Integrating Humanitarian Engineering Design Projects to Increase Retention of Underrepresented Minority Students and to Achieve Interpersonal Skill-Related Learning Outcomes

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An Evidence Based Practice: Integrating Humanitarian Engineering Design Projects to Increase Retention of Underrepresented Minority Students and to Achieve Interpersonal Skill Related Learning Outcomes

Abstract
This complete evidence-based practice paper analyzes the effectiveness of a newly implemented design project module in a second-semester introduction to engineering course at Chandler-Gilbert Community College (AZ). Engineering and library faculty have collaborated with biological sciences faculty, local industry, and the college’s facilities director to develop and implement the project each semester since Fall 2014.

This seven-week design project module introduces freshman engineering students to the National Academy of Engineering’s (NAE) Grand Challenges for Engineering (2017), providing students opportunities to discover and explore the myriad of ways engineering serves to improve society. Engineering programs typically see student retention rates of only 60% after the first year, and the percentage of women in most undergraduate engineering programs has remained at or below 20% for decades, as estimated from enrollment and degrees awarded from National Center for Science and Engineering Statistics data (2012). Further research indicates that women in engineering programs value social context in their program of study. To this end, the design project discussed in this paper integrates humanitarian application experiences using the NAE Grand Challenges as well as campus-specific projects.

It is hypothesized that implementation of this module will a) increase students’ perspective of engineering as a socially meaningful career option and, b) show higher retention and successful completion by female and underrepresented minority students enrolled in the course.

This paper describes the design project module and its effectiveness to date. Effectiveness was evaluated using Chandler-Gilbert Community College’s Institutional Research’s fall 2014 through fall 2016 data on students’ enrollment and successful completion of the course, as well as ongoing assessment of graded materials and institutional student learning outcomes. Successful completion of the course among female students and underrepresented minority students was 100% and 94% respectively in the Intervention sections as compared to 81% and 77% in course sections at the same institution taught with traditional curriculum and 86% and 87% for course sections taught across the community college system (district-wide) using traditional curriculum.
Introduction

This evidence-based practice paper analyzes female and underrepresented minority community college students’ retention and successful completion in the second-semester introduction to engineering course, ECE 103: Engineering Problem Solving and Design, that uses a newly implemented college infrastructure/human development focused project model as part of the curriculum. This college infrastructure/humanitarian development design project model introduces freshman engineering students to the National Academy of Engineering’s (NAE) Grand Challenges for Engineering (National Academy of Sciences, 2017) providing them opportunities to discover and explore the myriad of ways engineering serves to improve society. The model uses five of the NAE’s 14 Grand Challenges for Engineering and integrates project-based learning and information literacy strategies into an application experience that challenges the students’ worldviews and perception of engineering.

Chandler-Gilbert Community College (CGCC) is one of ten colleges in the Maricopa County Community College District (MCCCD) and has a student annualized headcount of 14,630, drawing students primarily from east valley communities in the Phoenix area. According to the Maricopa Trends Report (2016), 72% of CGCC student body is part-time credit seeking, and 81% of the student population is 24 years of age and under. Females constitute 53% of total student population and males at 47% of the total student population. American Indian, Pacific Islander, Black and Hispanic students represent 35% of the total student population with Whites representing 52% of the student population.

The creation, implementation, and assessment of the new project module is grounded on the Grand Challenges DELI (Discover, Explore, Learn, Imagine) Project (Hunter and Baygents, 2012) and CGCC’s institutional pedagogy. The Grand Challenges DELI model originated after a 2011 strategic planning process that began with a strength, weakness, opportunities and threats (SWOT) analysis of the current first year engineering experience. The SWOT results were used to identify short and long term goals for a next generation first year engineering experience. Those goals embraced student-directed learning through an “emphasis on societal, global, environmental and economic context” and integrating the engineering design process and tools such as SolidWorks.

