A Longitudinal Evaluation of an AP Type, Dual-Enrollment Introduction to Engineering Course: Examining Teacher Effect on Student Self-Efficacy and Interest in Engineering (Evaluation)

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Abstract

ENGR 102 HS is an introduction to engineering course taught by 37 high school teachers in both public and private high school classrooms. This university level, dual enrollment course offers high school students three units of credit towards an engineering degree. Unlike an Advanced Placement (AP) class, students who successfully complete the course receive a university transcript. In the ten years since the initial pilot, more than four thousand high school students have taken the course and of those, 2704 students have enrolled and received college credit. With a nearly identical core curriculum as the semester long, ENGR 102 on campus course, the high school program runs for a full school year and thus provides students with increased contact time. Extra classroom time in the high school program allows students to participate in service learning projects, online modules and multiple teacher-designed hands-on projects. Each spring students in the program are asked questions about multiple topics as part of a course evaluation survey.

In this longitudinal evaluation, we examine seven years of survey data and report on changes over time in teacher (n=66) effectiveness and explore how teachers influence student self-efficacy and interest in pursuing a career in engineering. The effects of teacher/student gender match was also explored. Teachers with engineering degrees were compared to teachers without and no significant differences were found in effectiveness, course quality or student interest in engineering. However, when students were divided by gender, results showed that female students preferred teachers without the master's in engineering whereas teachers with the master's in engineering were preferred by male students.

1. Introduction

Dual credit and Advance Placement (AP) courses have been around for decades. Typically, these types of courses have focused on core subjects such as Mathematics, English, Economics and History. While some might question the value of AP courses in predicting college success, there is no doubt that these types of courses are enriching and popular with college-bound, high school students [1]. For 11 years, the University of Arizona (UA) has offered an award winning, dual credit, introduction to engineering course to high school students. Results collected from course evaluation surveys have shown that after course completion, nearly 80% of students enrolled exhibit an engineering self-efficacy of at least 3.5 out of 5, and over 67% of the students report the ENGR 102 HS course increased their interest in becoming an engineer [2, 3, 4]. Teacher effectiveness is also measured and is consistently high year after year with 86% of students reporting that their teacher is always or usually effective.

With the successful launch of the Advanced Placement (AP) Computer Science course in 2016, engineering educators, NSF and the College Board accelerated the development of an Introduction to Engineering AP course. College of Engineering deans from across the country were surveyed and multiple meetings of engineering thought-leaders and educators were convened to decide on a course of action [5]. With these strides to establish an AP Engineering course for American high school students have come many questions about the legitimacy of such a plan. Questions about what to teach, how to grade student work and how to train teachers are some of the most prevalent. One universal question posed is: Can high school teachers, most of whom are not engineers, effectively teach a college level introduction to engineering course?

In this paper, we will examine longitudinal data documenting the success of the UA dual credit course, ENGR 102 HS. We will specifically tease out teacher effectiveness in relation to years in service, and teacher/student gender match. Finally, we will examine teacher education comparing those meeting the Higher Learning Commission (HLC) guidelines and those requiring exceptions as it correlates to student interest in engineering, student self-efficacy in engineering and overall course rating.

2. Background

Development of ENGR 102 HS

As part of a push to improve freshman quality and retention, the College of Engineering at the University of Arizona (UA) piloted the first ENGR 102 HS classroom in AY2008-09. The impetus for the course was to provide an AP type, university engineering experience for high school juniors and seniors. Its goal was to offer students an introduction to engineering course as a pathway to a possible career without the risk involved in taking the course at the university or committing to an engineering major.

ENGR 102 for high school was fashioned after the on-campus ENGR 102 course that offers students a multitude of learning modes as is necessary for active learning [6]. The survey course introduces the student to various fields of engineering through a main lecture and hands-on lab sections. The primary project in the course is the design, test and build of a solar oven. This inquiry/project-based learning framework was carried over to the high school version of ENGR 102. The primary difference between the two versions of the course is increased classroom time at the high school level. With the extra instructional time and teacher scaffolding, high school ENGR 102 students enhance their learning through multiple authentic hands-on projects. Towards the end of the school year, high school ENGR 102 students prepare the solar oven project in much the same way as their undergraduate counterparts. Some high schools even travel to campus to compete with university students in the solar oven competition held on the university mall. ENGR 102 HS teaching objectives and benefits to students can be found in Appendix I.

