (only 27% of the CU interns have attended graduate school). Ten of the 78 participants have attended graduate school at CU, and many more have applied. There also appears to be some cohort effect evident. For example, the 2000 cohort had very low graduate school attendance (only 1 of 8), compared to a very high percentage of the 2003 and 2004 students (15 of 16 attended graduate school). Some of the alumni who are currently working have indicated an intent to attend graduate school in the future. Of the 2011 cohort, one has applied to graduate school, one has been admitted to the BS/MS program, and the other eight are still undergraduates.

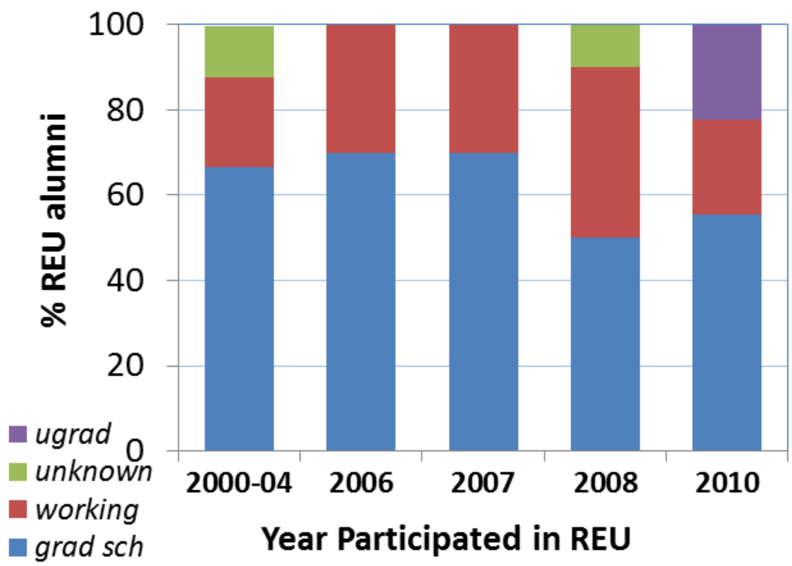

Figure 3. Percentage of the REU site alumni who continued to graduate studies or work; individuals who did not respond to the alumni survey are listed as unknown and some students have not yet completed their undergraduate degree.

Program Administration Recommendations

The first recommendation for individuals considering an REU site is to ensure that there will be administrative support. In our 2006-2008 site there were funds for partial graduate student support. This individual compiled all of the application materials and summarized the information in a spreadsheet, assisted with various seminar logistics, and served as a universal mentor for all of the students. This support was removed from the 2010-2012 grant upon a requirement from the NSF to reduce our budget. The PI only receives 40% of 1 month of summer salary for the REU site, which is vastly insufficient for the amount of time invested without an assistant of any kind.

The number of student applicants can be overwhelming. Each applicant requires multiple emails. From the applicant there is usually an inquiry before application, sending the application itself, and follow-up questions about whether transcripts have been received. Each applicant submits two recommendation letters that are generally emailed directly to the PI. The PI emails the applicant at multiple points: acknowledgment of receiving application, acknowledgment when application is complete (including the formal transcript and recommendation letters), update on status of selecting interns, and final email with either an offer or decline to offer position. In addition to the logistical challenges, there are often so many good student applicants that selection becomes very challenging.

The second recommendation is to maintain some discretion of the PI in the selection of the student interns. Based on the mentor priorities for selecting interns, it would be quite possible to not meet our diversity goals if each mentor was given full discretion in selecting their student interns. Our system works such that the PI screens the student applicants down to ~4-10 students per project, and then forwards these applicants to the faculty mentor(s) of the research projects.

Students forwarded to faculty always have a stated interest in the research and strong reference letters, but may have a range of technical backgrounds evident (based on coursework and/or previous research), GPA, and demographic characteristics. The faculty mentors are then at their own discretion to interview the applicants by phone or email to rank their preferences for their desired student. The PI retains the final approval for each offer that is made. This process has resulted in improved diversity of the student participants in the 2010-2011 REU site, as compared to the earlier process in 2000-2004 where the faculty mentors had complete discretion to select their intern.

Some students who are selected are able to succeed under any conditions, mentoring aside. They are simply independent enough, assertive enough to find help from other students in the lab, etc. Other students require a greater "investment" on the part of the mentor, and with appropriate guidance can grow significantly over the course of the 10-weeks. Over time a PI will become familiar with faculty mentors and can discuss the availability of additional graduate student mentors. This knowledge can be helpful in recommending students for a particular faculty mentor. In addition, some faculty might be unavailable during part of the summer due to travel plans, and arrangements and advance consideration must be taken into account. In our case, there is greater demand by faculty than available funding for student interns, so some faculty are not given students to mentor every year depending on their success and/or availability for mentoring.