Engineering programs typically see student retention rates of only 60% after the first year, and the percentage of women in undergraduate engineering programs has remained at or below 20% for decades (with the exception of bioengineering), as estimated from enrollment and degrees award from National Center for Science and Engineering Statistics data (2012). Research indicates that women in engineering programs value social context in their program of study. Kolmos, Mejlgard, Haase and Holgaard’s research on gender and motivational factors revealed that “Wanting to make a difference in the world” was stronger for female students and “inventing something new” was stronger for male students (2013). Engineering programs’ student retention research done by Amelink and Meszaros indicates that female students value connecting with other females with a passion for engineering and participating in student organizations and in study groups; “females explained that it was the intrinsic benefits received from participation in such programming that served to encourage them” (2011). Both female and male engineering students expressed frustration that it was “two years into the degree program before they had a chance to begin making connections between coursework and applying the knowledge they learned in entry-level classes to real-world problems” (2011).
Problem and project-based learning pedagogy is a core value and practice for Chandler-Gilbert Community College. It is integrated in courses, programs, and service learning and cross curricular initiatives. “PBL is learning that best be an active and contextualized process” allowing students to actively construct their own knowledge and apply it, rather than the passive exposure of knowledge via the traditional lecture model (Maurer and Neuhold, 2012). A comprehensive problem or project-based learning approach incorporates multiple skills and measurements for content and communication. The engineering design process requires teamwork, interpersonal, and both oral and written technical communication skills. Workplace readiness studies have indicated there is a competency gap between graduates’ soft skills (social, leadership, workplace diversity) and what is needed by employers. Students have the content and technical knowledge, but they lack the skills and experience to share that knowledge in an accessible way, with diverse groups and in multiple modes as dictated by the nature of the project or workplace. Jollands, Jolly and Molyneaux’s 2012 research on engineering curriculum that requires multiple technical writing, presentation and communication opportunities, that includes peer and faculty feedback, better prepares their graduates for the workplace. An Economist Intelligence Unit Report, Driving the Skills Agenda: Preparing Students for the Future (2015), states that the most highly sought after workplace skills are problem solving, team working, and communication; critical thinking and creativity round out the top five.

Engineering faculty began in fall 2014 to collaborate with library and biological science faculty and the college’s facilities director to develop and implement the Grand Challenges for Engineering design projects as part of a first-year engineering experience. The Grand Challenge design projects described in this paper are designed using a project-based learning approach, integrating college infrastructure and humanitarian applications, and utilizing a feminist technologies studies framework as described by Riley et. al (2009). Scaffolded deliverables require the students to think beyond the standard definitions of engineering as “problem solving” or the “application of science,” to contemplate more socially grounded questions such as “For whom do engineers work?” “What is the role of science in engineering application?” “Who benefits from engineering solutions, and what populations are overlooked?” and to articulate this information in written assignments and to their peers through class presentations.

The projects are carried out over a seven-week period at the end of the semester. The projects are done in teams of four students, and each team is provided with a unique project. This allows students to both a) select a project in which they are most interested, and b) broaden their worldview by learning about other projects and challenges through guest lectures and peer class presentations on the other topics. The details of each project are constructed around local design opportunities and resources to make the experience as “real life” as possible for students.

**Methodology**

Typically, three to four sections of ECE 103: Engineering Problem Solving and Design with a student capacity of 24, are offered each semester at the college. Students self-enroll, based on the day and time the section is offered or prior experience with or knowledge of the faculty. At this time, only one of the three faculty teaching this course has implemented the Grand Challenges problem-based learning model. The other sections are taught using traditional curriculum. Using the Grand Challenges DELI model (Hunter and Baygents, 2012) as a starting point, the Grand Challenges used in this module were further refined by engineering and library faculty to reflect the college’s mission and initiatives and/or relate to imminent projects in the college’s
operational improvement plans. The curriculum is intentionally designed for the students’ holistic exposure to engineering and research skills, practices, and content area experts. The refined Challenges are described in Table 1 below and in greater detail in the following section.

