2006-1229: UNDERGRADUATE RESEARCH ON APPROPRIATE AND SUSTAINABLE TECHNOLOGY

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Undergraduate Research on Appropriate and Sustainable Technology

Abstract

This paper describes the funding sources, educational outcomes, and diversity of students served by conducting research on appropriate and sustainable technology. Since 2001, more than twelve undergraduate students have conducted research on the water treatment effectiveness of the Filtrón, including eight students independently and four students as a class team project. The Filtrón is a point-of-use drinking water filter that can be produced inexpensively in communities world-wide. Some of the student researchers were participants in the Environmental Engineering Research Experience for Undergraduates (REU) site and Summer Multicultural Access to Research and Training (SMART) program. Students have also been funded through the Discovery Learning (DL) Apprentice Program, Undergraduate Research Opportunities Program (UROP), and the Engineering Excellence Fund (EEF). Students have also earned three credits of Independent Study that they applied as a technical elective toward their B.S. degree. The undergraduate student researchers majored in civil, chemical, environmental, or mechanical engineering, and have included four underrepresented minorities and seven women. Research is currently continuing with a grant from the U.S. Environmental Protection Agency (EPA) P3 program. The Filtrón research also has been used as a demonstration in numerous outreach activities. The filter has been evaluated in service-learning projects through Engineers Without Borders (EWB-CU) and capstone design to provide safe water. Laboratory research on the Filtrón is also contrasted with opportunities to earn course credit for involvement with EWB projects. This serves as an example of how research on appropriate technology appeals to a diverse range of students and can provide real benefits to developing communities.

Background

The purposes of academic engineering research activities can be broadly grouped into two main goals that are complementary yet distinct: (1) education of students; and (2) production of new knowledge of practical importance. Participation in research activities has numerous benefits to the education and professional development of students. In particular, Seymour et al.[1] did an exhaustive study to document the outcomes of summer research experiences for students in science, math, and engineering fields. The benefits of undergraduate research were grouped into six main areas: personal/professional; thinking and working like a scientist; skills; refining career/educational paths; enhanced career/graduate school preparation; and changed attitudes toward learning and working as a researcher. Some of these beneficial outcomes may be difficult to achieve in traditional coursework that comprises the bulk of most engineering curricula.

Within environmental engineering and other fields, most of the research in the U.S. is focused on "high-tech" solutions. However, there is a great need to provide low-cost, *appropriate and sustainable technology* (AST) solutions to basic needs in developing countries for water, sanitation, energy, and shelter.[2] AST is suited in size and complexity to the local conditions, can be maintained using locally available resources and human capital, and does not deplete long-term sustainability through inefficient energy use, depleting natural resources, or creating byproducts that pollute the environment. In rural areas of developing countries, AST is typically small scale, energy efficient, environmentally sound, labor-intensive, simple and designed to foster self-reliance, cooperation and responsibility.[3]

Although somewhat less glamorous in some respects, basic research on AST has the potential to make improvements in solutions to pressing needs that will have significant impacts on the quality of life for millions of people worldwide. Within the Environmental Engineering program at the University of Colorado at Boulder (CU), students have been conducting research on AST solutions to water and sanitation problems since 2001. The purpose of this paper is to compare and contrast the research experiences of students working on "traditional" environmental engineering projects with the students working on AST-related projects.

Description of Research Opportunities

Students can participate in extracurricular research at CU via a number of different programs and arrangements. Table 1 briefly compares and contrasts these opportunities.

