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The Skyline TEAMS Model: A Longitudinal Look at the Impacts of K-12 Engineering on Perception, Preparation and Persistence

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ABSTRACT

This paper describes the longitudinal impacts of a partnership between the University of Colorado Boulder's K-12 Engineering Education initiative and the St. Vrain Valley School District. Together, university and high school educators created a replicable pre-college engineering model in a nine-school feeder system, which serves many Colorado students who are traditionally underrepresented in the engineering profession, and culminates with a high school STEM (science, technology, engineering, and mathematics) Academy whose graduates are motivated to thrive in engineering colleges. However, the following question, "Is this an effective model for increasing student STEM persistence and performance?" remains a driver for our investments as we refine the K-12 engineering program based on partner school feedback and quantitative and qualitative assessment results.

Data show that our K-12 engineering program has positively impacted student perception, preparedness, and persistence in engineering based on regular, pre-college hands-on engineering design experiences. A description of the multi-year K-12 engineering model and longitudinal analysis

of students' concurrent math course choices is presented. Also, subsequent student persistence in and from the STEM Academy is addressed.

TRENDS IN K-12 ENGINEERING

According to the U.S. Census Bureau, one half of the U.S. population by 2050 will be nonwhite [1]. This means that engineering solutions will have to be acceptable to an increasingly diverse population, and the engineering profession will have to draw much more heavily on underrepresented groups for the country to maintain, let alone increase, its technological capability [2].

While the overall number of engineering degrees granted in the U.S. has gone up in recent years, although not to its historic high of almost 80,000 in 1985 [2], just 4.5% of our nation's BS graduates earn engineering degrees, masking the reality that only 1.6% of all bachelor level degrees are awarded to women in engineering [3, 4]. As women make up an increasingly higher majority of all college graduates, the system resistence to expanding women's participation in engineering is alarming; begging the question of who will engineer our processes and products of the future? By comparison, throughout Asia, 21% of university graduates are engineers, while in Europe, 12.5% of university graduates earn engineering degrees [2].

The persistently low student achievement among high poverty students is not an acceptable baseline condition for the engineering profession—and is a barrier to broadening participation. To help close achievement gaps, engineering offers a real-world application of the fundamental science and math principles that students explore early in their education. Schoolroom experiences in an engineering context provide a gateway to creative, real-life problem solving, and exploration in all areas of science and mathematics. By experiencing the engineering design process first hand, students begin to see how engineering ingenuity and inventions touch and shape their everyday lives, and they begin to develop a self-identity that possibly encompasses a science, technology, engineering, and mathematics (STEM) future.

An engineering education creates access to the American dream and should provide people from all backgrounds, regardless of circumstance, the opportunity to share in that dream. However, African Americans and Hispanics collectively accounted for only 11% of BS engineering graduates in the U.S. in 2009 [5]. And, despite strong K-12 preparation, the participation of women in the engineering and technology pipeline has declined since 1995, now accounting for 18.1% of engineering bachelor's degrees awarded in 2010, up slightly from 17.8% in 2009 [5]. And, sadly, the technology gender gap is wide: while girls comprised 49% of high school students taking the AP calculus exams in 2011, only 21% of teens who took AP computer science exams were female [6]. Clearly, as society becomes more technology-driven, the representation of women interested in contributing to the technological revolution is shrinking.

Together, our education system and contemporary society poorly arm youth with the tools and interest to succeed and compete in STEM fields, discouraging them from joining the ranks of tomorrow's scientists and engineers. And, while today's students show decreased inclination to choose science, engineering and technology futures, our nation's need for product and process innovations—the work of engineers—has never been more compelling. Further, research reveals that K-12 students are not considering math and science as professionally relevant—tragically, closing off future career pathways as early as third grade [7]. Continuing on this path will greatly diminish our state and nation's capacity to perform, boding poorly for our nation's productivity and future. Only with *bold, replicable strategies* to augment the preparation of high-potential, disadvantaged K-16 students can engineering colleges more broadly serve the profession and our nation's students.

REVIEW OF LITERATURE ON HANDS-ON ENGINEERING IN K-12

Engineering design at the pre-college level has exploded through the introduction of nationwide competitions and partnerships with local engineering colleges. In 2006, the National Academy of Engineering (NAE) and the National Research Council responded to the increase in K-12 engineering initiatives by forming the Committee on K-12 Engineering Education to investigate the learning of engineering in K-12 settings and what, if any, best practices exist for K-12 engineering instruction and learning [8]. The resulting 2009 publication, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, analyzed myriad engineering curricula, the science of learning engineering in the K-12 setting, and evidence supporting the effectiveness of engineering in the K-12 arena. The investigation articulated a need for more research around potential impact on students from practicing engineering at the K-12 level; however, they did find evidence of improved learning and achievement in science and mathematics, as well as an increased awareness of engineering as a career [8] from early experiences.

K-12 engineering work is often grounded in the existing research on inquiry- and project-based learning, whose popularity reflects research advances on cognitive development in the fields of neuroscience and psychology. The research findings propose that learning is partly a social and cultural activity, and learners access and use their prior knowledge to explore, construct, and create new knowledge [9]. Students engaged in project-based instruction in the classroom demonstrate somewhat increased content knowledge, with even deeper conceptual understanding and ability to extend the skills to other situations [10]. Evidence also shows that a project-based instructional method provides a motivating environment for the teaching of basic skills, increased student cognition with more complex problems, as well as student exhibition of higher professional skills and creativity, than students who are taught traditionally [9, 10, 11]. As a result, the K-12 engineering community has tailored project-based engineering design experiences for K-12 audiences [11].