**Table 1. Refined Grand Challenges**

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Description</th>
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<tr>
<td>Restore and Improve Urban Infrastructure</td>
<td>Two distinct design projects are included: a) a campus traffic analysis and parking lot redesign, and b) a campus storm-water drainage assessment and redesign.</td>
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<tr>
<td>Engineer Better Medicines</td>
<td>Students are tasked with addressing issues related to heart disease and ethical responsibilities specific to biomedical engineering.</td>
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<tr>
<td>Make Solar Energy Economical</td>
<td>The project focuses on solar energy applications on campus including cost benefit and GHG payback analyses of a new 1.4MW photovoltaic array.</td>
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<tr>
<td>Provide Access to Clean Water</td>
<td>Students are tasked with development and preparation of a proposal to the Bill &amp; Melinda Gates Foundation (2017) requesting funding to address water and sanitation needs in Dharavi, India.</td>
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<tr>
<td>Engineer the Tools of Scientific Discovery</td>
<td>Students develop a proposal for a National Geographic Grant (2017) requesting funding to utilize GPS technology to address specific improvement areas in sub-Saharan Africa.</td>
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The college facilities director, human anatomy/biology faculty, and engineers from General Dynamics Corporation, (a U.S. Department of Defense contractor with Scottsdale, AZ locations), serve as content specialists, and join the class as guest speakers throughout the module. The content speakers share their background and life’s path into their field of expertise; their technical knowledge and current projects; and make themselves available to the Challenge teams for proposal design questions and advice.

Each Challenge project has seven deliverables, two individual-submitted and five team-submitted. The deliverables are strategically scheduled in the seven weeks as benchmarks for evidence of individual learning and accountability, and team progress and cohesion. The deliverables include a critical research findings document, a written summary on their Challenge, technical memos, draft grant proposals, life cycle and cost-benefit analysis reports, traffic flow analysis and parking lot plan design drawings, SolidWorks-based prototypes, and the team’s final, 10-minute presentation. The overarching goal is that the first-year engineering students are exposed to real-world engineering expectations and opportunities by embracing the worldview that engineers can and should contribute to solving global challenges.

In this paper, we look specifically at the effectiveness of utilizing this module in the second semester freshman level course, ECE 103: Engineering Problem Solving and Design, on the successful completion of female and underrepresented minority (URM) students.

CGCC Institutional Research data on successful course completion by female and URM students was analyzed for five semesters, fall 2014 through fall 2016. The data collected compares
course sections at Chandler-Gilbert Community College that used the Grand Challenges design project (Intervention sections) to sections of the same course within the college that used traditional curriculum, and; compares the Intervention sections to Maricopa Community College District-wide sections using traditional curriculum.

Assessments are done throughout the course of the project to address the official course competencies as well. The course competencies are established by the Engineering Instructional Council (IC) for college district and applied to all sections of the course taught in the Maricopa Community College District. The course competencies can be categorized into content / technical skills and interpersonal skills (“soft skills”). The complete current list of competencies can be accessed through the Maricopa Community College District’s website (Maricopa, 2017).

The course competencies addressed in this research are, the students’ abilities to:

1. Identify and display effective team working skills
2. Apply a computer-aided drawing tool to develop and describe an engineering design,
3. Effectively communicate design process decision making, and
4. Effectively communicate technical information in writing and presentation formats.

Assessments are done via faculty graded assignments and content quizzes, as well as peer evaluations and peer feedback at project benchmarks. Moreover, information literacy outcomes are assessed throughout the project, using the college’s institutional General Education Literacy Outcomes rubrics (ACRL, 2000) and the ACRL Framework (ACRL, 2016).

**Design Project Descriptions**

The module includes six separate design projects based on a selection of the Engineering Grand Challenges modeled on those presented in the *Grand Challenges DELI (Discover, Explore, Learn, Imagine) Project* (Hunter and Baygents, 2012). The average class size is 24 students which is split into six four-student teams. Teams are built based on student topic interest submitted via an online survey and information on student teamwork preferences and individual skillsets. Each of the six teams is assigned a unique project. This allows students to both a) select a project that they are most interested in, and b) broaden their worldview by learning about other projects and challenges through guest lectures and peer class presentations on the other topics. The details of each project are constructed around local design opportunities and resources to make the experience as “real life” as possible for students.