The pilot ENGR 102 HS course was taught by a high school teacher whose credentials include BS EE, MS EE, a master's in education and five years professional engineering experience at Motorola. This teacher was selected so that all doubts about teacher qualifications could be eliminated and the focus was instead put on curriculum development and student performance. Once student performance was found to be more than adequate, eight additional non-engineer teachers were brought on with a careful attention towards their training at an intense, 2 week workshop. As course evaluation data came in and a comprehensive teachers' manual and other instructional materials were developed, concern about teacher effectiveness was alleviated and the ENGR 102 HS workshop was condensed to 5 and then 4 days each summer.

ENGR 102 HS Teacher Qualifications and Effectiveness

Teacher qualifications and effectiveness are an important metric for program success. New Higher Learning Commission (HLC) guidelines issued in early 2016 call for all adjunct/dual credit instructors to have a master's degree in their field as a minimal requirement [7]. The HLC guidelines focus on dual credit programs and outline a few exceptions to the master's degree in the field of instruction requirement. As engineering is a multidisciplinary field, encompassing other STEM areas to include Science, Technology and Mathematics, degrees in these STEM areas meet the requirement for teaching an engineering course. Exceptions to a master's degree mentioned in the HLC guidelines and incorporated in the ENGR 102 HS teacher minimum criteria include a BS or BA degree in a STEM field plus: Career and Technical Education (CTE) certification in Engineering Science, 18 credit hours of graduate work in a STEM field or 5 years of experience in an engineering related industry. Interestingly, the 2016 HLC guidelines make no mention of minimal education requirements for high school teachers providing AP instruction.

As mentioned earlier, the ENGR 102 HS pilot school teacher was highly qualified with a BS and MS in electrical engineering, however, he is not the norm. Many of the teachers have undergraduate degrees in Math or Science education and an MS in Science education or other STEM field. In fact, the teacher who was selected by students to be the ENGR 102 HS 2012 and 2015 teacher of the year and went on to win Arizona Engineering Educator of the year in 2013 has an undergraduate degree in Theater and Math, along with a MS in Mathematics and Education.

ENGR 102 HS Summer Workshop Training and Content

The annual ENGR 102 HS teacher workshop operates for four days and is typically held at a resort in Tucson, AZ during the off season month of July. Effort is made to provide nice meals and accommodations so the teachers look forward to attending each summer. The college does not pay high school teachers to deliver ENGR 102 HS since it is a dual credit offering in their high school, however, a modest stipend is paid for workshop attendance and travel expenses are covered. Faculty who teach the ENGR 102 course on campus spend time training the high school teachers. The high school and university ENGR 102 teaching teams bond in the retreat-like atmosphere of the workshop and natural mentoring relationships form.

The first two days of the workshop are for teachers new to the program and day one begins on campus with tours of the UA College of Engineering laboratories and competition of paperwork. Teachers review the curriculum to include a printed teacher's manual and extensive digital content to include lecture power points, homework assignments and grading rubrics.

Figure 1. A representative from Caterpillar, Inc. demonstrates mold casting to ENGR 102 HS teachers at the 2018 summer workshop.

The remaining time for new teacher training is devoted to the core content of the ENGR 102 course. This content is taught by faculty and is the critical link between the high school and on campus versions of the course. A full day is spent working through the lesson content for the primary hands-on project in ENGR 102: the design, iterative build and testing of a solar oven. New teachers conclude their portion of the workshop with Excel training in the computer lab, a Design of Experiment (DOE) activity and an extensive catapult, hands-on project that involves collection of data, graphing and analysis. Due to additional classroom time, ENGR 102 core content takes about 10-12 weeks to deliver in a high school setting.

Returning teachers join in on the third day and everyone completes the rest of the workshop together. The last two days of the ENGR 102 HS summer workshop are devoted to supplemental, hands-on project ideas that teaches may use to fill out their school year. ENGR 102 HS teachers are allowed the freedom to use these supplemental lessons in their classrooms or to develop their own lessons. This flexibility is another key component to the success of ENGR 102 HS. The high quality professional educators recruited to teach for the program are allowed the autonomy to make the course their own.