Table 1. Types of Research Experiences for Students

Type	Typical Duration	Rewards	Typical Outcomes	Student reported total hours spent
Undergraduate summer program (REU/SMART)	10 weeks in summer	funding; 3 credits	written proposal, oral presentation, website	175 – 400
Undergraduate DL intern	16 weeks over academic semester	funding	oral presentation; poster	*150 (based on available funding)*
Undergraduate Multicultural Engineering Program (MEP) intern	16 weeks over academic semester	funding	write-up	128
Independent study course (undergraduate or graduate students)	16 weeks over semester or more	3 credits	written report	200 – 480
Research Assistant (typically graduate students)	1 yr minimum	6 credits; stipend	written thesis; oral defense; publication	900

The Research Experience for Undergraduates (REU) and Summer Multicultural Access to Research and Training (SMART) programs are organized. Students from across the U.S. can apply to participate, and are selected based on academic credentials and the fit of the student interests to projects available from faculty mentors. They have group activities devoted to training students on research, making them aware of opportunities in graduate school, and group social activities. Undergraduate student participants receive living expenses, a stipend, and 3-

credits that they can typically apply as technical elective credits toward their B.S. degree. Funding for these programs is provided by the National Science Foundation. A number of universities have these programs. At CU, the SMART program is operated from the graduate school and supports students in majors including engineering, math, and science. The REU program in Environmental Engineering spanned five summers from 2000 through 2004. For a list of other programs that are currently active see the NSF website (http://www.nsf.gov/crssprgm/reu/list_result.cfm?unitid=10006). About 25 programs are directly related to environmental engineering.

The Discovery Learning (DL) Apprenticeship Program initially supported 12 undergraduate students per semester doing research in the Discovery Learning Center (http://ecadw.colorado.edu/engineering/activelearning/discovery.htm). Descriptions of the specific research projects available are provided to the students, who indicate project preference when they apply to the program. The program pays students an hourly wage ($10/hr, for a maximum of $1500/semester). Thus the typical time invested is about 10 hours per week. At the end of the semester, a Discovery Learning Symposium is held where all students present the results of their work orally and with posters. The program now supports about 25 to 30 students per semester and includes cost sharing between the project's faculty mentor and the College.

Individual undergraduate students are sometimes able to make arrangements for small grants through the University of Colorado's Multicultural Engineering Program (MEP) (http://www.colorado.edu/engineering/MEP/). This takes the form of one-time grants of about $1500 or internships similar to the DL program where students earn an hourly wage for their participation in a research project with a faculty sponsor.

At any time, students can make arrangements with an individual faculty member to register for an "Independent Study" course. The number of credit hours can range from one to six, but is typically three. These credits count as a technical elective toward a B.S. degree, out of approximately 128 credits total. In general, students approach faculty members when they have an interest in researching a particular topic. As a rough rule of thumb, students are expected to devote about 10 to 15 hours per week over 15 weeks to their project, which would be on par with the effort for other 3-credit upper division engineering courses. Sometimes, the student work will span more than one semester when the research is proceeding slowly. However, students typically only receive 3 credits.

Three students conducted Independent Study projects that were associated with Engineers Without Borders (EWB) – CU projects. These students were participating for over one year on project teams to develop appropriate and sustainable technology solutions to specific needs for communities in Rwanda, Haiti, and Mali. All of the students traveled internationally in association with their project. They were already devoting a large amount of effort to these activities, and a facet of the EWB project was expanded to encompass an Independent Study of 3 credits. In one case, the student did literature research and design. In the other two cases, the students learned laboratory techniques that they were unfamiliar with, tested these methods at CU, and then applied them to varying extents during their international trips. Each student completed a written report that included background on the country and culture, literature survey on feasible technologies, and designs or experimental data results.

Students sometimes receive grants for their Independent Study work from on-campus sources. Two students received grants from the Undergraduate Research Opportunities Program (UROP) of approximately $1500. The majority of the funding was used to travel abroad to Nicaragua and Peru, with some additional funding for research supplies. Two grants from the Engineering Excellence Fund (EEF) of $500-$800 were also received. This money was used to buy research equipment and supplies, specifically to facilitate enumeration of water-borne pathogens.