The module begins by looking at the Grand Challenges at a large scale. Students perform critical research on their Challenge’s history and potential developments and identify implementation opportunities, explaining why they are essential to society. Their critical research findings are used to prepare and deliver a two-minute overview presentation explaining their Challenge. Students then each prepare an individually written summary of their team’s Challenge. The first team presentations are given during the start of the third week of the design project, see Figure 1.
Table 1. Grand Challenge Design project schedule. Executed the last seven weeks of the semester. Project deliverables are shown in parentheses. Tasks 1, 2, and 3 are unique to each project and described in detail in the following sections of this paper.

<table>
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<tr>
<th>Week</th>
<th>Tasks</th>
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<tr>
<td>1</td>
<td>Grand Challenge Project Selection and Team Formation (Team Contract)</td>
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<td></td>
<td>Critical Research Day (Research Worksheet, 2-minute Team Whiteboard Presentation)</td>
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<td>2</td>
<td>Technical Writing (Individual Grand Challenge Written Summary Essay)</td>
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<td></td>
<td>Engineering Design Process and Team Presentation Work Day</td>
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<tr>
<td>3</td>
<td>Grand Challenge Background Team 10-minute Presentations</td>
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<td></td>
<td>Team Maintenance and Project Management (Critical Path Project Schedule)</td>
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<tr>
<td>4</td>
<td>Grand Challenge Team Project (Task 1)</td>
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<tr>
<td></td>
<td>Critical Research Day</td>
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<tr>
<td>5-6</td>
<td>Topic Expert Guest Speakers (Topic Quizzes, Task 2)</td>
</tr>
<tr>
<td>7</td>
<td>Final Projects and Team 10-minute Presentations (Task 3)</td>
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Figure 1. Grand Challenge Design project schedule. Executed the last seven weeks of the semester. Project deliverables are shown in parentheses. Tasks 1, 2, and 3 are unique to each project and described in detail in the following sections of this paper.

The initial background presentations are designed to explain each Engineering Grand Challenge generally for the class by answering key questions about their topic:

1. What is the Engineering Grand Challenge, as defined by the NAE?
2. What has been done in the past to address this Challenge?
3. What is being done currently to address this Challenge?
4. What are the barriers or obstacles that need to be overcome in this Challenge?
5. How does society benefit from taking action on this Challenge?
6. Whose voice or perspective is missing from the discussion of solutions/approaches to the Challenge?

Each presentation concludes with a brief explanation of their team’s unique research and design project. The projects range from a college campus traffic flow / parking lot and storm water management re-designs to the development of a proposal to the Bill and Melinda Gates Foundation to address water and sanitation needs for a slum in India. The teams then use the engineering design process along with MATLAB, SolidWorks, critical research, project management, and teamwork skills to develop their proposal, create a prototype or schematic, and prepare and deliver a 10-minute technical presentation that describes the outcome of their work. As they progress through the design process, teams’ deliverables are submitted in a scaffolded schedule by Task. The schedule is illustrated in Figure 1; Tasks for each project are described in the following paragraphs.
**Restore and Improve Urban Infrastructure:** Two design projects fall under this Grand Challenge.

The first is a campus traffic analysis and parking lot redesign. The community college is a commuter school serving over 10,000 students. The traffic flow and parking configurations are a common frustration and continually under analysis and subject to re-design. Students are given access to the most recent traffic analysis data the campus has, provided reasoning behind recent changes, and tasked with assessing recent modifications then developing and proposing their own redesign.

**Activities:**
- Task 1: Letter to local Members of Congress expressing gratitude or concern about current state of transportation planning and funding.
- Task 2: Two-page technical memorandum discussing research analysis of the modes of transportation students utilize to get to Campus, a commuter college, and how it compares with research done on best practices in campus design. And their assessment of the parking lot redesign done on campus based on their experience with it and the presentation by the Facilities Director explaining the design process and decision justifications.
- Task 3 Design report presenting their complete redesign of campus parking to best manage student traffic.

The second project is a campus storm-water drainage assessment and redesign. In 2014 the area and the campus experienced an unusually large storm event, on the order of a 1000-year event, which exposed many of the weaknesses in the current drainage facilities. Students begin this project with a green infrastructure assessment of campus, and follow with a drainage analysis and redesign of facilities to sufficiently handle a storm of the size seen in 2014. The college’s facilities director (a mechanical engineer) gives a guest lecture to the class that provides background on both projects as well as data for the redesigns.