3. Methods

Participants

Data analysis for this paper will concentrate on selected questions from the ENGR 102 HS course evaluations collected for Academic Years (AY) 2011-12, 2012-13, 2013-14, 2014-15, 2015-16, 2016-17, 2017-18. Results will examine female (n=435) and male (n=1757) high school student responses. Data represent high school juniors and seniors from 44 diverse Southwestern American high schools, across 17 school districts, and taught by 66 teachers. Student participants are 27.2% Hispanic, .9% American Indian/Alaskan Native, 10.5% Asian.

2.4% Black/African American, .4% Native Hawaiian/Pacific Islander, 53% White; and 5.6% multi-racial. Student results will be sorted by the 66 teachers who have taught the course over the seven years this data was collected. Teacher participants are female (n= 14) and male (n= 52).

Instrument

At the end of the school year, ENGR 102 HS students fill out an online, 25 question course evaluation. The first four questions provide demographic data and the next 19 questions are built on five-point Likert scales and probe topics ranging from teacher effectiveness to satisfaction with the service learning program to college choice. The remaining two questions are open-ended and allow students to describe their favorite ENGR 102 HS design and build project and comments about their teacher. Many of the Likert scale questions for the online survey were obtained from the on-campus course evaluations handed out to undergraduates in the ENGR 102 course and deal with the quality of instruction and content. Additional questions, those dealing with self-efficacy, were selected from the Longitudinal Assessment of Engineering Self-Efficacy (LAESE) instrument measuring student self-efficacy [8]. In this work, answers from the five questions relating to efficacy were averaged to create an Efficacy scale (α=.67). These questions included: How confident are you that you can succeed in a university engineering curriculum; How has your confidence in your ability to succeed in a university engineering curriculum been affected by ENGR 102 HS; How has your confidence in your ability to succeed in an engineering curriculum been affected by your math and science courses; Do you think you will feel like "part of the group" if you pursue a career in engineering; and How well can you cope with doing poorly (or not as good as you hoped) on a test. A Student Interest in Engineering scale was calculated (α=.66) by taking the mean of two questions including; How interested are you in becoming an engineer and How was your interest in becoming an engineer affected by ENGR 102 HS. Finally an overall course evaluation scale was created (α=.86) by averaging three items including; What is your overall rating of your teacher's teaching effectiveness, How much do you feel you have learned in the course, and What is your overall rating of this course?

4. Results

To assess the effect of teacher ENGR 102 HS experience on student efficacy, interest, and overall course evaluation, each student was coded as being taught by a first-year participant, second year participant and so on up to those taught by teachers with seven years of experience in the ENGR 102 HS program. One-way ANOVAs were calculated showing significant differences in the area of student efficacy {$F(6, 2185) = 2.353$, $p=.029$; equal variances not assumed} and overall course evaluation {$F(6, 2184) = 4.830$, $p \leq .0001$; equal variances not assumed}. Student interest in engineering was not influenced by teacher year of experience {$F(6, 2184) = 1.435$, p= n.s.}. Since homogeneity of variance assumptions were violated, Games Howell post hoc tests were conducted. Students of teachers with four years of ENGR 102 HS teaching experience had higher engineering efficacy (M=4.0510, SD=.56123) than those taught by teachers with six years of ENGR 102 teaching experience (M=3.8603, SD=.65695). Overall student course evaluation was found to be higher for teachers with two (M=4.2092, SD=.72928) and four (M=4.2939, SD=.69435) years of experience compared to those with one (M=4.0547, SD=.81565) and three (M=4.0340, SD=.87603) years of experience. The higher course evaluations in years two and four over years one and three bears further scrutiny. Differences could be caused by attrition of less successful/interested teachers or by other factors including training and support. To assess the role of attrition, the calculations were repeated only including teachers who taught in the ENGR 102 HS program for at least four years. Overall course evaluation differences remained significant {$F(6, 1247) = 4.119$, $p \leq .0001$; equal variances not assumed}. Games Howell post hoc tests were conducted. Overall student course evaluation was found to be lower for students with teachers in their third year (M=3.9606 SD=.93612) compared to students with teachers in their second year (M=4.1927, SD=.70118; Cohen's d=.2806), fourth year (M=4.2939, SD=.69435; Cohen's d=.4044) and sixth year (M=4.2048, SD=.67462; Cohen's d=.2958) of experience. All deficits in the first year were eliminated suggesting these were due to the attrition of less successful/interested teachers who did not return after their first year. The slump in the third year remained and exhibited a small to medium effect size.

