Continuously Improving a Diversity-Bolstering System through Integrating Quantitative and Qualitative Engineering GoldShirt Program Facets

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Evidence-Based Practice: Continuously Improving a Diversity-Bolstering System through Integrating Quantitative and Qualitative Engineering GoldShirt Program Facets

Abstract

The University of Colorado Boulder Engineering GoldShirt Program was created and launched in 2009, with the aim of providing an alternative pathway to and through university engineering programs. Using an Inclusive Excellence framework, the program provides a system of initiatives to broaden the participation of students traditionally underrepresented in engineering. The Engineering GoldShirt Program is committed to a research→practice→research cycle. This paper focuses on the implementation of research driven program changes in one facet of the Engineering GoldShirt Program— the Explorations through Physics course—an essential first year preparatory course preceding calculus-based physics. Results from our work demonstrate the need to combine and carefully weigh quantitative and qualitative research results real-time to make well-informed and timely programmatic decisions that directly impact student performance and retention. We advocate for engineering colleges to move away from single intervention approaches for bolstering diversity to systems approaches that encompass myriad academic, social and engineering identity development components to attract and retain underrepresented students in engineering.

Motivation

For 30 years, U.S. engineering colleges have created and supported specialized programs aimed at attracting and retaining diverse populations of engineering students. While many programs have produced significant assessment and research results, national achievement in *broadening participation in engineering* has remained flat[1]. Given the number and differing objectives of diversity-focused engineering programs, unimpressive national outcomes suggest that pathways to and through engineering appear blocked to students from underrepresented groups. Additionally, potential remedies to alleviate blockages remain unclear.

This paper challenges the notion that single, “silver bullet” approaches can sufficiently expand access pathways to and through engineering *enough* to impact the profession as engineering educators aim to be more responsive, and responsible, for significant outcomes in an environment of shifting population demographics. We posit that holistic investigations, characterizing the multi-faceted components of a *broadening participation system*, could be key to successfully increasing diversity in engineering.

Background

For five years we have investigated and honed an *inclusive excellence* system aimed at broadening the participation of underrepresented students in undergraduate engineering. Inclusive excellence refers to creating pathways to and through engineering that promote success for a highly diverse student body through learning communities, engaging academics and innovative policies and practices. A main facet of this system is the Engineering GoldShirt Program. This paper focuses on a mixed-method research process used to assess and continuously redesign all components of the model at the core of the *inclusive excellence* system, specifically academic components of three science, math and engineering design foundation courses. We focus on a preparatory physics course as the exemplar for the integrated program evaluation and evolution process that has advanced the program and curriculum.

The Engineering GoldShirt Program's first-year curriculum is characterized as a *performance enhancing year*, including preparatory mathematics, physics and leadership courses, as well as small-section, interactive courses in engineering design and humanities. The foundation math and physics courses are continually assessed using both qualitative and quantitative feedback measures, and redesigned as necessary to promote engineering success and retention. Wrapping the academic components of the course is an engaging two-year living and learning community that our data shows is highly valued by the program's participants.

Early on, the program's design and implementation team realized that evaluation of program outcomes would be complex, would go far beyond the academic component, and would require a different way of looking at system *inputs*. We soon came to appreciate that better understanding of early program outcomes required knowledge and experience beyond that of our engineering faculty. We sought help from School of Education faculty experienced in qualitative program evaluation in an engineering college setting (lucky us), with an aim of integrating qualitative and quantitative program outcomes to provide a rich picture of our students' experience.

Method

Various *qualitative* methods were thus employed, including ethnographic fieldwork, indirect observations in courses and learning communities, focus groups and ethnographic interviews. Constant comparative analysis, involving concurrent engagement in data collection and analysis, served as the primary analytic approach for the ethnographic data. The analysis of early fieldwork led to a preliminary grounded theory, which in turn led to further fieldwork to refine the theory through multiple iterative cycles.

We simultaneously employed *quantitative* methods, including tracking of student performance variables, pre- to post-test analysis using t-tests and repeated measure ANOVA, predictive analyses such as exhaustive CHAID, and multiple regression and correlational analyses.

Both qualitative and quantitative data were shared with the implementation team to support real-time program changes. The analysis included all aspects of the student experience including: family and residential life, interaction with GoldShirt program participants and other engineering students, advising and mentoring, curricular components, and GoldShirt program culture. A key approach to our mixed-method research is that both the qualitative and quantitative results were shared *real-time*; thus, the two different types of data were converted to evidence-based *information* that helped the curriculum decision-makers quickly implement changes with a high degree of confidence that the changes were program improvements.