Summary and Recommendations

Student participants from all demographics (years of college completed, major, etc.) were successful when given appropriate mentoring. A wide breadth of learning outcomes were achieved, and the attributes of an REU site could be tailored to achieve specific outcomes (i.e. such as the ethics supplements provided to sites that selected this focus). The greatest gains in knowledge, skills, abilities, and confidence generally occurred among students with little or no previous independent research experience, regardless of the number of years of college completed. Therefore, the REU sites should target such students while other programs and/or research funding are appropriate for students after an intensive research experience program. Across all ten years of the REU Site to date, only one student who had only completed one year of college has participated in the program. This single experience did not go well, although this student also received very weak supervision in the laboratory with no dedicated individual in the lab to answer day-to-day questions. However, this experience indicates that some caution should be exercised when selecting younger students as REU interns. Faculty should be advised on the mentoring expectations of the program and care should be taken to select projects appropriate for execution over the duration of the program.

Acknowledgments

This material is based on REU sites supported by the National Science Foundation under Grant Nos. 9988062, 0552895, and 1004122. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Bibliography

1. National Science Foundation (NSF). 1990. NSF's Research Experiences for Undergraduates (REU) Program: An Assessment of the First Three Years. NSF Report 90-58. http://www.eric.ed.gov/PDFS/ED322850.pdf
Gibbons, M.T. 2011. Engineering by the Numbers. http://www.asee.org/papers-and-publications/publications/college-profiles/2010-profile-engineering-statistics.pdf

2. NSF. REU. Accessed 12/12/2011 Map of REU sites. (http://www.nsf.gov/awards/award_visualization.jsp?org=NSF&pims_id=5517&ProgRefCode=9250&QueryText=REU+Site&RestrictTitle=on&BooleanElement=true&BooleanRef=true&from=fund).

3. NSF. Award Search. Accessed 12/12/2011. http://www.nsf.gov/awardsearch/piSearch.do?PIFirstName=&PICountry=&Search=Search&PIZip=&PILastName=&PIInstitution=&Restriction=0&SearchType=piSearch&page=1&d-49653-s=2&QueryText=REU+Site+AND+environmental+AND+engineering&d-49653-o=2&d-49653-p=1&PIState=#results

4. NSF. 2009. Research Experiences for Undergraduates (REU): Sites and Supplements. Program Solicitation NSF 09-598.

5. Russell, S.H. 2005. Undergraduate Research Opportunity Programs Evaluation: Student Outcomes and Perceptions. Opening Plenary. Pan REU Workshop: Final Report. Sept. 20-22.

6. Bennison, L., j. Koski, E. Villa, R. Faram, S. O-Connor. 2011. CUR Quarterly. Evaluation of the Research Experiences for Undergraduates (REU) Sites Program. Sept. 6 pp. http://www.cur.org/quarterly/sept11/Beninson.pdf

7. AAUW. 2010. Why So Few? Women in Science, Technology, Engineering and Mathematics. Washington D.C. www.aauw.org/learn/research/whysofew.cfm

8. National Academy of Sciences. 2011. Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads. National Academies Press. Washington D.C. ISBN 978-0-309-15968-5

9. Grimberg, S.J., T.A. Langen, L.D. Compeau, S.E. Powers. 2008. A Theme-Based Seminar on Environmental Sustainability Improves Participant Satistfaction in an Undergraduate Summer Research Program. International Journal for Engineering Education.

10. ABET. 2010. Criteria for Accrediting Engineering Programs. Effective for Evaluations During the 2011-2012 Accreditation Cycle. ABET, Inc. Baltimore, MD. www.abet.org

11. American Academy of Environmental Engineers (AAEE). 2009. Environmental Engineering Body of Knowledge. AAEE, Annapolis, MD.

12. American Society of Civil Engineers (ASCE). 2008. Civil Engineering Body of Knowledge for the 21st Century. Preparing the Civil Engineer for the Future. Second Edition. ASCE, Reston, VA. www.asce.org

13. Kardash, 2000. Evaluation of an undergraduate research experience: perceptions of undergraduate interns and their faculty mentors. Journal of Educational Psychology. 92 (1): 191-201.

14. Seymour, E., A-B. Hunter, S.L. Laursen, T. Deantoni. 2004. Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. Science Education. 88(4): 493-534.

15. Gibbons, M.T. 2011. Engineering by the Numbers. American Society for Engineering Education. 37 pp. www.asee.org/

16. Russell, S.H. 2004. Evaluation of NSF Support for Undergraduate Research Opportunities. 2003 NSF-Program Participant Survey. Draft Executive Summary. Mar. 4. SRI International. Arlington VA. Prepared for the National Science Foundation.

17. Atman, C.J., S.D. Sheppard, J. Turns, R.S. Adams, L.N. Fleming, R. Stevens, R.A. Streveler, K.A. Smith, R.L. Miller, L.J. Leifer, K. Yasuhara, D. Lund. 2010. Enabling Engineering Student Success: The Final Report for the Center for the Advancement of Engineering Education. San Rafael, CA: Morgan & Claypool Publishers. CAEE-TR-10-02. www.engr.washington.edu/caee ISBN 978-1-60845-562-1

18. Delatte, N. 2004. Undergraduate summer research in structural engineering. Journal of Professional Issues in Engineering Education and Practice. 130 (1), 37-43.

19. Briedis, D. 2010. Developing Rubrics. ABET Webinar. http://www.abet.org/developing-rubrics/