**Activities:**
- Task 1: Two-page technical memorandum defining Green Infrastructure best management practices in stormwater management design and summarizing results from their initial application of the EPA’s National Stormwater Calculator (U.S. Environmental, 2017).
- Task 2: Two-page technical memorandum reporting results of basic hydrologic and hydraulic analysis of flood events on campus and identification of campus stormwater management shortcomings.
- Task 3: Design report presenting their redesign of campus stormwater management to accommodate flood level quantities of stormwater.

**Engineer Better Medicines:** Students are tasked with addressing issues related to heart disease under this challenge. The project begins with comparison exercise reviewing codes of ethics from the National Society of Professional Engineers, the Biomedical Engineering Society, and the World Medical Association, followed by a review of current research in biomedical engineering and heart disease. Biology and anatomy faculty give a guest lecture on the human
heart which includes a heart dissection lab for the entire class to develop a basic understanding of heart structure, function and possible health complications. Students create 3D models of several current biomedical heart devices using SolidWorks and then apply the Engineering Design Process to improve upon current technologies.

Activities:

- Task 1: Two-page technical memorandum comparing codes of ethics in engineering and medicine and discussing findings on current state of biomedical technologies that address heart disease.
- Task 2: SolidWorks Models of three existing biomedical technologies, SolidWorks models of three improved biomedical technologies and one-page memo documenting engineering design (with specific reference to each step in the engineering design process) of improved technology designs.
- Task 3: Deliverable: Design report presenting their improved technology design and discussion of ethical requirements and concerns associated with bioengineering and heart disease.

**Make Solar Energy Economical:** Students perform a campus energy use and energy resource assessment. The project then narrows focus to solar energy applications on campus which includes a walking tour of the college’s photovoltaic and solar thermal systems. This system was installed spring 2016 through a collaborative partnership among CGCC, Salt River Project (the electric utility company used by the Maricopa Community College District) and Solar City (solar equipment installation and maintenance provider). Students are tasked with performing a life cycle analysis (LCA) as well as a cost benefit analysis of the 1.4MW photovoltaic array installed on campus in 2016. The college’s facilities director (and mechanical engineer) is a guest lecturer who provides detail on solar energy technologies used at the college, its return on investment, and contractor and utility services provider contracts and pricing details for the for the recently installed 1.4MW photovoltaic solar array. Students conduct research on life cycle assessment methodology and are provided data to complete the assessment.

Activities:

- Task 1: Two-page technical memo summarizing the purpose and rationale for ISO 14000 Environmental Management International Standards, and describing the three components of LCA: Impact Assessment, Inventory Analysis, improvement assessment.
- Task 2: Two-page technical memo summarizing benefits, concerns, and challenges associated with lease buy-back options for solar energy installations. A model of the 1.4MW PV Array using the National Renewable Energy Laboratory’s PVWatts Calculator (Alliance for Sustainable Energy, 2017) and summary of findings on the estimated cost payback period.
- Task 3: Design report presenting the results of all task deliverable including the final LCA results quantifying the life cycle greenhouse gas (GHG) emissions of the new installation and the overall GHG payback time of the installation.

**Provide Access to Clean Water:** Students are tasked with development and preparation of a proposal to submit to the Bill & Melinda Gates Foundation (2017) requesting funding for a project to address water and sanitation needs in Dharavi, India which is the largest slum in the
city of Mumbai. In addition to requirements provided by the Gates Foundation, the proposal must show how their project will meet the needs of the people served under three categories: 1) improvement of water supply and sanitation conditions, 2) economically (the area has funding and knowledge to maintain the system), and 3) is culturally sensitive.

Activities:

- Task 1: Two-page technical memorandum summarizing a) Gates’ Foundation proposal guidelines and required elements, b) core values of the Gates’ Foundation organization, and c) ethical considerations to be included when designing a project to improve water supply and/or sanitation circumstances in Dharavi based on background research on Mumbai.
- Task 2: Two-page technical memorandum identifying progression through engineering design process steps to arrive at proposed project. Draft proposal document.
- Task 3: Final grant proposal document including design drawings and itemized budget.

