AC 2011-1042: WORK IN PROGRESS: DESIGNING AN INNOVATIVE CURRICULUM FOR ENGINEERING IN HIGH SCHOOL (ICE-HS)

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Work In Progress: Designing an Innovative Curriculum for Engineering in High School (ICE-HS)

Abstract

The projected job growth for Science Technology Engineering and Math (STEM) professionals is expected to be 22% as reported by the Occupational Outlook quarterly in spring 2007. According to the National Science Foundation, only about 17 percent of U.S. college graduates earned a degree in subjects related to STEM; this falls well below the world average of 26 percent. In order to fulfill this projected need, state governments have initiated STEM education programs in high schools across the country. The challenge faced by high school administrators and teachers is not only to develop a new set of modules for engineering, but also to imbed innovative pedagogy while implementing them. Moreover, they are faced with the task of identifying the scope and sequence of engineering education at a high school level. Traditionally, high school students were introduced to engineering during summer camps at a college of engineering. The summer camp or out-reach activities were university developed and delivered. Seldom did they last more than a few weeks. Exemplary vendor-sold curricula such as *Project Lead the Way* and *Infinity* provided the scope and sequence for teaching engineering in high school. They also assisted schools in the form of training, teaching materials, and web support. Agencies such as NSF and ASEE have developed engineering education websites such as egfi.org, teachengineering.org, and cadrek12.org that are not utilized by the vendor-sold curricula. Expense and investment in teacher implementation training time remain important factor in implementing vendor- sold curricula. The ICE-HS presents a step-by -step methodology for developing a four- year high school engineering curriculum framework based on backward design and systems thinking approaches. The ICE-HS is structured around two major objectives: attracting the high school students to STEM and providing a flexible engineering foundation. It does not prescribe specific modules but offers integration with the other disciplines such as language/arts and traditional science courses. The ICE-HS is currently being piloted in a charter high school, Da Vinci School for Science and the Arts. The ICE-HS uses the modules developed by several sources such as NSF and ASEE and provides a framework that allows the school to customize its delivery for appropriate grades and levels. The main contributions of this framework are the defined scope and sequence and the outcomes and rubrics that utilize an array of publicly available resources for teaching engineering throughout the high school.

Introduction

The imperative of an increasingly global economy is that improved STEM education will help ensure a diverse, scientific and technical workforce, as well as a citizenry capable of mastering the scientific and technical concepts and skills required to function in work and home environments characterized by increasing technological sophistication. A decade ago, the Glenn Commission Report [1] voiced grave concern that declining performance and interest in STEM subjects among U.S. students would significantly impact efforts to increase the size of a technical workforce already too small to meet the hiring needs of the nation's firms, that were poised to face drastic reductions as Baby Boomers reach retirement age. Since the release of that report, STEM education reform has been a growing priority of both government and private sector agencies, as reflected by a proliferation of STEM initiatives at national, state, and local levels.

Key recommendations of the Glenn Commission [1] and more recently the National Academies [2] indicate wide consensus that better preparation of K-12 STEM teachers and a more rigorous K-

12 curriculum are necessary to improve student performance in STEM subjects at college and career levels. While progress has been made, there is growing recognition that affecting a complete paradigm shift in an education system as large and complex as ours will take time and commitment on the part of all stakeholders in STEM education. For example, Occupational Outlook Quarterly [3] projected job growth for STEM professionals is expected to continue increasing at a rate of approximately 22 percent per year. The National Science Board[4] indicates that one third of the degrees awarded in the U.S. are in Science and Engineering, however half of them are in the social and behavioral sciences, which suggests its technical workforce is falling behind other nations, in that 26 percent of graduates of foreign universities earn STEM degrees.

Pre-college engineering is especially problematic in STEM education reform since there is no well-established tradition of engineering in the K-12 curriculum, or as part of teacher preparation and certification processes. The result: most K-12 teachers and administrators are ill-prepared to advise students about engineering careers, much less to introduce engineering knowledge and skills into the classroom. While there is a growing appreciation that engineering may be a positive vehicle to motivate K-12 student study of other STEM subjects [5,6,7] some emerging research indicates that there are circumstances in which this position may not be entirely valid [26]. However, the gaps in experience with engineering in the K-12 setting make these kinds of discussions difficult to a large degree, because there is no epistemic foundation to give them context. Engineering in K-12 Education, a report released recently by the National Academy of Engineering [8], make a number of convincing arguments for engineering as “a catalyst for a more interconnected and effective K-12 STEM education system,”(page 12) and recognizes that this outcome “will require significant rethinking of what STEM education can and should be”.(page 12)

Among the wide variety of engineering programs developed for K-12 education, most exhibit a common set of characteristics but differ in the scope and approach to packaging the content. Our proposed ICE-HS curriculum complements existing programs by providing a flexible framework for selecting, adapting and integrating such materials, and it also follows the principles outlined by the National Academy of Engineering[8].