Research at CU-Boulder focusing on the retention of engineering students who have exposure to a hands-on, project-based design course in their first year of undergraduate study shows an overall 64% retention rate into the seventh semester (compared to a 54% retention rate of students not enrolled in the course), with an even higher retention of women and minority students [12, 13]. Similarly, analysis of hands-on engineering design activities in the K-12 setting has demonstrated an increase in students' STEM content knowledge and interest in engineering [14]. Although only a small number of K-12 students go on to pursue engineering careers, the broad exposure to engineering at the K-12 level can lead to more technologically-literate citizens and hopefully increased numbers and diversity of engineers [14, 15].

Throughout twelve years of executing and refining a K-12 engineering education program within three school districts, CU-Boulder's K-12 engineering education work has employed accepted longitudinal tracking methods to determine benefits to participants, long-term project outcomes, and impact on the partnering institutions [16, 17]. We have found that involvement in the K-12 engineering education partnerships supports students' enrollment in more rigorous courses of study in high school, and—in many cases—affected their college decisions (i.e., whether or not to pursue a collegiate engineering education) and, ultimately, their career path [14]. Furthermore, engagement of high school students in a multi-year, university-sponsored program can also inspire allegiance to that university [14].

TOMORROW'S ENGINEERS...CREATE. IMAGINE. SUCCEED. PROGRAM

In 2004, the Integrated Teaching and Learning Program in the University of Colorado Boulder's College of Engineering and Applied Science identified the student populations of the Lafayette, Colorado-area schools and the Denver School of Science and Technology as the focus of its GK-12 engineering initiative. Their goal, to improve science and math literacy and increase the number of high school students prepared to choose an engineering and/or technology

Fifth grade TEAMS graduate engineering fellow teaches elementary students how engineering can help lessen the impacts of natural disasters.

college path, led to the TEAMS Program and partnership—Tomorrow's Engineers… creAte. iMagine. Succeed. Their approach in the TEAMS initiative was to partner with high-need schools to make engineering exploration part of every child's educational experience in grades 3–12, through weekly, in-class, hands-on, inquiry-based engineering instruction, augmented with summer programming (http://itll.colorado.edu/index.php/k-12_engineering/tomorrows_engineers).

After success in Lafayette, in fall 2009 they implemented the TEAMS program in the St. Vrain School District, in Longmont, CO—partnering with six elementary, two middle and one high school in a district that has a diverse student population and a strong desire to increase the number of students pursuing a STEM future. For two years prior, the TEAMS Program collaborated with district and school officials to set the stage for this opportunity, as they restructured to become STEM focus schools in response to the planned opening of a new high school, a few miles away, in a high-income community. To help reduce the high number of students, particularly white students, who would leave the school (as predicted by district officials) and open enroll in the new high school, or drop out of high school completely, the Skyline High School STEM Academy program was created to prepare students for career opportunities of the future as well as develop students' 21st century skills. Further, thinking was that a "white flight" demarcation in demographics would deny all students the rich, diverse cultural experience and education that Skyline High offered its students. Today, the work to prevent "white flight" appears to have worked: the high school population is comprised of ~45% free/reduced lunch and ~52% minority students—mirroring the demographic makeup of the surrounding community. And, CU's TEAMS Program support of Skyline High School and its eight feeder schools aligns directly with the high school's mission for increasing the number of under-represented students who enter the STEM higher education pipeline.

The TEAMS model digs deep into the district's feeder system, engaging over 1,900 students annually in all nine schools in the Skyline High feeder system, priming students from 5th through 8th grade to take full advantage of the high school STEM Academy. This *systems approach* is intended to significantly increase the number of graduates who enter engineering college and other STEM programs—and is designed to be replicated in other high schools across the nation.

THE SKYLINE HIGH SCHOOL STEM ACADEMY

Skyline High School appears at first glance to be a below average American high school. Located in Longmont, Colorado, and one of the St. Vrain Valley School District's ten high school options, it is a diverse school with 1,230 students across grades 9–12. Recent composite ACT test scores, required by state mandate to be taken by all 11th grade students, for the Skyline students are 17.7 (2009), 18.9

(2010), and 17.5 (2011), compared to the 2011 district wide and statewide averages of 20.4 and 19.9. Likewise, 45% of Skyline's students are from economically disadvantaged families (free and reduced lunch eligible), compared to a high school average in the district of 20% and state of 40%.

However, a closer look shows that Skyline High School is not average at all. In 2009, Skyline began an innovative STEM Academy (http://shs.stvrain.k12.co.us/stem.htm) to help curtail the exodus of academically-oriented students *and* increase student accomplishment and graduation of students at risk. Believing that the "E" in STEM should not be a *silent* vowel, the Skyline leadership team partnered with the long-established TEAMS program at the University of Colorado Boulder. One of the goals of the STEM Academy is to mirror the demographics of the school population, ensuring that the program is serving their entire population—including minority youth and girls, both under-represented in STEM-related fields, and low-income youth from all backgrounds. The Skyline STEM Academy opened in fall 2009 with 80 freshman and 12 sophomores, and grew to 249 students in fall 2011, comprised of 35% female, 35% minority, and 23% F/R lunch students across grades 9-12.

The first four-year STEM Academy cohort to graduate will do so in 2013. Evidence that the STEM Academy is moving Skyline students beyond average level of academic preparation are the 2011 school wide CSAP results (Colorado's "No Child Left Behind" assessment test), which reveal that while the majority of Skyline's 9th and 10th grade students scored only *partially proficient* in math, writing and science, the average STEM Academy student scored *proficient* in every one of these content areas—success by any measure, and this achieved so early in the program's tenure.

