Grand Challenges DELI (Discover, Explore, Learn, Imagine) Project Update

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Dr. Jane Hunter is the associate director of the Engineering Management program at the University of Arizona. In addition to her responsibilities in Engineering Management, she oversees the required entry-level course Introduction to Engineering at the University of Arizona which enrolls 600+ students. She is actively involved in the high school version of the course that is offered at twenty-three high schools in the southwest United States. Dr. Hunter is the principal investigator for a NSF Transforming Undergraduate Engineering Education in STEM (TUES) grant to develop innovative, web-delivered units based on the Grand Challenges for Engineering. In addition, she is Key Personnel on a NSF ITEST grant awarded to the Southwest Institute of Research on Women (SIROW). Her B.S. and M.S. degrees are in Engineering and her Ph.D. is in Higher Education. Her primary research interest is developing educational materials that portray engineering as a profession that helps people for lower-division undergraduate and K-12 students.

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James C. Baygents is the associate dean for Academic Affairs in the College of Engineering at the University of Arizona. Baygents is a member of the Department of Chemical & Environmental Engineering (ChEE) and the Program in Applied Mathematics at the UA. Baygents joined the UA engineering faculty as an Assistant Professor in 1991, the same year he received a Ph.D. in chemical engineering from Princeton University. He also holds an M.A. (Princeton, 1981) and a B.S. (Rice, 1980) in chemical engineering. For three years prior to joining the UA, Baygents was a Visiting Scientist, then a Research Fellow, at the Space Science Laboratory of the NASA Marshall Space Flight Center in Huntsville, Ala. In 1995, he received the Arizona Mortar Board Senior Honor Society award for outstanding faculty service. In 1997, he was awarded an International Research Fellowship by the National Science Foundation for study at the University of Melbourne. In 2009, he was recognized by ChEE and the College for Excellence at the Student Interface. He is a member of Phi Beta Kappa, Tau Beta Pi, and Phi Lambda Upsilon honor societies, as well as the College of Fellows at Rice University's Will Rice College. Baygents's research interests include transport processes in natural and engineered systems; separations and water treatment processes; diffusion-reaction-precipitation in aqueous electrolyte systems; electrokinetic theory, measurements, and separations; electrically driven fluid motion and transport processes, including microfluidics; pattern formation in caves associated with Karst water systems; and industrial water treatment for recycle and re-use.

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Introduction

Here we report on data collected for a project in which five new web-based lines of study, referred to as Elective Units, were developed by engineering faculty members with expertise in topics related to the NAE Grand Challenges.[1] In a previous communication,[2] we described the rationale, development scheme and topical content of the Elective Units. In this work we summarize selected results for the first full-scale offering of the Elective Units to a large cohort of students (400+) enrolled in an undergraduate engineering program. The Units were designed to give freshmen and prospective engineering students, many of whom are still in high school, an opportunity to explore topics of their choice in the engineering foundation course, *Introduction to Engineering*, offered by the University of Arizona (UA). The selection of topics was based on a Grand Challenges Interest Survey administered to 100+ freshmen engineering students, as part of the groundwork for the project. Students participating in the Interest Survey were asked to investigate the fourteen Grand Challenges for Engineering established by the National Academy of Engineering and indicate which challenges captured their interests. The five new Elective Units were modeled after a pilot Unit that was developed and successfully delivered in Spring 2010 as a result of a Learner-Centered Course Redesign Innovation Grant, funded by the Arizona Board of Regents. The learning in the Units is experiential in that each Unit allows students to address, first-hand, various types of problems that engineers attempt to solve. The activities require students to use a variety of tools to investigate the topics in order to establish a foundation of knowledge. Students are encouraged to further investigate topics and make connections to the societal, global, environmental and economic context that frame the Grand Challenge. The assignments are designed to motivate students to engage in higher-level thinking. Vignettes, i.e. short videos, describing each challenge and emphasizing the important role that engineers play in solving these challenges, were recorded. In addition, detailed written descriptions of the Units were developed. Students use the vignettes and reference materials to decide which Elective Unit(s) they wish to study. They then have the opportunity to devote four weeks of the semester, roughly one Carnegie unit of effort, to the exploration of the topic by making use of the cyberinfrastructure.