Several major outcomes emerged from this work that have already been put in practice in our college. Implementing a "research → practice → *research more*" evidence-driven cycle allows us to test program "improvements" real-time to see if they really are.

Results and Discussion

The research team met regularly to review and interpret the extensive qualitative and quantitative data to find patterns to inform our thinking on recommendations for future changes to the program. Data integrated include analysis of: 11 focus-group results; over 200 hours of field observations from courses and other routine activities; 24 interviews; input gathered via one-on-one relationships between researchers and individual students; course pre- and post-survey results; qualitative and quantitative course student group exit interview results; annual program feedback survey results from students; and quantitative academic performance measures in courses. While many comprehensive academic and learning community program changes were made as a result of these qualitative and quantitative inputs, in this paper we highlight the research *process* as it applied to the evolution of the preparatory physics course.

During the first four years of the Engineering GoldShirt Program, most students took a traditional preparatory physics course to prepare for calculus-based physics. The physics course was designed for the program's high potential GoldShirt engineering students, who mostly hail from minority-dominant high schools where the availability of higher-level math, science and AP level courses is limited, or where success in those courses did not sufficiently prepare the GoldShirt students for the college-level engineering curriculum. While the course increased students' knowledge of physics as assessed by a standardized, nationally normed Force-Motion Concept Evaluation[2] (FMCE) assessment (average gain of 0.21), and students did reasonably well in the subsequent calculus-based physics course, we ascertained that the course could do much more to boost students' confidence in engineering and prepare them even more to academically excel in the subsequent physics course and beyond. Hence, a significant course redesign was implemented for GoldShirt cohort 5 in fall 2013.

Both structural changes in the course and implementation strategies were modified for fall 2013. Notably, the Engineering GoldShirt Program director had previously taught the course, but pervasive qualitative feedback from students revealed that having the program director also teach the first-semester physics course over-exposed students' prior and current academic performance, such that students felt they could not have a "normal" faculty/student relationship in the course. In essence, all of their prior program baggage went into the classroom every day; they could not hit the "reset" button as students typically do every semester as they encounter different instructors. We became convinced through student testimonials that they needed to feel like, and be "regular" engineering students. Yes, they were admitted through a special program because of their potential, but once in the engineering college, students just wanted to be "normal."

To boost both students' learning and their beliefs that they belong in engineering, in fall 2013 we converted the traditional preparatory physics course to a hands-on format, implementing weekly engineering-focused laboratories that focused on data collection, analysis and synthesis, and flipping the classroom to an active-learning format. We converted the course from a PHYS (physics) nomenclature to GEEN (General Engineering) and renamed the course *Engineering Explorations through Physics* to underscore its applied, engineering-focused nature. All resources previously developed for the course were shared with a new instructor, and a close collaboration between the previous and new instructor ensued. The course structure was continually monitored and changed throughout the semester, based on real-time qualitative and quantitative student feedback and performance.

Of major note was that the students—all new to engineering and college in the fall semester–found the flipped classroom too disarming, and too unfamiliar based upon their prior knowledge and experience. So we backed off, and lectured a bit more. By the last one-third of the 15-week course, students reported that the new pedagogy, which included 15 to 30 minutes of traditional lecture per week, worked well.

Gains in Content Knowledge Do Count: Quantitative results from our fall 2013 offering were remarkable. Student scores on the FMCE, a well-respected standardized physics test, were by far the highest (average 31.4 out of a possible 47) of all five cohorts to date, and the gains from the pre- to post-test were also, by far, the highest ever, as shown in Table 1. Without a doubt, students' physics preparation was significantly increased through the course redesign and separating instruction from program administration.

We attribute these results to real-time, applied assessment: we sought continuous and deep feedback, and the instructor changed the course structure in real-time, based on student feedback and performance throughout the course. During the end-of-course mixed method student group feedback session, students confirmed their desire for the entire course to have been conducted as it was during the last five weeks. From student surveys, another crucial improvement from previous course offerings was implementing weekly hands-on laboratories with real-time data collection and analysis. Students reported these labs as among the most beneficial aspects of the course.

Table 1. FMCE pre- and post-semester scores for students in a preparatory physics course.