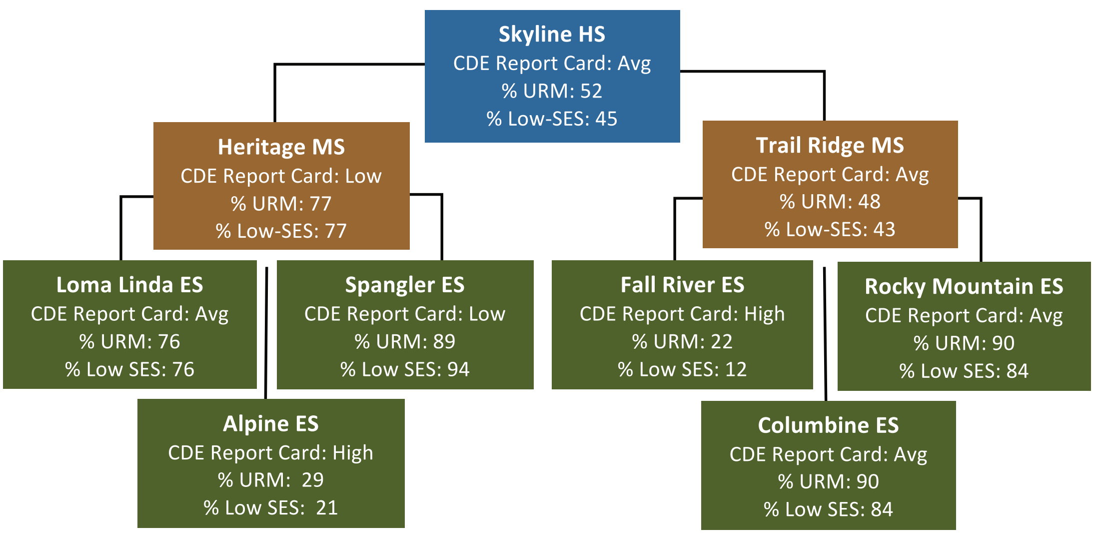

Figure 1. The St. VrainValley School District's Skyline Feeder System.

Skyline's feeder elementary and middle schools mirror the demographics of Skyline High School and are a key component in the recruitment and retention of underrepresented populations to the Academy (see Figure 1). The TEAMS program was introduced into all eight feeder school's curriculum, inspiring Skyline's leadership to develop shared learning goals between the nine schools—*including* the high school. To achieve this goal and ensure that all schools remain invested, regular Feeder Principal Meetings have been conducted for the past three years, and outreach to all feeder schools by Skyline's leadership team has been a priority to create a sense that *all* students in the feeder system will enroll at Skyline High School. (This has not been the case in the past, as many students—perceiving that Skyline High School had a lack of rigor, too much focus on discipline instead of academics, and low expectations for their students—*opted out* of the feeder system and enrolled in one of the district's alternate high schools.)

Building Momentum

To increase community awareness of the Skyline STEM Academy, the Skyline leadership team (and a host of enthusiastic students) frequently conducts tours of the newly renovated school for Parent/Teacher Organization groups, participates in community events at the feeder schools, and collaborates with the feeder schools on their grant proposals. Plans also include hosting elementary and middle school workshops in the summer to increase the commitment and expectation that students enroll at Skyline High School and, hopefully, become part of the STEM Academy. The high school also hosts a STEM Lecture Series throughout the academic year featuring guest speakers prominent in local STEM industries; several elementary and middle school classes regularly attend the presentations. Also, Skyline invites all feeder schools to bring students to their engineering design expo, held at the end of each semester to showcase the projects that STEM Academy students create during their engineering design classes.

Implementation of the Skyline STEM Academy

Students are given the opportunity to apply to the high school STEM Academy during their 8th grade year. Middle school visits (even to those schools outside the feeder system) are conducted in December, and an Open House, hosted at Skyline High School, allows students and parents interested in the STEM Academy to see first-hand the new facility and meet with teachers and students about the program. Students apply in December, and include in their application recommendations from teachers who can speak to their STEM abilities and academic motivation.

Through several iterations, and building off of the successful TEAMS Program teach-the-teacher model, the combined Skyline and TEAMS leadership team developed a comprehensive education plan (summarized in Table 1) for the high school Academy, with the overarching goal of students

Subject	Description	Years Required
	Core Requirements	
Math	Must successfully complete a minimum of Pre-Calculus/ Trigonometry by graduation.	4
Science	At least one full credit must be earned each year; required: at least one year of biology, chemistry, and physics. Must complete at least one full year of any AP science course.	4
Single Foreign Language	Three years of one world language or two years each of two separate world languages.	3
	STEM Academy Requirements	
STEM Elective-WIRED	Required course for all STEM Academy 9th graders; can also be taken the summer prior to 9th grade. This course provides students with a basic introduction to Internet and technology resources such as Google Docs® and Power Point®.	0.5
STEM Elective-Computer Science	Can be taken any time during the 4 years: Introduction to Programming, Introduction to Computing, Computer Science or AP Computer Science.	0.5
Explorations in STEM	(No Prerequisite) This course provides students with a foundation in the topics and skills necessary for success in upper-level STEM courses. Required course during freshman year (either semester)	0.5
Creative Engineering	(Prerequisite: Explorations in STEM) Students take one full year (two classes) during their sophomore year. Course options are evolving, and so far include: Robotics, Assistive Technologies, Sustainable Design, and Structural Design.	1
Advanced Engineering	(Prerequisite: Creative Engineering) Students take one full year (two classes) during their junior year. Course options are evolving, and so far include: Robotics, Biomedical Engineering, Engineering Science, and Applied Software Engineering.	1
Senior Capstone Design Course	(Prerequisite: Advanced Engineering) Students take one full year during their senior year.	1
Other STEM Electives	Any additional math, science, computer science, or STEM class beyond requirements.	1