In addition to the numerous independent research opportunities, some required courses also require students to conduct research activities, in order to fill ABET criteria b. In the Water Chemistry course at CU that is taught by Professor Joe Ryan, student teams select a topic and conduct a mini-research project. This requires about 20 hours of time per student. In spring 2002, one group of 4 civil/environmental engineering students chose to conduct their lab project on nitrate and turbidity removal by the Filtrón. The team was composed of 3 females and 1 male student. Due to the minimal amount of time devoted to the research activity, these students were not included in the surveys.

The majors of the undergraduate students mentored and co-mentored by Dr. Bielefeldt from 2000 through 2005 are summarized in Table 2. The larger time-frame than the Filtrón-related research (2001 to 2005) was selected so that a wider pool of students could be surveyed. Students participating in research on the Filtrón and other AST spanned many different engineering majors, including civil, environmental, chemical, and mechanical. For a larger pool of undergraduate students conducting research in Environmental Engineering, note that of the 39 participants in the REU program from 2000 through 2004, 79% were female and 21% were from underrepresented groups.

Table 2. Students Participating in Research Mentored by Dr. Bielefeldt, 2000 - 2005

	Number of Undergraduate Students		
Engineering Major	Filtrón Research	EWB Independent Study projects	Other Environmental Engineering Research
Civil	2	2	2.5
Environmental	4		1.5
Chemical	1	1	2
Mechanical	1		
Biosystems			1
Demographics*			
Male	4	1	0
Female	4	2	7
Underrepresented	4	0	2

* Note that a student can be both male and underrepresented (or female and underrepresented)

Master's degree students in environmental engineering have also conducted laboratory research or literature/design/modeling research efforts on AST. One of the students who worked on the Filtrón was initially planning to do a full thesis, but due to a combination of funding challenges and a lack of passion for lab work opted for an Independent Study report instead. These graduate students include 2 women and 2 underrepresented minorities researching the Filtrón or AST (of 3 students total). Students working on other Environmental Engineering research under Dr. Bielefeldt's mentoring from 2000 to 2005 include 5 women, 1 minority, and 1 international student (of six total).

Survey

A written survey instrument was developed to evaluate the potential benefits of the student research and independent study opportunities, and to look for similarities and differences based on the type of research project. The survey questions were based primarily on: (1) ABET A-K criteria[4] and (2) Seymour et al.[1] reported benefits of undergraduate research to SME students. The survey was distributed by email to all students who had conducted research with the Filtrón, students who conducted research on other AST, and a selected "control" population of students who researched traditional environmental engineering problems under the direction of Professor Bielefeldt. (Note that not all students were surveyed because current email contact information was not known for all of the students. In addition, many of the 13 REU students in 2003-2004 were mentored by other faculty, and were not surveyed to eliminate differences between research mentors.) The survey was first sent out November 7, 2005. A follow-up email was sent January 3, 2006. Table 3 summarizes the students who were sent surveys and responded. A total of 13 undergraduates and 5 graduate students returned surveys, of the 21 total distributed (but on one survey only 11% of the questions were answered; no questions on the outcomes of the experience were answered; therefore of truly useful surveys, this represents an 81% useful response rate).

Table 3. Student Research Participants who were Surveyed and Responded

Type of Research Experience	Years	Students Surveyed (m = minority; F = female; M = male)	Respondents
REU			
Filtrón	2003-2004	2 F	2
Traditional EnvEng	2003-2004	3 F	2
SMART, Filtrón	2005	1 mM	1
DL Intern, Filtrón	2004	1 mF, 1 M	1
MEP Intern, Filtrón	2003-2005	1 mF, 1 mM	2
Undergrad Independent Study	2002-2005		
Filtrón		1 mF, 1 M	1*
Other AST		2 F, 1 M	3
Traditional EnvEng		2 F	1
MS Independent lab research	2003-2005		
Filtrón		1 F, 1 mM (in progress)	2
Traditional EnvEng		2 F	2
MS Thesis	2002-2004		
Other AST		1 mF	0
Traditional EnvEng		1 F	1

* an additional student only answered 12 questions: time spent, motivating factors, and open ended questions; none of the Likert-scale research outcomes questions were answered

The number of students surveyed and responding based on Table 3 do not add to 21 and 18, respectively, because three of the undergraduate students participated in more than research category and are "double counted" in the table. One student researched the Filtrón as both a DL and MEP intern. Of the students who researched non-AST environmental engineering topics, one was both an REU intern and completed another Independent Study project, and another was initially a paid hourly and in a later semester completed an Independent Study project.