To assess the effect of teacher education on student efficacy, interest and overall course evaluation independent sample t-tests were conducted first on the whole sample and then on male and female students separately. Teachers were coded as those who met the HLC guidelines of having a master's degree in engineering (N=6) or as needing an exception (N=60). Those who needed the waiver included those with a bachelor's degree in engineering (N=13), bachelor's or master's in another STEM area (N=13), bachelor's or master's in education (N=33), or another degree (N=1).

For the entire sample of students, teacher education made no difference in student efficacy {$t(2189)=.703$, p= n.s.}, interest in engineering {$t(2188)= 1.184$, p= n.s.}, or overall course evaluation {$t(2188)= -1.121$, p= n.s.}. However, when students were split out by sex, provocative differences emerged. For males, teachers with master's degree in engineering were associated with greater efficacy {$t(292.356)= -3.548$, $p \leq .0001$; Glass' delta=.0910}, greater interest {$t(278.660)= -2.109$, $p= .036$; Glass' delta=.1381} and higher course evaluation {$t(301.851)= -6.101$, $p \leq .0001$; Glass' delta=.2176} than teachers with other degrees. The effect size was very small to small. For female students, the pattern was reversed and demonstrated a small effect size. Teachers without a master's degree in engineering were associated with greater student efficacy {$t(431)= 2.097$, $p= .037$; Cohen's d= .2016}, interest $t(431)= 2.131$, $p= .034$; Cohen's d= .2050} and higher course evaluation {$t(431)= 2.157$, $p= .032$; Cohen's d= .2076} than teachers with the master's in engineering.

To assess the effect of teachers' sex on student efficacy, interest and overall course evaluation independent sample t-tests were conducted first on the whole sample and then on male and female students separately. There were no differences in student efficacy, interest or course evaluation based on teachers' sex. See Table 1. for more details.

Table 1. Effect of Teachers' Sex on Student Efficacy, Interest and Course Quality						
		Female Teachers		Male Teachers		
		Mean	SD	Mean	SD	t-test
Entire Sample	Engineering Efficacy	3.9597	.56502	3.9644	.61878	t(2190)=.133, p= n.s.
	Engineering Interest	4.0309	.88836	4.1134	.81105	t(2189)=1.728, p= n.s.
	Overall Evaluation	4.1596	.68395	4.1226	.81223	t(567.606)= -.905, p= n.s*
Female Students Only	Engineering Efficacy	3.7435	.63065	3.8717	.65779	t(431)=-1.623, p= n.s.
	Engineering Interest	3.9000	.87899	4.0086	.91414	t(431)=.989, p= n.s.
	Overall Evaluation	4.0294	.74765	4.0268	.89234	t(431)= -.025, p= n.s.
Male Students Only	Engineering Efficacy	4.0276	.52600	3.9861	.60699	t(412.737)= -1.164, p= n.s.*
	Engineering Interest	4.0720	.88892	4.1381	.78320	t(1753)=1.252, p= n.s.
	Overall Evaluation	4.2005	.65889	4.1458	.79136	t(425.609)= -1.216, p= n.s.*

* Equal variances not assumed

A final set of calculations was made based on matching versus non-matching sex of student and teacher and its effect on student efficacy, interest and overall course evaluation. Independent sample t-tests were run to see if having a teacher who was the same sex as their student had an effect in these areas across the entire sample. Efficacy was not different for students who matched their teacher's sex (M=3.9730, SD=.61056) versus those who did not match (M= 3.9399, SD= .60813; t(2187)=-1.141, p= n.s.). Student interest in engineering was higher when students matched their teacher in sex (M=4.1252, SD=.79022) versus when they did not match their teacher's sex (M=4.0636, SD=.90301; t(1011.446)=-2.146, p=.032; Glass' delta=.0984 equal variances not assumed). Finally student overall course evaluation did not differ based on matching their teacher's sex (M=4.1395, SD=.78927) versus not matching their teacher's sex (M=4.1029, SD=.80262; t(2186)=-.973, p=n.s.). Student interest in being an engineer was, therefore, very modestly higher when teacher and student sex were the same, but efficacy and course evaluation did not change.