Table 1: Graduation requirements of Skyline High School students completing the STEM Academy certificate program.

pursuing post-secondary STEM degrees. In order to receive a STEM certificate upon graduation, students are required to take 28 total high school credits (minimum district graduation requirement is 24.5 credits) and follow an increasingly challenging education plan during all four years in the STEM Academy. Students must attain grades of C or better in each of their core and STEM courses, and graduate with at least a 2.5 unweighted GPA to receive the STEM certificate. Additionally, students must still meet all graduation requirements mandated by the school district.

High school STEM Academy students work with 5th grade client (a local elementary student with a disability) in understanding her needs for an improved water fountain device.

A key component of the STEM certification program is four full years of math and science for all STEM students, with the requirement of completing Algebra 1 by 9th grade. To ensure that students are prepared to succeed in Algebra 1, Skyline and its two feeder middle schools committed to the implementation of a CTAG (Closing the Achievement Gap) grant, provided by the Colorado Department of Education, for the past three years. The grant led to a change in Skyline's master schedule to provide three tiers of intervention for those students entering 9th grade at the Algebra 1 level. For example, students in Tier 1 are prepared for Algebra 1 at 9th grade, while students in Tier 2 are less prepared, and are concurrently enrolled in both Algebra I and an additional math lab to address specific holes in their math learning. Students in Tier 3 take an intensive Algebra 1 course every day (double the time of a regular Algebra 1). Thus, every student who enters 9th grade deficient in Algebra 1 is met with a plan to boost their math achievement. Because of these math tier system interventions, the Algebra 1 failure rate at Skyline High School has already been reduced from 38% to 16%—a remarkable outcome.

Also, on average, 25% of 9th graders—more than those coming in at the Algebra 1 level—take Geometry or Algebra 2. Pushing the educational innovations lower, both feeder middle schools now use the Tier 2 model with their 7th and 8th grade classes to address holes in math preparation *before* students get to high school.

As can be seen in Table 1, three full years of STEM engineering courses are required to earn a STEM Academy certificate. Each of the courses has been developed in collaboration with CU-Boulder's College of Engineering and Applied Science, and provides students with fundamental engineering design principles and experiences, arming them with the resources for a successful first-year engineering program at the college level. Students begin the engineering sequence with exploring the engineering design process and the importance of teamwork in engineering.

As students grow through the sequence of courses from *Explorations in STEM* (in grades 9-10) to *Senior Capstone Design,* they are engaged in increasingly complex hands-on design projects that peer into a variety of engineering disciplines. The curriculum uses a modified First-Year Engineering

Projects course curricula, as instructed at CU-Boulder and described in "Improving Engineering Student Retention through Hands-On, Team Based, First-Year Design Projects," by Knight, et al. [13]. Each of the engineering courses culminates in an Engineering Design Expo, where the high school students present their final products and display posters to an audience of engineers, school district officials, and K-12 students from other schools. To view Skyline STEM Academy students displaying their assistive technology products for a local elementary school client (see videos at: http://spot.colorado.edu/~schaefem/pageAEE.html).

Several other courses have been developed to meet the Academy goals. The 9th grade *WIRED* course prepares students to operate in a digital academic environment and connects them to technology in a project-based environment. Students begin building an eFolio that will house their STEM work throughout their four years in the Academy, learn how to prepare a professional presentation—a skill that they will hone in all STEM classes—research STEM careers, and begin a "College in Colorado" profile.

The *Senior Capstone Design* course provides students with the opportunity to research and design a year-long engineering project, and employ the engineering design process while working in a team. These projects may also be part of the *Innovation Center,* where students take R&D ideas from local businesses and develop a project with the goal of taking the idea to production or the marketplace.

Interestingly, one of the required computer science courses, *Introduction to Programming,* developed prior to founding of the Academy, is one of the most popular courses at the school, with 141 students enrolled, of which 40% are Latino.

Students in the STEM Academy also aid in the district-wide collaboration to align curriculum between the feeder elementary and middle schools with the high school. For example, STEM Academy students actively participate in the STEM Lecture Series—a community event that brings feeder middle and elementary students to the high school to learn alongside older students. During these lectures, STEM Academy students assist with the hosting of the lectures and regularly solicit thoughtful, relevant questions of guest speakers.

RESEARCH QUESTIONS AND ASSESSMENT METHODS

Is a multi-year, comprehensive STEM Academy an effective model for increasing student perception and persistence into STEM careers? The goal of this research is on creating a systemic high school STEM experience that is based on current knowledge of skills necessary for success in undergraduate STEMdisciplines. Specifically, this research paper addresses student perception, preparedness, and persistence in engineering for students in a public high school who have regular, pre-college hands-on engineering design experiences.

Everything worth doing is worth measuring. The STEM Academy program is assessed on a continuous evaluation cycle, with quantitative and qualitative methods used to assess the program's success in meeting measurable objectives and outcomes. Each assessment method is selected to help determine if program objectives have been met.