Survey Results: Time Invested

The survey began by asking each student to report the duration of their project experience and average number of hours per week that they spent on their project. Results were given in Table 1. Responses varied significantly, as expected given the different structure of each type of experience. It is the opinion of the author that there is a rough correlation to the diversity of beneficial outcomes achieved from the experience and the time invested, within a single type of experience. For example, over the four respondents who participated in the REU program, respondents "strongly agreed" with 71, 63, 55, and 16 beneficial aspects of the experience based on self-reported time invested of 400, 400, 350, and 175 hours, respectively.

Survey Results: Motivating Factors

The first set of survey questions related to the students' motivation for participation in research. Students were asked to rank 8 possible reasons for participating in the experience from most important (#1) down as many rankings as were applicable. Note that two of the motivating factors, "earn money" and "alternative way to earn credits toward graduation", were only possible for some of the different types of experiences (as described in Table 2). To aid in interpreting the results, each list was then converted to a rough "percentage" of total motivation. All of the students universally included "learn about an interesting topic" as a motivation; and this reason had the highest converted total score. The second most significant motivating factor was "wanted to benefit society through the research results". Undergraduates researching the Filtrón ranked "benefit society" as 1, 1, 1, 2, 3, 6, and not applicable; in comparison, undergraduate students who researched other topics ranked this aspect as 2, 7, and not applicable. All of the students who worked on an EWB-related independent study indicated that "benefit society" was one of the top 3 motivating factors for participation. For the M.S. level graduate students, the Filtrón researchers ranked a desire to benefit society as 1 and 2; non-Filtrón researchers ranked this as 1 and not applicable.

Of the other motivating factors, the main differences were:

- "clarify career interests" was less important to non-Filtrón or AST lab researchers
- "resume enhancement" and "wanting to create new knowledge" was less important to EWB participants than the lab researchers

Survey Results: Undergraduate Student Feedback on ABET-Related Outcomes

A number of the survey questions related to students' perceptions of how their experience resulted in learning benefits identified as important by ABET; results are summarized in Table 4. This table only includes feedback from the undergraduates because only the undergraduate engineering degrees at the University of Colorado are ABET accredited. The individual student responses have been averaged and the standard deviation shown. When the student left the item blank, a "4" was used for purposes of averaging, since that student only filled in responses of 1 to 3, then left other items blank. One of the EWB independent study student respondents (column 4) has also been listed in column 2 as the "AST" researcher (since the student received a UROP grant and did significant laboratory research in addition to her community-based EWB project). In general, students reported benefits that spanned all of the ABET A to K criteria. Differences between the types of experiences are generally less significant than individual response differences. However, the Filtrón and AST research topics yielded significantly higher gains for ABET criteria k, i, and j than non-AST research topics (based on student's t-test at 90% confidence). The students who worked on an EWB-related project had generally higher self-reported improvement in the ability to work on multi-disciplinary teams and understanding of professional and ethical responsibility. The students who worked on the EWB independent study projects reported less gain in the "ability to design and conduct experiments", with the exception of the student with who also wrote funding proposals and conducted significant laboratory experiments. Other responses, such as presentation skills, reflected differences in the specific expectations of the experience (REU students were required to give an oral presentation at the end of the summer; independent study students generally write a final report but do not orally present their research findings).