The three general principles of the National Academy of Engineering[8] include emphasis on design; appropriate math, science and technology content; and engineering habits of mind. The design process is the main trait of engineering by identifying and solving problems. Mathematics and science concepts serve as the foundation to understand engineering; however, the conventional approach is to include only the minimum needed. The engineering habits of mind emphasize skills such as systems thinking, creativity, optimism, collaboration, communication and ethical considerations. These principles are covered, with different depth levels, by each engineering program studied. The intent of the ICE-HS framework is to provide schools the flexibility they need to select the resources that best fit their objectives while maintaining commitment to the general principles.

The proposed ICE-HS framework includes courses similar to other programs in engineering in grades 9-12, introducing the threads of design and technology. In contrast to the conventional approach that skims over mathematics and science concepts, however, we have structured a set of relations between the science and math courses to create synergy with the engineering curriculum. For example, the inquiry-based learning method emphasizes higher-order thinking, the second strand of the science thread. The strength of our approach comes from the systems thinking and collaboration emphasis.

Thematic Basis of the Curriculum Framework - The ICE-HS Curriculum Framework is designed with a logical instructional model that is based on the professional standard for instructional delivery (e.g., Madeline Hunter's Lesson Plan Model[9]). This format begins with clear objectives for student outcomes using Bloom's Taxonomy; a Motivational or Student Engagement Component; an array of delivery methodologies including team work, lecture, project-based learning and inquiry-based learning; concluding with self-reflection exercises and assessment of the objectives.

For example in Figure 1, the Framework in the 9th grade begins with Engineering & Me. The primary objective is to teach students about the roles and challenges that engineering professions face, along with the required skill levels, knowledge and tools they must master. Imbedded in this unit is the Motivational or Student Engagement Component whereby students make connections with the Engineering profession by meeting and interviewing engineers, learning of their humanitarian projects, and coming to appreciate contributions of engineers to students' interests or tentative career choices.

The next unit, Systems Models, addresses the second objective for that year which is to understand the seminal concept used by engineers: the Engineering Algorithm. Once this thinking tool is introduced and understood, the third unit, Systems Engineering Project, is presented. The students and teacher move from the theoretical to the hands-on application. During the implementation/application phase, students will deliberately practice the work habits of engineers (i.e., teamwork protocol) and use the tools appropriate to their level (i.e., data-driven decision making) to accomplish their mission.

The 10th grade units progress in a similar pattern, incorporating age/grade appropriate knowledge and skills that complement the other grade level subjects to fortify and enhance the introduction of this new discipline.