The goals of the project are to increase the commitment of engineering students to the pursuit of engineering as an academic major and a profession and to increase the number of women and underrepresented minorities matriculating into engineering at the UA. These goals are predicated on several important factors. The geographic region, i.e. Arizona and the Desert Southwest, faces significant problems such as shortage of water and an aging infrastructure. These problems are aggravated by rapid population growth. State universities, such as the UA, are faced with the task to educate an ample supply of engineers prepared to address these significant challenges and foster economic opportunity. The 2008–09 U.S. Bureau of Labor Statistics Occupational Outlook Handbook[3] stated that "by 2015, more than 75 percent of the jobs will require workers with special skills in science, technology, engineering and mathematics," and that "the STEM gap will increase significantly in the future." Many universities across the US strive to produce sufficient engineering graduates. Therefore, recruitment and retention of students to STEM fields, particularly engineering, is a major priority. A second, more specific goal is to improve recruitment and retention of underrepresented groups including women and ethnic minorities in engineering. Women and ethnic minorities are significantly underrepresented in engineering. Successful implementation of the plans to enhance the commitment of students to the field of engineering should impact the long-term goal to increase the recruitment and retention of

students in engineering, and more specifically, increase the number of women and Hispanics who matriculate and ultimately graduate with engineering degrees from our university.

Project Evaluation: Selected Results from the Formative Stages

The evaluation plan includes formative and summative components. During the initial phase of the formative evaluation, a group of 18 volunteer students evaluated early prototypes of the Units (late Fall 2011 and early Spring 2012). Based on the feedback from this group of students, the Units were modified. The second phase of the formative evaluation involved a pilot of the Units in two sections (85 students) of the introduction to engineering course, during the latter third of the Spring 2012 semester. At the conclusion of the pilot, an online student survey and focus group discussions were conducted. In general, students' views of the online delivery were favorable. The Elective Units were well received with a high percentage of students indicating that having a choice positively impacted their learning for four of the six Units (Figure 1). Similarly, for four of the six Units offered during the Spring 2012 pilot, the percentage of students indicating that they were strongly committed to engineering increased (Table I).