Quantitative methods include student attitude surveys; Academy application analyses; collection of school demographic data; and student attendance and retention comparisons. Following the successful assessment of the TEAMS program prior to working with the Skyline STEM Academy, longitudinal tracking of participant course choices, grades, and transcripts are also employed. Qualitative methods include open-ended survey questions for students; small focus groups for students per semester; and weekly discussions with teachers, though these are not the focus of this paper and will be elaborated on in future publications.

Thus far, information has been gathered on 103 students who participated during the inaugural year of the STEM Academy (2009–10), and 168 students who participated during the second year (2010-11). This includes ~350 matched pre-to-post semester attitude surveys over the two academic years (the number reflects 10th and 11th grade students who have taken more than one semester-long course), and eight small (5–6 students each) focus groups in each of the upper-level engineering design courses. More than three times that number of STEM Academy applications have been analyzed to provide information on the characteristics of students attracted to this type of program. Also, attendance, and retention comparisons have been made to the student population of the school (1,251 students in 2009-10 and 1,230 students in 2010–11).

IMPACTS OF THE STEM ACADEMY

Student Perception of Engineering

The results of 103 9^{th} and 10^{th} grade students, participating in four sections of the 2009–10 *Explorations in STEM* course and 168 9^{th} through 11^{th} grade students during the 2010–11 *Explorations in STEM* and *Creative Engineering* courses, provide some insight into the impact of the STEM Academy on student interest and awareness of engineering. After a brief introduction to engineering careers at the beginning of the semester, the *Explorations* course engages students in three or four multi-week, project-based engineering explorations guided by the engineering design process, ending with design prototype completion. The *Creative Engineering* courses engage students in a more in-depth semester-long engineering design project. These classes are taught by three high school science teachers with prior experience and training in engineering design through CU-Boulder's teacher professional development. In addition, a CU TEAMS engineering graduate student helps instruct the classes weekly, providing student support on their design projects.

Students were given engineering attitude surveys about their semester-long *Explorations* course experience with choices on a five-point Likert-type scale ranging from "strongly agree" to "strongly disagree," pre- and post-semester, to measure changes in student attitudes towards engineering as a result of exposure to engineering design. The survey instruments were modified from instruments already in use by CU-Boulder to evaluate their *First-Year Engineering Projects* course. The survey questions probe student attitudes and include awareness of engineering careers as well as interest in learning more about engineering. The surveys are paired pre- to post- for each student. T-tests are used to separately determine the significance of pre- to post-matched survey scores for awareness of engineering careers and interest in engineering. Mean scores are presented here and have been adjusted to a five-point Likert-type scale.

This 2009–10 survey data contains responses to fourteen questions that queried about engineering careers (eight items) and interest in learning more about engineering (six items). The scores were summed separately from the careers questions and interest questions to get two aggregated scale scores for awareness and interest. For example, a higher pre-survey score for interest indicates a student's greater initial interest in learning more about engineering.

The pre- to post-mean scores of the overall 2009-10 *Explorations* course (n=103) demonstrate a significant gain from the pre-assessment (mean=4.15) to the post-assessment (mean= 4.47), $p < 0.01$, for engineering awareness, indicating that the pre- to post-gains are real, and the *Explorations* course increased student awareness of engineering as a career. The mean scores of these students (n = 104) with respect to interest in engineering relay a gain from the pre-assessment (mean = 3.81) to the post-assessment (mean = 3.88); however, T-test statistical procedures indicate that this gain is not statistically significant ($p = 0.35$).

Gender Differences

These results, separated by gender, provide more insight into the interest and awareness gains of STEM Academy students, although it should be noted that sample sizes are fairly small for this type of analysis. With respect to gender, the mean scores of awareness and interest for both females and males in the inaugural cohort of the STEM Academy are shown in Table 2. Female students reported similar gains in engineering awareness over the semester as their male counterparts, and greater gains in their interest in engineering. Calculated gains are significant for engineering awareness but not for interest in engineering.

Variable	N	Pre Survey Mean (SD)	Post Survey Mean (SD)	Mean Difference
Engineering Awareness				
All	103	4.15 (0.44)	4.47 (0.49)	0.32*
Female	34	4.06 (0.46)	4.57 (0.32)	0.51*
Male	69	4.19 (0.43)	4.43 (0.55)	0.24*
Interest in Engineering				
All	103	3.81 (0.69)	3.88 (0.78)	0.07
Female	34	3.77 (0.57)	3.96 (0.63)	0.19
Male	69	3.86 (0.75)	3.85 (0.84)	-0.01

** Significant at the $p < 0.05$ level, paired t-test

Table 2: Preliminary results of the Skyline High School inaugural 2009–2010 STEM Academy cohort.

A 1-5 Likert-scale adjusted mean is given, pre then post, with standard deviations in parentheses.

The preliminary results and early patterns were promising in support of hands-on high school design courses and indicated that more research is needed to evaluate the impact of the STEM Academy on student perceptions and attitudes. This led to a refinement of the surveys for the 2010-11 academic year in order to look more closely at student attitudes with respect to self-efficacy in engineering and identity with the engineering profession.

Digging Deeper

Initial analysis confirms that 9th, 10th and 11th grade student perceptions of engineering continued to increase in the Skyline STEM Academy during the 2010–11 academic year (n = 168). The new survey questions include factors to measure how the students identify with the group of engineers (12 items) and self-efficacy around engineering (11 items). The latter includes questions around interest in engineering (*I think engineering is interesting*) and confidence to succeed in engineering (*I can succeed in an engineering curriculum*). These factors were confirmed through a Principal Components Analysis.