5. Recommendations and Discussion

Findings from this evaluation support the following recommendations for the improvement of the ENGR 102 HS program.

1. First year teachers should be provided more support (e.g., in person help with registration, extra classroom visits and additional, “first year” training sessions) but should not be pressured to remain in the program as the natural attrition improves the remaining teacher pool.

2. The use of teachers without the master’s in engineering was preferred by female students whereas teachers with the master’s in engineering were preferred by male students. The effects for the male students were “very small” and for the females it was “small”. There are several possible reasons for this difference. Perhaps males were attracted to the higher status of master’s level engineering teachers but females were put-off. Perhaps teachers with a master’s in engineering had internalized more of the male-centric ethos commonly reported among engineers and this was detrimental to female students but empowering to male students. Perhaps the extra training in educational techniques of the teachers without a master’s degree in engineering (e.g., teachers with bachelor’s and master’s in education) had a greater influence on the female than on the male students. Although the exact reason for these differences is unclear from the current data, there is support that the gender diversification of engineering would be served by the use of teachers with degrees other than a master’s in engineering.

3. Although the teacher’s sex, did not directly affect student interest, efficacy, or course evaluation, students who had the same sex as their teacher did report greater interest in being an engineer. The effect however was very small. Again, the gender diversification of engineering might be served by the use of more female teachers. However, since the benefit was so small, the very small negative effect of this on male students’ interest needs to be considered.

4. All teachers should be offered additional training and support before and during their third year of teaching ENGR 102 HS to minimize the third-year slump. This slump had a small to moderate effect size. This support could include special recognition in the form of opportunities to collaborate with outside projects and invitations to present at the summer workshop as well as specialized mid-year trainings and classroom visits.

As the sample size of the ENGR 102 HS program continues to increase, two factors concerning the interpretation of the data should be mentioned. It is clear that there is ample power to detect even small differences. When elements are found to not differ in a statistically significant way, one can have confidence that there are no real differences that were not detected. Conversely, the high power engendered by the large sample size means that even small differences will be detected. Since a statistically significant difference is not the equivalent of a meaningful difference, attention to the reported effect sizes is important.

6. Conclusions

An AP like, dual credit introductory engineering course can be successful as long as qualified high school teachers and adequate teacher training are available. Higher Learning Council guidelines permit some qualification exceptions for high school teachers providing such courses. For the ENGR 102 HS program, these exceptions seem warranted and do not adversely affect the overall quality of the program.

Our data suggests it does not take a master's degree in engineering to deliver a high quality introductory engineering course. A gifted, dynamic STEM teacher who has a passion for students and a deep seeded interest in the field of engineering can also be quite effective. These qualities, along with our 4-day summer workshop prepare ENGR 102 HS teachers to deliver the college level course. The key to the success of the program is the annual workshop were new teachers receive training on the core curriculum and veteran teachers also assemble for additional professional development. This evaluation underscores the importance of additional support and training for first year and third year teachers, particularly those without an engineering master's degree.

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APPENDIX 1

ENGR 102 HS Teaching Objectives

While providing high quality instruction ENGR 102 HS teachers will:

1) Show students that engineers use skills in mathematics and science to help people in a variety of global, economic, environmental, and societal contexts
2) Increase student self-efficacy in engineering — that is, increase students’ belief in their ability to pursue and succeed in the engineering profession
3) Elevate the visibility of engineering as a viable and rewarding career path
4) Prepare students to make informed choices about their academic and career options by providing them with information regarding the vast number of engineering career paths
5) Help students identify “false positives”- that is, allow students who think they want to be engineers to explore the field and to figure out if engineering is for them within the safe environment of their high school classroom

ENGR 102 HS benefits high school students by allowing them to:

1) Explore an introduction to engineering and the engineering profession without having to commit to a semester’s worth of engineering courses at the University level
2) Gain a better understanding of what an engineer is and does; explore a variety of engineering disciplines through campus visits and lab tours
3) Become familiar with the demands and expectations of college-level courses
4) Receive credits for 3 units of required UA engineering coursework at significantly reduced tuition