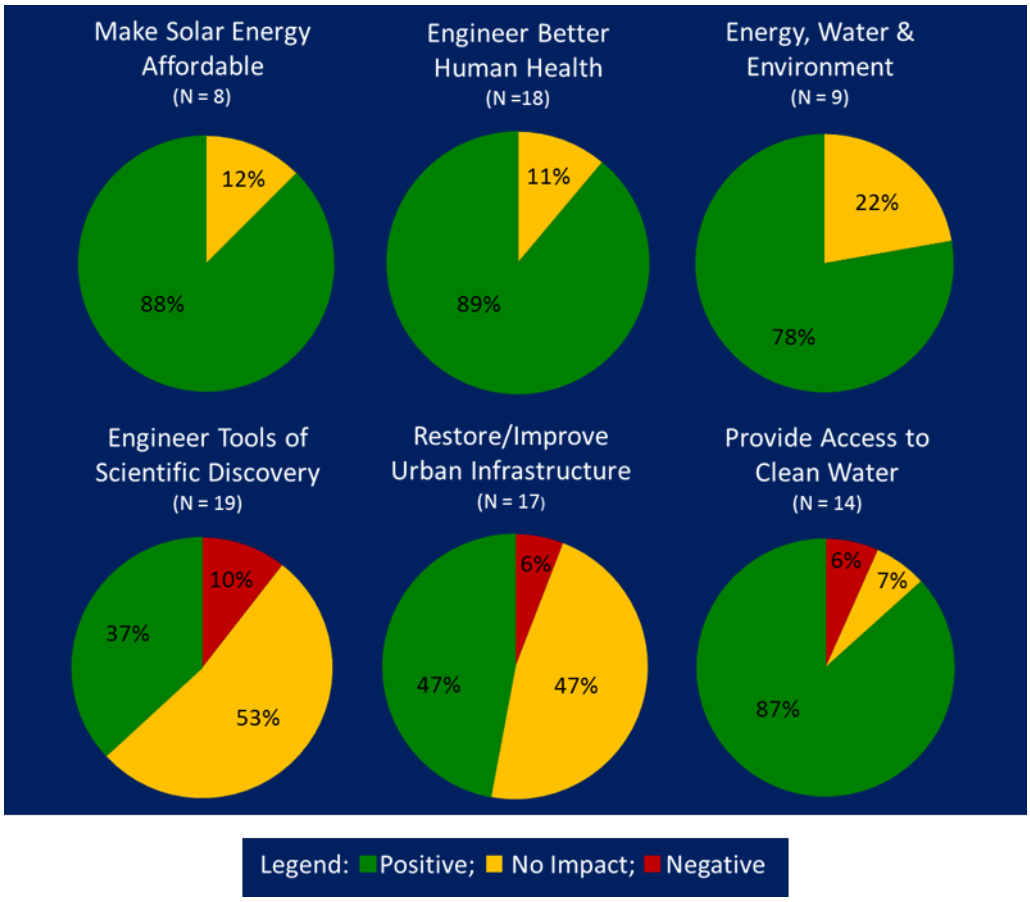

Figure 1. Impact of choice on student learning for Spring 2012 pilot.

Table I. Percentage of students who indicated they were strongly committed to engineering before and after taking an Elective Unit in Spring 2012 pilot offering.

Title of the Elective Unit	No. Students	BEFORE the Elective Unit	AFTER the Elective Unit
Energy, Water and the Environment	9	22%	67%
Engineer Better Human Health	18	27%	50%
Make Solar Energy Economical	8	37%	75%
Provide Access to Clean Water	14	40%	60%
Engineer the Tools of Scientific Discovery	19	58%	42%
Restore and Improve Urban Infrastructure	17	75%	53%
Total	**85**	**45%**	**55%**

The criticisms of the two units that did not yield an increase in student commitment to engineering, viz. ENGINEER THE TOOLS OF SCIENTIFIC DISCOVERY and RESTORE AND IMPROVE URBAN INFRASTRUCTURE, were largely focused on the work load associated with the materials—students thought the units involved too much work and did not see sufficient purpose or value in the assignments. So, prior to offering the menu of Elective Units to the full cohort of UA freshman engineering students in Fall 2012, improvements to the materials were implemented. Specifically, the scope of RESTORE AND IMPROVE URBAN INFRASTRUCTURE was reduced and the activities for ENGINEER THE TOOLS OF SCIENTIFIC DISCOVERY were streamlined. Based on feedback received in focus-group discussions, on-line instructions were improved and clarified for all the Units.

Summative Evaluation: Selected Results from Fall 2012

The Fall 2012 offering of *Introduction to Engineering* encompassed 11 sections of approximately 45 students per section. More than 400 of these students provided responses to an online survey completed toward the end of the Fall 2012 semester, following rollout of the Elective Units (suitably revised in accordance with the results of the Spring 2012 formative assessments). Consistent with the pilot offering, a high percentage of students indicated that they liked the opportunity to choose a topic of interest and that having a choice positively impacted their learning (data not shown).

Table II. Percentage of students who indicated they were strongly committed to engineering before and after taking an Elective Unit in Fall 2012.

Title of the Elective Unit	No. Students	BEFORE the Elective Unit	AFTER the Elective Unit
Energy, Water and the Environment	56	48%	57%
Engineer Better Human Health	121	37%	55%
Make Solar Energy Economical	32	56%	59%
Provide Access to Clean Water	31	48%	42%
Engineer the Tools of Scientific Discovery	101	53%	61%
Restore and Improve Urban Infrastructure	69	55%	61%
Total	**410**	**48%**	**57%**

In Fall 2012, the percentage of students indicating that they were strongly committed to engineering increased for five of the six Units, as summarized in Table II. In contrast to the Spring 2012 pilot, the Units on ENGINEER THE TOOLS OF SCIENTIFIC DISCOVERY and RESTORE AND IMPROVE URBAN INFRASTRUCTURE each yielded modest increases in the percentage of students commitment to engineering. However, the Unit on PROVIDE ACCESS TO CLEAN WATER did not show as well, when offered to a larger group of students (the reasons for this are currently under review). While there are certainly differences between the responses seen in the Spring 2012 pilot and the results for the full freshman engineering cohort of Fall 2012, the aggregated response of the students from Fall 2012 is remarkably similar to that found for Spring 2012.