Table 4. ABET outcomes of the undergraduate student experiences, rated on a scale of 1 (strongly agree) to 3 (neutral) to 5 (strongly disagree); average ± standard deviation shown.

My experience improved my:	lab research on Filtrón and AST (n = 7)	non-AST lab research (n = 3)	independent study on EWB project (n = 3)
ability to apply knowledge of math, science, and engineering (a)	1.6 ± 0.5	**1.0 ± 0**	1.7 ± 0.6
ability to design and conduct experiments ability to analyze and interpret data (b)	1.4 ± 0.5 1.4 ± 0.4	2.3 ± 1.5 2.3 ± 1.5	3.0 ± 1.7 1.7 ± 0.6
ability to design a system or process to meet desired needs (c)	1.6 ± 0.8	2.0 ± 1.7	1.7 ± 0.6
ability to function on multi-disciplinary teams (d)	2.1 ± 1.5	3.3 ± 1.2	***1.0 ± 0***
ability to identify, formulate, and solve engineering problems (e)	1.6 ± 0.8	2.7 ± 1.2	2.3 ± 0.6
understanding of professional and ethical responsibility (f)	2.1 ± 1.1	3.0 ± 1.0	***1.0 ± 0***
Communication skills (g) writing skills presentation skills	2.0 ± 0.6 2.0 ± 1.0 2.6 ± 1.5	2.7 ± 1.2 1.7 ± 0.6 2.0 ± 1.0	1.7 ± 0.6 2.0 ± 0 2.3 ± 1.2
understanding of the impact of engineering solutions in a global and societal context (h)	**1.1 ± 0.4**	3.0 ± 1.0	1.0 ± 0
recognition of the need for, and an ability to engage in life-long learning (i)	**1.0 ± 0**	3.0 ± 1.0	1.3 ± 0.6
knowledge of contemporary issues (j)	**1.7 ± 0.5**	3.7 ± 0.6	1.3 ± 0.6
ability to use techniques, skills, & modern engrg tools necessary for engrg practice (k)	1.4 + 0.5	2.7 + 1.5	1.7 + 0.6

In Table 4, the numbers in **bold** indicate a statistically higher value at 90% confidence in a student's t-test comparing lab research on Filtrón and AST vs non-AST topics. Numbers ***italicized in bold*** indicate a statistically higher value at 90% confidence in a student's t-test comparing lab research on Filtrón vs EWB independent study projects.

Survey Results: Student Feedback on Broader Outcomes

There was a long series of questions designed to determine the broader outcomes of the student's experiences with research and/or EWB projects. These aspects were all taken from results reported by Seymour et al.[1], and students were asked to rates their agreement/disagreement on a scale of 1 (strongly agree) to 5 (strongly disagree). Some students simply left some aspects blank; one undergraduate student only indicated 1 to 3 on 40 of the 108 questions, leaving the others blank. Examples of outcomes from selected survey questions are provided in Table 5. Note that different groupings of student experiences have been made in comparison to Table 4. In addition, some students fit into more than one category; for example a survey respondent who was an undergraduate that conducted research on the Filtrón would be represented in both columns 2 and 4. The aspects listed are not fully inclusive. The three EWB project participants also universally indicated increases in: knowledge, critical thinking, motivation, intrinsic interest in learning, leadership skills, recognition of fit between own interests and environmental engineering, and understanding the nature of science and engineering. These were noted for their experiences working on the project at the University; the students separately noted the benefits of there field experiences in the international communities. The nine undergraduates who participated in laboratory research indicated increases in: the probability of going on to graduate school, understanding of how to approach research problems, and understanding of the research process. Responses among the five graduate students survey respondents were more diverse, likely due to differences in preparation prior to graduate school including previous research experiences and work as professional engineers. All students noted that the research experience helped them establish a mentoring relationship with faculty.