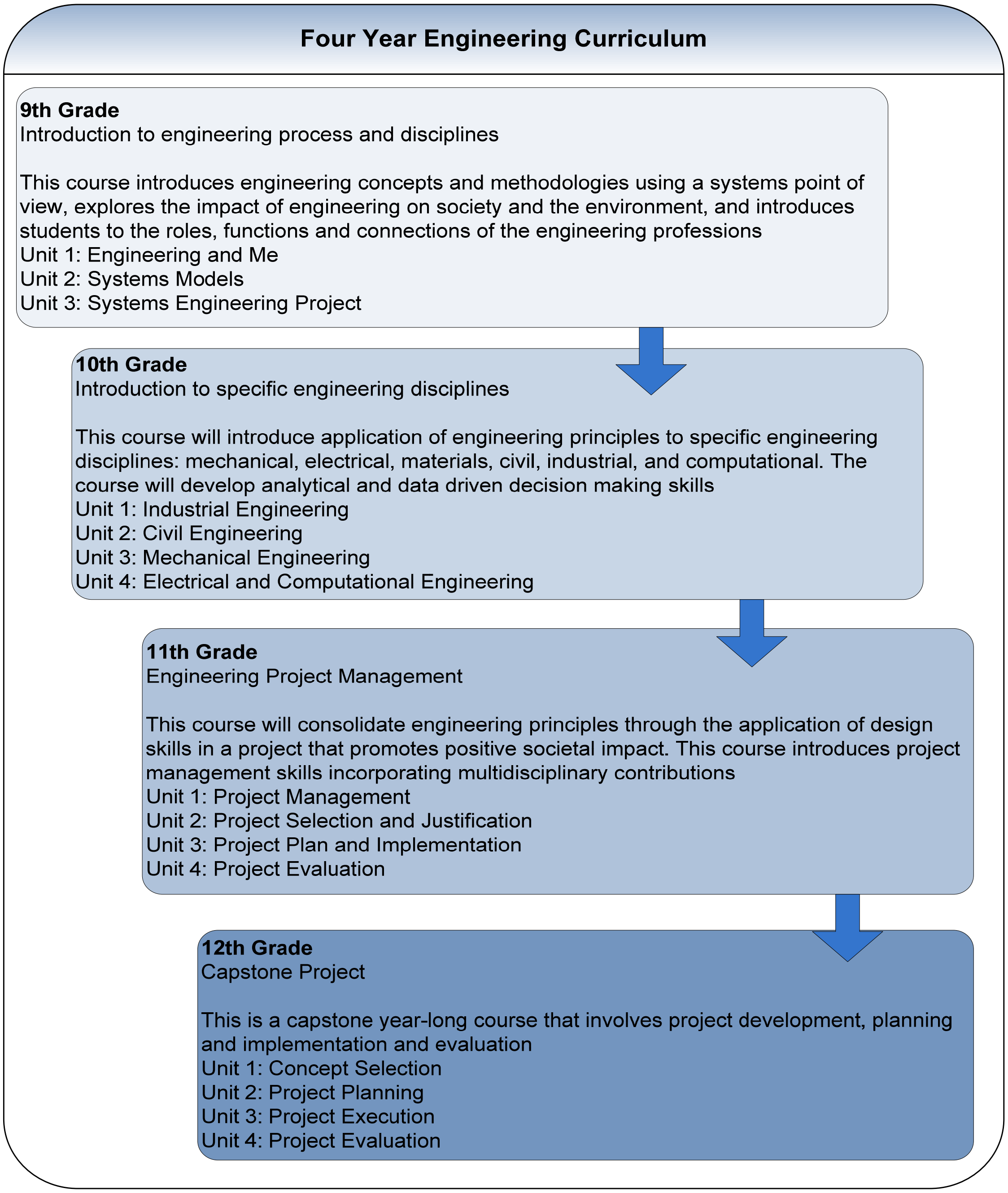

Figure 1: Four Year High School Engineering Curriculum

The curriculum framework is based on the backward design approach. Educational policy debates of the last 50 years have challenged K-12 teachers to become much more focused on the psychological principles of how students learn [10] and to define effective teaching through clear demonstration of student learning. One of the most effective conceptual models supporting such an approach that emerged is that of “backward design” to guide curriculum development. Backward Design as laid out by Wiggins and McTighe [11] involves three stages:

Stage 1) identification of desired results in terms of established goals or standards, what essential questions will be considered, what understandings are desired on the part of students, and what key knowledge and skills students will acquire as a result of a particular unit or module;

Stage 2) determination of acceptable evidence, including performance tasks and other evidence (tests, quizzes, prompts, work samples, observations) that will show that students understand, as well as student self-assessments and reflections about their learning; and

Stage 3) planned learning experiences, the sequence of teaching and learning experiences that will equip students to engage with, develop, and demonstrate the desired understandings.

The ICE-HS was developed using these steps in a workshop. The workshop resulted in a curriculum with vision, mission, mission goals, measureable objectives and four-year engineering curriculum customized for the Da Vinci high school. The sequence of four engineering courses shown in Figure 1 was designed based on the workshop results. Work in progress with the framework involves the implementation and assessment of the framework.