In addition to commitment to engineering, students were asked to indicate their commitment to the topic area of the Elective Unit that they studied. Table III lists the percentage of students who indicated that they were somewhat or strongly committed to the topic of the Unit, before and after completion of the Unit. When these results are filtered, so as to include only those students strongly committed to the topic of their chosen Elective Unit (Table IV), one can see that the Unit on MAKE SOLAR ENERGY ECONOMICAL did not have the desired result on students strongly interested in the topic. One possible explanation for this specific result is that this particular unit emphasized the economics of solar energy, including the mining and refining of raw materials (e.g. silicon for photovoltaic cells), as opposed to the science and/or materials science and engineering of solar energy. Efforts are underway to determine in what respects particular Units are deficient and/or require refinement.

Table III. Percentage of students who indicated they were somewhat or strongly committed to the topic of the Elective Unit, before and after completion of said Unit in Fall 2012.

Title of the Elective Unit	No. Students	BEFORE the Elective Unit	AFTER the Elective Unit
Energy, Water and the Environment	56	52%	70%
Engineer Better Human Health	121	61%	76%
Make Solar Energy Economical	32	34%	38%
Provide Access to Clean Water	31	42%	58%
Engineer the Tools of Scientific Discovery	101	47%	54%
Restore and Improve Urban Infrastructure	69	33%	62%
Total	**410**	**48%**	**63%**

Table IV. Percentage of students who indicated they were strongly committed to the topic of the Elective Unit, before and after completion of said Unit in Fall 2012.

Title of the Elective Unit	No. Students	BEFORE the Elective Unit	AFTER the Elective Unit
Energy, Water and the Environment	56	23%	41%
Engineer Better Human Health	121	31%	45%
Make Solar Energy Economical	32	16%	3%
Provide Access to Clean Water	31	13%	10%
Engineer the Tools of Scientific Discovery	101	13%	19%
Restore and Improve Urban Infrastructure	69	14%	28%
Total	**410**	**20%**	**29%**

Discussion

As this point it seems clear that much of the course material developed on this project has had a beneficial effect on the students enrolled in the freshmen-level introduction to engineering course at the UA. Prior studies show a positive relationship between interest in a subject and persistence for science and engineering majors.[4,5] Furthermore, lack of commitment to a career in engineering may be key to explaining non-persistence.[6] It is not surprising, then, that students reported that having a choice of which Elective Unit to study had a positive impact on their learning. Four of the six Units clearly increased the number of students strongly interested in the topic they chose (see Table IV), which suggests reinforcement of the students' choices and this may be related to why students also report an increased commitment to engineering (Table II).

One very important consideration in offering these Elective Units as part of a general introduction to engineering course is that, in doing so, we provide the students some autonomy and a chance to take control of their learning. Two of the course goals are centered on retention and student maturation. It seems more than obvious that one cannot cover all the various engineering disciplines in one course. Moreover, even if one could, a significant fraction of the students would be disinterested in the material at least some of the time. For example, many students interested in electrical and computer engineering are not likely to feel engaged when a hypothetically comprehensive introductory course turns to, say, chemical engineering or mining engineering. The online format of the Elective Units allows topics of specific interest to be embedded in a course that also covers topics of general interest, while encouraging students to take an active interest and role in their learning at a comparatively early stage of their development.