_Engineer the Tools of Scientific Discovery_: Students develop a proposal for a National Geographic Grant (National Geographic Society, 2017) requesting funding for a technology research project designed to address two of the six identified areas for improvement in sub-Saharan Africa: food supply and energy supply (the other four are health care, education, governance, and infrastructure), (Pew Research Center, 2015). Selected research methodology must incorporate the use of GPS technology. In addition to research and provided reading materials, guest speakers in computer science and engineering from aerospace and defense companies in the area present a variety of GPS applications utilized in current projects.

Activities:

- Task 1: Two-page technical memorandum summarizing a) National Geographic Young Explorer’s proposal guidelines and required elements, b) core values of the National Geographic Young Explorer’s organization, and c) ethical considerations identify ethical considerations for using GPS technologies in developing countries related to each of the six improvement areas (health care, education, governance, food supply, infrastructure, and energy supply) based on background research on Sub-Saharan Africa and ethics in Information Technologies and Outer Space Activities.
- Task 2: Two-page technical memorandum identifying progression through engineering design process steps to arrive at proposed project. Draft proposal document.
- Task 3: Final grant proposal document including design drawings and itemized budget.

_Results_

Chandler-Gilbert Community College Institutional Research data on successful course completion by female and URM students was analyzed. Data from Fall 2014, Spring 2015, Fall 2015, Spring 2016, and Fall 2016 was available for female student enrollment and successful course completion, however, data from Fall 2016 for URM student enrollment and course completion was not available. The data collected compares ECE 103: Engineering Problem Solving and Design course sections at CGCC that used the Grand Challenges design project (Intervention) to sections of the same course within the college that used traditional curriculum (College), and the compares the Intervention sections to Maricopa Community College District-
wide sections that use traditional curriculum (District).

Analyses of this data show positive results, shown in Figure 2. Successful completion of the course among female students was 100% in the Intervention sections as compared to 81% in course sections at the same institution taught with traditional curriculum and 86% for course sections taught District-wide using traditional curriculum.

Successful completion of the course among URM students was 94% in the Intervention sections as compared to 77% in course sections at the same institution taught with traditional curriculum and 87% for course sections taught District-wide using traditional curriculum. Students included as URM students in these results self-identified as either American Indian/Alaska Native, Black/African American, Hispanic/Latino, or Native Hawaiian/Other Pacific Islander.
Additional assessments are done throughout each semester to address the official course competencies. The course competencies were established by the engineering instructional council for the college district and are applied to all sections of the course, district-wide. Assessments are done via faculty graded assignments and content quizzes, as well as peer evaluations and peer feedback at project benchmarks. The successful completion of all students in the Intervention sections indicates that the learning outcomes are being met utilizing this curriculum.

Moreover, information literacy outcomes are assessed throughout the project, using the college’s institutional General Education Literacy Outcomes (ACRL, 2000) rubrics and the ACRL Framework (ACRL, 2016). These literacy outcomes assessments provide insight into students’ abilities to engage in critical research and perform synthesis, integration and application of the information obtained. The assessment findings reinforce that first year engineering students are novice researchers and that these skills require nurturing and guidance at this stage with opportunities for continued application.

Discussion

The Intervention sections are taught by a female professor, which since students self-select into the courses, this is a factor that could influence, if not the successful completion by female students, certainly the higher enrollment percentage of female students in the Intervention sections. The percentage of successful completion of the Intervention sections by female students is reflected by other underrepresented minority students in engineering as well. This is encouraging and suggests to the authors that the content variety and structure of the projects used in this model is one avenue that can be utilized to foster diversity in first year engineering programs. The design allows students to explore technical topics of interest, selecting the ones they view as most relevant to their lives, and are then able to connect their experience to the engineering profession.

Assessment of the curriculum materials and information literacy outcomes via graded assignments and content quizzes, as well as peer evaluations and peer feedback were used to strategically review and redesign the Challenge model’s curriculum and learning activities to address the skills gaps and revised the deliverables to prompt more student and team accountability. Information literacy assessment findings reinforced that the students are novice researchers and the complexity of synthesis, integration and application requires higher order thinking skills; these skills are nurtured through successive learning and deliverables related to their Challenge.

References