Year	Average Pre	Average Post	2013 % Increase-Post Test	Gain*	2013 % Increase-Gain
2009	**8.2**	**20.0**	**57%**	**0.28**	**107%**
2010	**10.2**	**14.6**	**116%**	**0.15**	**287%**
2011	**9.6**	**15.3**	**105%**	**0.12**	**383%**
2012	**12.2**	**22.0**	**43%**	**0.33**	**76%**
2013	**10.2**	**31.4**	**—**	**0.58**	**—**

* Gain = (posttest% - pretest%) / (100-pretest%)[3]

Not Good Enough-Yet. Apart from the impressive content gains, qualitative investigation revealed that students were not particularly happy with the redesigned class nor with their perceived level of learning. At the end of each semester, outside facilitators conduct a course-wide mixed-method exit group feedback session in which students work in teams to define the course strengths and suggestions for improvement. Students then individually and anonymously rate the extent to which they agree with the student-defined course strengths and suggestions for improvement. This process revealed 29 areas identified by students as needing improvement; privately, at least two-thirds of the students agreed with 16 of those. In summary (and to our surprise), students did not appreciate the flipped classroom; they wanted more class lectures. They also had considerable dismay about the less-than-seamless integration of resources employed in the course—the textbook, online homework, labs, notebooks, pre-lecture videos, etc. The students articulated that the course moved down different tracks that did not coherently merge; to help facilitators understand the significance of the issue, a student drew a diagram on the whiteboard of three parallel tracks. Additionally, some students reported a diminishing motivation as the course proceeded; this was in part the result of a repetition of material that they had learned in high school, but without an openness to allowing them to do things in familiar ways. Another critique of the course, and one that resonated with a more general critique of the Engineering GoldShirt Program, was that the course did not seem like the "real physics" that they had expected in college, but rather that it seemed like a "fifth year of high school." Coupled with qualitative observations, interviews and focus groups throughout the semester, it was clear that many students were not happy with their physics experience during the fall 2013 course offering. And, because we care about retention in this program, we cared about how students characterized their learning experience. In short, the impressive content gains were not deemed to be sufficient.

Another source of feedback from students was the university's Faculty Course Questionnaire (FCQ) administered at the end of each course. The fall 2013 FCQ results showed that the course and instructor overall ratings were lower than those in similar courses in the college, with median ratings of 4 out of 6 for both. The average course rating was 3.7 and the average instructor rating was 3.6 on the same scale. Of note was that no student rated the instructor with the highest rating of 6. This was no surprise, as this was a new course instructor, with a completely redesigned course, and we had articulated that, with a dedicated and caring instructor, it would take three offerings of the course to get to excellence. But our results still disappointed the team.

Or Was It Good Enough? Analysis of student performance in their *subsequent* calculus-based physics course—the first physics course that direct-admit students not in the Engineering GoldShirt Program typically take—in spring 2014 showed that all GoldShirt students who first took the *Engineering Explorations through Physics* in fall 2013 were successful in the subsequent physics course. This is a remarkable outcome by any measure, and particularly when one considers that Engineering GoldShirt Program students are more academically at risk than our overall engineering student population. And, the results were in contrast to our college-wide results, in which 5% of engineering students were unsuccessful that semester in the same physics course.

Subsequent Results Matter. While at the time, GoldShirt students perceived their *Explorations* course grades to be too low, and not indicative of their knowledge level, analyses revealed a statistically significant correlation between students' numeric grades in *Explorations* and their subsequent calculus-based physics numeric grade ($r=0.6382$, $r^2=0.4073$, $p=0.004$), showing that the student performance in the hands-on preparatory course was predictive of their future physics performance. About halfway through the subsequent physics course, students were asked to reflect on the preparatory physics course; many boasted of their success and shared what a great teacher the *Explorations* instructor had been after all. Several promptly went to his office to tell him so. Hindsight indeed has its value.

Significance of Responding to Integrated Qualitative and Quantitative Results. Our big lessons were both about process and perspective. If we had only quantitatively looked at the impressive content gains achieved in fall 2013, without considering the student feedback, we may have concluded great success and that the instructor should subsequently keep everything as it was during that implementation. By contrast, if we had only listened to the students' qualitative feedback without measuring their content gains and subsequent semester physics performance, we may have assumed that the instructor was not effective. Only when we considered all the sources of information, balancing what we heard with what we qualitatively and quantitatively measured, could we weigh the importance of a single piece of data and make well-informed, course-improvement decisions that focused on student performance and retention.