Again, mean factor scores were used and correspond to a five-point Likert-type scale. For example, a higher average pre-survey score for identity indicates a student's greater initial identity with their engineering peers. The surveys were then paired pre- to post- for each individual. T-tests were used to determine the significance of pre- to post-matched survey scores for *awareness of engineering careers* and *interest in engineering* separately.

Variable	N	Pre Survey Mean (SD)	Post Survey Mean (SD)	Mean Difference
Engineering Identity				
All	168	4.03 (0.61)	4.14 (0.61)	0.11*
Female	57	4.04 (0.52)	4.07 (0.53)	0.03
Male	111	4.03 (0.66)	4.18 (0.64)	0.15*
Engineering Self-Efficacy				
All	168	4.22 (0.51)	4.29 (0.53)	0.04*
Female	57	4.05 (0.54)	4.16 (0.49)	0.11*
Male	111	4.31 (0.47)	4.35 (0.55)	0.04*

** Significant at the $p < 0.05$ level, paired t-test

Table 3: Results of the Skyline High School fall 2010 STEM Academy cohort.

A 1-5 Likert-scale adjusted mean is given, pre then post, with standard deviations in parentheses.

The pre- to post-mean scores of STEM Academy engineering students for fall 2010 (n = 168) demonstrate a significant gain from the pre-assessment (mean = 4.03) to the post-assessment (mean = 4.14), $p < 0.05$, for engineering identity. And, the mean scores of these students (n = 168) with respect to efficacy in engineering relay a gain from the pre-assessment (mean = 4.22) to the post-assessment (mean = 4.29), $p < 0.05$ (presented in Table 3).

These results, separated by gender, provide more insight into the evolving perceptions of the STEM Academy students. With respect to gender, Table 3 gives the mean scores of engineering identity and engineering self-efficacy for both females and males during fall 2010, for the entire STEM Academy cohort. As shown, female students did not demonstrate similar gains in engineering identity to their male counterparts over the course of the semester. Also, female students showed greater overall gains in engineering self-efficacy ($p < 0.05$) but still did not match the self-efficacy gains of their male counterparts. The male students in the STEM Academy reported a higher self-efficacy in engineering than female students both pre- and post-semester. While, independent samples t-tests confirmed that the pre- and post-survey scores for engineering identity were not statistically different between females and males, the pre- and post-scores for engineering self-efficacy were indeed different ($p = 0.002$ and $p = 0.27$, respectively).

Student perceptions of engineering, including engineering identity and engineering self-efficacy are changing for students in the STEM Academy. While we continue to survey students every semester during their tenure in the Academy, we hope to specifically answer how their perceptions are evolving, both by grade and demographics. Coupled with thoughtful qualitative analysis, this research is poised to inform the engineering education research community on the value of early and frequent exposure to engineering.

Student Preparedness for Success in Engineering Careers

Students take the application process seriously, writing thoughtful essays and highlighting their academic accomplishments in middle school. And, a definite measure of success is that from 2009-11, Skyline saw an 11% increase in the number of students enrolling in the school from charter schools or middle schools *outside* of Skyline's two feeder middle schools. And, an added measure of success: students are staying in the Skyline feeder system who would have otherwise gone to the IB program at another high school in the district. The K-16 team is encouraged that such intentional *diversity through excellence* can be a model for other school settings.

The average GPA of STEM Academy student's is greater than the average of the overall school, as shown in Table 4. As of spring 2011, the STEM weighted GPA was 3.30, while the overall school (grades 9-11 only for accurate comparison) had a weighted GPA of 2.65.

Retention in the program from year-to-year is also promising. For the current 11th graders, 77% (70/91) of the cohort are still in the program, as are 99% (75/76) of current 10th graders. From the initial cohort of current 12th graders, 47% (9/19) are still in the program—even though they have not experienced a full four years of the Academy, which is believed to be instrumental in year-to-year retention.

Changing School Culture

Although the inaugural class of STEM Academy students will not graduate for another year, the school has already seen an increase in the number of students participating in STEM-related activities. Three years ago there were no computer or engineering classes being offered at the high school,

Grade	STEM GPA	School GPA
9	3.35	2.57
10	3.27	269
11	3.15	2.70
Overall	3.30	2.65

Table 4: Spring 2011 average STEM Academy student GPA vs. overall school GPA.

and now Skyline has four teachers (2.33 FTE) teaching 28 sections of computer and engineering courses. And, now their growing Computer Science and Engineering Program is a testament to student interest.

Skyline STEM students also successfully partner with several post-secondary groups, offering skills to help students succeed as they pursue STEM undergraduate degrees (see box at right). Two groups of students have been working on out-of-class projects with professors from Universities in Oregon and Arizona. Another four students have been hired by a local business partner, RidgeviewTel Wireless, employing skills they learned at Skyline through STEM Academy courses.

My role in the Pykata project was to lead and organize the programmers, to organize problems, and help create solutions for programs. This project was extremely different than others as it was primarily student led with teacher guidance. It was awesome to have Skyline High School back us up on our programming development. I am honored to have worked with the brightest students in the field of computer programming at Skyline High School.

– Meng Koh, Class of 2011

Student Persistence: Attendance and Retention of STEM Students

Over the last few years, the attendance at Skyline High School has steadily improved. In 2008-09, a 90% attendance rate, coupled with an astonishing 142 suspensions, was the norm. In 2009-10, however—with the inception of the STEM Academy—attendance rose slightly to 91%, with an 18% decrease of suspensions (to 116). Last year (2010–11) saw an even greater increase in attendance (at 93%) and a further 17% decrease in suspensions (to 96). The school leadership attributes this increase in attendance and decrease in suspensions to the engagement of students in the STEM Academy, as students take responsibility for learning and have pride in themselves and their school.