Table 5. Survey aspects ranked as 1 or 2 by all of the student survey respondents in the category

	Column headings are the # of students who responded to the survey in the group described			
Question: The experience increased my:	10 lab project undergrads	3 EWB project undergrads	5 MS researchers	8 Filtrón researchers (2 Grad; 6 UG)
self-esteem	x			
confidence	x			
confidence in ability to do research	x			
knowledge of sustainability		x		x
tolerance for frustration, setbacks, failure	x	x		x
ability to work independently		x		
willingness to take on responsibility for the project	x	x		x
lab/field skills	x	x	x	x
ability to formulate own ideas and contribute to project direction		x	x	x

Results: Faculty Mentor Impressions

From a faculty perspective, research on AST has been somewhat constrained by resource limitations since none of the projects on AST were conducted with traditional grants to fund the purchase of experimental supplies or fund graduate students as research assistants working toward a thesis. The lack of funding particularly for graduate student research assistantships has limited the number of students participating in the research. Student interest is high, but finding agencies to fund the work on a scale similar to other research has been difficult. To the open-ended survey question "what did you like least about your research topic/experience" one of the graduate students working on the Filtrón noted "lack of funding". Both graduate students researching the Filtrón also noted "lack of training [in the lab]" or "lack of knowledge base at the university" as other limitations and/or negatives of their experiences.

Prior to receiving the results from the survey instrument, my observations were that the quality of the student learning experience of the laboratory-based research projects are similar for AST and traditional topics. The AST projects combine requirements for in-depth understanding of fundamentals (chemistry, microbiology, fluids, statistics) with practical constraints of engineering applications. The quality of the experimental data in terms of ability to publish were similar for AST projects to the majority of other unfunded work conducted by undergraduates without the benefit of close mentoring by a graduate student. I believe that the undergraduate students who worked on the Filtrón or AST projects were more independent than is often the case, since long-term graduate student mentors were not available.

Verbally, two undergraduate students noted that they might have chosen environmental engineering as major instead, in hindsight given their research experience with the Filtrón. Both may try to pursue environmental aspects in their careers or when then return to graduate school. Thus, AST for developing communities is perhaps an under-recognized aspect of environmental engineering that might prove to attract more students to environmental engineering.

Results: Course Integration

The research on the Filtrón and AST has been incorporated into a number of different courses in Civil Engineering at the University of Colorado. Undergraduate students in the 4-credit junior/senior Water Chemistry course (CVEN 4424) are required to conduct a team-based water quality research project. In 2002, a group of four students (three female, 1 male) chose to conduct their laboratory study on the effects on the Filtrón on turbidity and nitrate concentrations in water. In the sophomore/junior Fundamentals of Environmental Engineering course (CVEN 3414), a lecture on AST for drinking water treatment and sanitation was added in Fall 2004. The web-notes that were written to support this lecture, due to a lack of topic coverage in the textbook, included research results from the Filtrón. In the senior capstone Environmental Engineering Design course (CVEN 4434), a team of students recommended that the community of San Pablo, Belize, use the Filtrón to achieve safe drinking water. The Filtrón has also been evaluated by other groups in their alternatives assessments for their service-learning projects.

Results: Outreach

The Filtrón has proven to be a good demonstration of environmental engineering for outreach activities to K-12 students. Examples of outreach activities include the open house for community members (usually perspective freshman students and their parents), the high school summer honors program, and engineering for middle school girls. Generally, the student researchers themselves have participated in these outreach activities. They are often better able to connect with and inspire the K-12 students than the faculty.

Summary and Conclusions

Although only a small number of students have completed research projects on the Filtrón or other appropriate and sustainable technologies for water and sanitation, to date it appears that this topic is able to provide benefits similar to that of other environmental engineering research. To confirm this impression, a greater number of students would need to participate in research opportunities and respond to the survey instrument. At present, differences in the length, time, and structure of the research experience itself seems more significant in determining the learning and personal outcomes for the students than the topic itself. Establishing funding in for AST research that is on par with other environmental engineering topics has proven challenging and is the only negative.

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