Spinning the Flywheel: Second Explorations Implementation. For the fall 2014 course implementation, many curricular and pedagogy changes were made to address the student suggestions for improvement in course flow. Our goal was clear: maintain the content gains, but do so through a learning experience and process wherein students are happier, real-time, about the learning experience. With myriad changes to the course, students continued to score well on the FMCE (average gain of 0.55, statistically equivalent to the fall 2013 results). The students' post-course FMCE subject area performance was also evaluated; results in particular topical areas will be used to alter the curricular focus in the third implementation of the course, putting less focus in one area (e.g., velocity graphs) and more in another (e.g., energy). Qualitative focus groups and interviews contrasted dramatically with those conducted during the 2013 offering. While in the previous year students had frequently offered unprompted criticisms of the course, students taking the 2014 offering did not critique the course during these data collection sessions. The fall 2014 course-wide end-of-semester, mixed-method group feedback session revealed 18 areas identified by students as needing improvement; privately, at least two-thirds of the students agreed with 11 of those—more in line with what we find for engineering courses that students appreciate. And, the overwhelming *feeling* among students was more positive than the previous year. The suggestions were generally small, easy-to-implement "tweaks" rather than overall course issues. An example of one "tweak," and the suggestion with most private agreement (96%) among student participants, was that the online homework should provide explanations for wrong answers. This type of suggestion is easily addressed but does not create concern about the course structure or the instructor. The prior issue of three different tracks was not even mentioned by students, suggesting the issue was addressed and resolved.

The fall 2014 FCQ results for the course and instructor also improved. The median rating improved to 5 out of 6 (from 4) for both the overall course and instructor, with average ratings of 4.2 and 4.4 respectively (up from 3.6 and 3.7). A drastic improvement was that 8 (30%) of the 27 students who provided FCQ feedback rated the instructor with the highest rating of 6, whereas none had the year before. *That* is progress!

Letting a Practice-Research-Practice More Model Drive Change. We designed the *Engineering Explorations through Physics* course with a focus towards fostering a positive and encouraging learning environment for students in the belief that *experiences do matter* in whether students choose to remain in engineering. We wanted students to achieve academic success while they were finding their ways in their first college semester, and to have a positive association between engineering and the fundamental science and math courses that lie ahead of them. So we listened, a lot, and trusted what students had to say about their learning. We asked for their help to make the course better for their successors. And, we were humble when we initially failed.

As a team, we were committed to finding a pathway for success for students who, by and large, and for a variety of underlying reasons, had limited tradition and/or prior experience with the intensity and quality of work that is required to succeed in this first semester *Engineering Explorations through Physics* course—and by inference in the subsequent engineering curriculum. For this four-credit hands-on course, we found that calibrating students' workload expectation was aided by developing language around "double digits." As in, you should expect to be working *double digits* (10 or more hours weekly) outside of class, or, "are you preparing double digits for the exam?"

Multiple teaching and learning modes, addressing a variety of learning styles, were implemented for each course topic—all with a tie towards addressing real-world engineering topics. Each module was assessed, and real-time changes resulted in a more optimized course design. This practice-research-practice *more* model is made possible by the energy and genuine interest in improvement of a multi-disciplinary course and instructional team, which includes undergraduate learning assistants, an assessment specialist, and engineering education and educational researchers.

The contribution of learning assistants was invaluable to the fall 2014 implementation. The three assistants were Engineering GoldShirt Program sophomores; two were alumni of the fall 2013 *Explorations* course. We purposely selected optimistic students who had both excelled and struggled in the course, knowing they could be powerful role models. The assistants were hired a semester in advance to actively contribute and vest in the course improvements; their input provided a lens to pedagogy that is relevant to students. The two primary assistants were trained in the Socratic method of teaching, and at least one assistant was at each class session to help facilitate the active-learning activities. And, learning assistants attending class helped maintain consistency between the classroom and help sessions, which were held three nights weekly in the residence hall of the GoldShirt participants. The end-of-semester group feedback results indicated that the learning assistants and the frequent help sessions were highly rated course strengths.

The small class size of ~30, which is slated to increase to 48 for fall 2015, allowed for course innovation and change. We could assess the degree of student learning in a measured way that led us to understand which approaches really worked and how to develop class activities that were effective. This was an exciting and meaningful way to develop a critical course with impact, while learning about what motivates these high-potential, less-prepared engineering students to achieve their short term performance goals as well as their long term dreams.

Next Steps

As we continue to test and redesign numerous components of our Engineering GoldShirt Program and our inclusive excellence model, using both quantitative and qualitative measures will be essential to better understand our student experience and outcomes. The continued analysis will include all aspects of the student experience such as family and residential life, interaction with GoldShirt program participants and other engineering students, advising and mentoring, curricular components, and Engineering GoldShirt Program culture. Specifically, the *Engineering Explorations through Physics Course* will be offered again in fall 2015 with improvements clarified by students' qualitative and quantitative feedback and quantitative standardized test results. Every component of the Engineering GoldShirt Program and inclusive excellence model will be continuously monitored and adjusted based on the ever-evolving feedback and results.