Also, the retention rates of students into the next year of the STEM Academy are promising. The first class, fall 2009, saw an 81% retention into the next year. The second cohort saw a 97% retention rate into fall 2011.

The University of Colorado admitted eight Skyline High School

First-year CU-Boulder students brainstorm on the best solution for improving an electrical device for their capstone engineering project.

graduates to their first-year engineering cohort for the current fall 2011 semester (a marked increased from previous years). These newly admitted students report that the presence of a serious, focused school culture helped lead them to matriculate to post-high school engineering studies. And, CU-Boulder's presence through the TEAMS Program made students aware of engineering as a career, and specifically towards engineering at CU-Boulder. Parents and students consider this partnership, along with a guaranteed admission to CU-Boulder's College of Engineering and Applied Science for STEM Academy students who meet certain criteria, as a strong argument when considering high schools.

LESSONS LEARNED

The Skyline STEM Academy is a dynamic process. The combined university and high school leadership team is committed to refining and improving the program through each subsequent year of implementation. Lessons learned from year to year help drive improvements in the program and increase student learning and success of the Academy.

The Application Process

Skyline High School has increased the quality of their application process from their first round of fall 2009 applicants. During the inaugural year, the Academy essentially admitted anyone who applied and even allowed teachers to verbally recommend some students who did not actually fill out the application. Nearly all of those students dropped out of the STEM program—believed to be due to a lack of program buy-in (none of those students had actually made the effort to fill out the application). The school has since required a more in-depth application process and, has seen a higher quality of applicants and student interest.

The high school still needs to better educate the middle schools on the importance of encouraging all of their students to at least investigate the benefits of the Skyline STEM Academy, just as they would an IB or AP program at other high schools. While parents are knocking on the school's doors to enroll their students at Skyline, they still have to work hard to get counselors and teachers to understand that anyone who is interested can, and should, apply to the STEM Academy.

Dynamic Teachers

Recruiting dynamic instructors is always a challenge. How does the school select teachers that can maintain the level and methods of instruction that they know works? It helps to have a passion about some field in particular. And, teachers in the STEM Academy encourage experimentation and students being a part of the daily discussion. The paradigm shift for teachers is that they have become *facilitators of learning;* thus, teachers must be willing and capable of learning alongside the students as they *all* encounter the magical world of engineering. The current Academy teachers fit this mold, but more teachers who share these characteristics will be needed as the Academy grows.

Integration of the Engineering Design Process

Skyline High School's four-year STEM curriculum focuses on higher-level thinking, communication, writing and many other 21st-century skills necessary for successful student learning. Students have expressed that the project team concept that is utilized in all of the STEM classes is essential for their learning and development as students prepare to be leaders in today's global economy. From the beginning, students understand the design process and begin to get a feel early on how engineers contribute to the health, happiness and welfare of society — an early decision made by the leadership team to focus on the engineering design process and embed it into the daily routine rather than do "science-fair type" projects in an after-school environment, as many STEM programs do. The STEM Academy allows students to design, test, re-design their products and present, and communicate their results, and engages students in enriching projects that they work on for many weeks or an entire semester—while learning that engineering is meaningful work that benefits humanity and our planet. Through the Academy, students are engaged during the school day, making science, technology, engineering and math part of their world *every day.*

While the engineering design process remains the consistent focus as students move through the program, students are given freedom to choose the type of engineering project that they wish to explore. The idea behind the *Senior Design Capstone* course is that students may pick from topics they have previously explored in their *Creative* or *Advanced Engineering* courses. This idea led to the concept of the *Innovation Center*—a center that allows students to work in a real business research and development environment, utilizing the Engineering Design process, to find solutions to actual, contemporary problems and projects facing industry.

Female and Minority Retention

The Skyline High School leadership team has learned that they need to be more purposeful about engaging girls and minorities in the STEM Academy program for the entire four years. While STEM teachers, guided by CU-Boulder diversity specialists and information gleaned from the National Academy of Engineering's *Changing the Conversation* study [19], have chosen engineering design areas they hope will appeal to girls and minority students more than traditional engineering topics, the leadership team must strive more purposefully to engage these groups to maintain their STEM interest and commitment through academic achievement. Likewise, the school needs to create a plan to more broadly generate 8th grade student interest and dispel the notion that only the top math and science students should apply to the program—essentially the same challenge that (fast forwarded four years) faces engineering colleges interested in *broadening participation* beyond majority men.

As the word "STEM" was abuzz in the Skyline community last year, the number of student applicants to the Academy greatly increased for fall 2011, but alas the school did not see an increase in female and minority students, and is not likely to without a purposeful communications and messaging strategy. With purposeful engineering interactions beginning in their elementary and continuing throughout their middle schools, the team intends to positively improve their participation results each year. This year, they will invite not only 8th grade students and parents to their December Open House, but also 7th grade parents and students to garner interest early. They will also work with their middle schools more closely to create an integrated STEM curriculum to ensure that their goals and strategies around engaging underrepresented populations mirror the high school's. One of the two feeder middle school has recently chosen STEM as their focus, which should greatly aid in the high school's recruitment into the STEM Academy.

Industry Partners

The school has realized that cultivating business partnerships is more than asking for donations or conducting financial transactions. Toward that end, the Academy leadership regularly meets with their industry partners to establish new student/industry collaborations. For example, they have developed a true industry partnership with a local telecommunications company, RidgeviewTel Wireless, that involves their CEO consulting with the school, employing Skyline students, and helping guide their program in such a way that their company benefits from Skyline's students and vice versa (evidenced through the boxed quote at right).