Based on the limited data set collected to date, the impact of the Elective Units for female and ethnic minority students did not differ significantly from that of the overall population of students. Female and ethnic minorities respectively comprised about 25% and 35% of the students involved in the study to date, which constitutes a pool of 125 to 175 students spread over six topic areas—so it seems hazardous to try to draw inferences about gender and ethnicity. Continued offerings of the Units will be evaluated to ascertain if significant gender or ethnicity

differences emerge. In general, retention of students in the STEM fields requires a high level of student commitment, particularly for underrepresented students who are faced with unique challenges in addition to the rigors of their studies. Leslie, McClure and Oaxaca[7] concluded that commitment to science and engineering is one of the most powerful concepts explaining the gender gap in science and engineering.

Going forward, the task is to sift through the recently-collected data to establish what should be improved in the individual Elective Units. To weigh these measures, survey data such as that shown in Figure 2 will be used. In this instance we show data that pertain to the learning activities associated with the Units. These data will be disaggregated at the level of the Elective Units, and compared with written/oral comments provided by students, to guide revisions to the material.

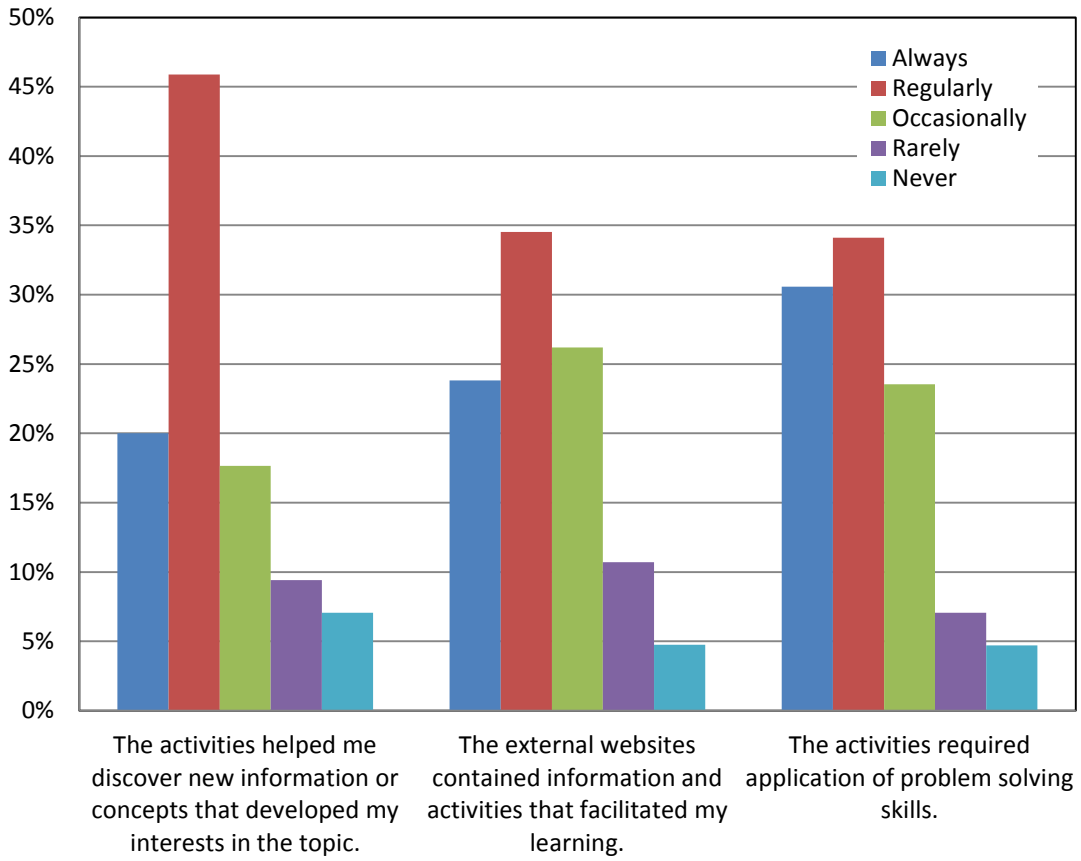

Figure 2. Student assessment of Elective Unit learning activities. The vertical axis gives the percentage of students who rendered a response of "always," "regularly," "occasionally," "rarely" or "never" with respect to the statements given on the horizontal axis.

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