Conclusions and Significance

While our results show great promise, and demonstrate the power of assessing learning outcomes *and experiences* as both being relevant to broadening participation in engineering, room for growth and improvement still exist. Our original charge to the instructor was to do his best to achieve high learning outcomes through having high scholarly expectations, listening (and responding) to students, and aiming to make the course excellent by the third offering. He had set a personal goal of achieving excellence by the second offering, but has come to realize that while he did his best each time, achieving excellence with a new course model while teaching new material takes practice, a continual look at student performance *and experience*, and thick skin. Having so many colleagues continually peering into course results (and his classroom!) takes a high degree of both peer trust and a commitment to making what is best for students one's first priority.

We highlight one course in the students' first-semester experience to demonstrate how a suite of qualitative and quantitative approaches and results together can provide a complex picture of the student experience, facilitating rapid cycling of the continuous improvement process. However, we did not only look at physics; we were focused on the entire five-course curriculum that most GoldShirt students engage in their first semester and looked beyond the academic curriculum as well.

The Role of Choice in Student Success. Educational environments that support autonomy have been shown to foster self-motivation, increased engagement, higher-quality learning and personal well-being[4-6]—all outcomes with the potential to positively impact retention in engineering programs. Through this qualitative work we came to understand the critical role that *choice* plays in the GoldShirt students' perceptions of being "real engineers."

Taking performance-enhancing year courses mostly with their peers made the GoldShirt students feel too separate and led them to question whether they were "real" engineering students; this was a pervasive theme in the qualitative work, and was explicitly raised by a majority of students. This was a huge takeaway for the research and implementation team. For the following year, the Engineering GoldShirt Program completed more upfront readiness assessments in the summer bridge program, and looked at every opportunity in the first semester curriculum to give students more options and autonomy in course choices. Through the summer, the Engineering GoldShirt Program director urged each student to improve his/her math skills prior to math course placement. As part of the course selection process during the summer bridge program, students received individual advising sessions during which advisors explicitly discussed the kinds of decisions to be faced: Should they move directly to calculus or start with pre-calculus? Should they take *Explorations*, or move directly to calculus-based Physics I (few are that math ready)? Which of two first-year design courses did they prefer? Were they particularly interested in one of the departmental introductory to engineering courses? Were they ready for a programming course? Students' first-semester humanities course is residence-hall based and enjoys a great reputation; thus, no pushback against taking that course was encountered. In the end, the courses fall 2014 students chose did not vary much from prior cohorts, but they were empowered to own—and understand—the placement decisions. Preliminary qualitative findings are promising—students in this cohort have not raised issues such as the "fifth year of high school" critique that was so prominent in previous cohorts.

The Importance of Integrating Qualitative and Quantitative Data. Looking back, we are thankful that we invested so much effort to better understanding how to make the first semester of the GoldShirt students' performance-enhancing year meaningful. Because we tried to measure everything, we found that listening to only one source of information could lead us to draw a wrong conclusion. Using the *Exploration*s course as an example, if we had only looked at student content gains as our measure of success, without considering how students felt about their learning experiences, we may have continued, unknowingly, to offer a course design that was at cross purpose to our retention goals. Conversely, if we had only listened to student feelings and complaints about the course, we could have made course design changes that lost the dramatic content knowledge gains that are a successful outcome of the course. But taken together, and situating the course within a first-semester experience that benefitted from more student choice and autonomy, enables us to move closer to understanding how to retain this population of high-potential, diverse students—many of whom share being underrepresented minority and/or first-generation college and/or English Language Learning and/or low income students within a college that is populated primarily by Caucasian, upper income progeny of college educated parents.

To achieve breakthroughs in broadening participation in engineering, we have begun to understand some of the subtle pieces that can lead to a system that provides multiple "on ramps" to engineering college, and supports diverse students to achieve their dreams, stay the course and one day contribute as engineers to the health and prosperity of our nation.

In just five years, the Engineering GoldShirt Program has become a mainstay of the access, retention and performance components of our engineering college's inclusive excellence system, and has dramatically shifted the college's *diversity through excellence* outcomes. A key component of its success has been the integration of real-time quantitative and qualitative research to drive program and curricular evolution.

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