Such industry engagement is important to the success of a STEM Academy. In March 2011, Secretary of the Interior Ken Salazar and other federal officials visited the Skyline High campus to tour the new STEM Academy facility and discuss with students their experiences. Salazar acknowledges that the partnership between industry, University, and a K-12 school makes engineering design at the K-12 level possible (see video at http://teachers.egfi-k12.org/colorado-

> *Working at RidgeviewTel was a wonderful experience for me. I learned how to work as a part of a team, something that is invaluable in the workspace.*
>
> *Education had been taught in the same ways for generations; however, I feel that Skyline has boldly marched into the 21st century by teaching with technology in a way the students understand and by encouraging collaborative efforts to solve a problem.*
>
> – Josh Rahm, Class of 2011

stem-salazar/) [18].

CONCLUSION

Central to the Skyline TEAMS model is their successful partnership with CU-Boulder's College of Engineering and Applied Science, their many industry partnerships and a focus on scholarship and achievement for all students. Sophisticated, integrated course work and reinforcing with students the choices they must make in order to be academically prepared for a post-secondary engineering and/or other STEM education is a main thrust of the STEM Academy. Unfortunately, K-12 engineering initiatives such as these alone will not create a significant enough STEM pipeline, since a vast number of high school students are not academically prepared to enter engineering college. While K-12 engineering experiences, such as engineering electives, may inspire an interest in engineering, students must also make course selections across the curriculum that adequately prepare them for an engineering future.

Skyline High School's four-year STEM curriculum is designed to be replicable at other high schools. There are several essential elements to reproduce similar systemic and cultural change. The Academy is a model that truly emphasizes STEM, requiring four full years of math, science, and engineering for all Academy students. Integral to this approach are a focus on 21st-century skills necessary to be leaders in today's global economy and the academic supports in place to help students choose and complete their courses. Students are required to complete Algebra 1 by 9th grade, and extra resource has been designated to help them meet this goal. The STEM Academy also incorporates hands-on engineering design courses in every year, cementing the real-world applications of what they are learning. This aggressive approach requires more credit hours of courses than the minimum graduation requirements in the district, but the program results indicate that this extra effort is worth it. Introducing the program to the elementary and middle school levels is necessary to excite and engage students early and is also beneficial for attracting diverse quality students into the program. Dedicated leadership, strategic university partnerships, and dynamic teachers all influence the perceptions, preparation, and persistence in STEM for youngsters that marks the success of this STEM Academy.

Attitude matters! The leadership team at Skyline High School and CU-Boulder believe that all students can achieve success at a high level no matter their status, race, ethnicity, or gender. Engineering requires upper-level critical thinking, and girls and boys at Skyline are learning that all students can *do* engineering. The STEM Academy provides a venue for students to *understand what engineers do*, explore engineering design, and gain the confidence to pursue post-secondary engineering or other STEM fields.

After years of school-wide academic and discipline struggles, the Skyline principal finally hears passion behind students' voices as they discuss their pursuits in *and* outside of the classroom at a more mature level. They know what they're learning and are proud to talk about it; they have become responsible for their education and interested in it. Increasingly, Skyline youth do not have barriers on their thinking, and, as such, the school is trying its best to harness that concept and foster creative student thinking. Students participating in the Skyline STEM Academy see their world as "full of opportunities rather than barriers." As evidenced by student presentations to Secretary of the Interior Ken Salazar and representatives from Ball Aerospace in the spring of 2011, Skyline STEM students not only want to be engineers, they are starting to think like engineers (see boxed quote at right).

> *At the moment I would love to be a civil engineer. But most importantly I would love to have a career in which I can make a difference by using math, science, and hard work.*
>
> *I heard about the STEM program when I was in middle school. I was interested in both IB and STEM programs. But after trying out IB, I feel that STEM would be a better fit for me.*
>
> – 9th Grade STEM Academy Student, Class of 2014

The Academy leadership team values the E in STEM and makes it an integrated part of the day and an integral part of the curriculum. And, they have set high expectations for all kids, not just the best performers, as all Academy participants are expected to rise to the challenge of becoming a "best" performer. The leadership team also shares a consistent vision for achievement which has become the norm of the STEM Academy, and spread to the entire school. Everyone who works on the team must buy-in to the vision, and everyone works towards the common set of goals.

And, crucial to the success of the program, the Skyline STEM Academy continues to grow each year—from 90 students in the first year to 249 students in the third year (2011–12). With this growth, the program needs to continue developing their courses to be engaging, such as the new junior-level *Advanced Engineering* and senior-level *Capstone Design* course. And, the hope is that CU-Boulder's College of Engineering and Applied Science reaps the benefits of a highly qualified, motivated crop of diverse students prepared to pursue an engineering future.

There are yet many questions that lay ahead in this journey, such as, how to measure a student's ability to think like an engineer? How to inspire the Academy students to continue to achieve academic excellence throughout their high school experience, and how will engineering colleges change to meet the needs of this new student already possessing years of engineering design savvy? The Skyline STEM Academy students are starting to recognize the needs in the world around them and thinking like engineers. Academy students are beginning to seek out problems and think about how to solve new challenges. The Academy instructors hope that the quality of the senior *Capstone Design* projects completed through the Innovation Center are relevant enough to industry that a student's value is seen as a viable resource for businesses looking to partner with Skyline High School. The Academy works to transition students from *wanting to be an engineer,* to believing that *they are an engineer* —before they enter a post-secondary institution *or* the workforce.

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