The Innovative Curriculum for Engineering in High School (ICE-HS)

This paper introduces the ICE-HS framework. There are three-dimensions to the ICE-HS framework: Teacher Development, Curriculum Development and Student Learning. The goals associated with each are:

1) Teacher Development: Enhance the ability of teachers to teach engineering in high school selecting, adapting and integrating grade-appropriate activities and materials from readily available, quality, research-based engineering, STEM instructional resources such as International Technology and Engineering Educators Association (ITEEA)
2) Curriculum Development: focuses on grades 9 and 10 and lead to the development of a dynamic four-year high school engineering curriculum that can be replicated and adapted in any high school. It will ultimately include discreet curriculum for grades 9, 10, 11 and 12.
3) Student Learning: The school’s 9th and 10th grade students will understand increasingly complex content and concepts by learning, practicing and applying engineering design, thinking and skills.

The three goals of the research are achieved through a three-year incremental deployment coordinated with the formative assessments. The ICE-HS framework, shown in figure 2, illustrates the major activities and the outcomes for each dimension.

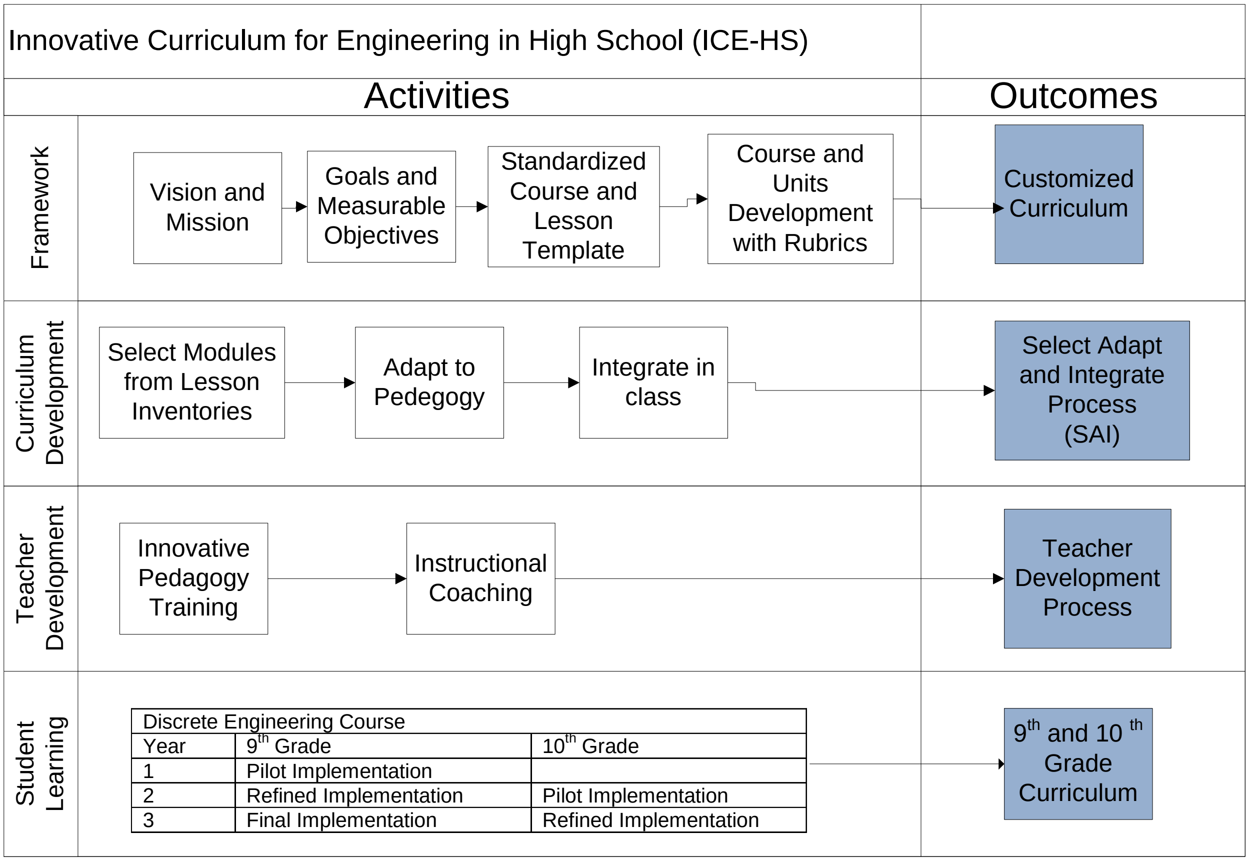

Figure 2. The ICE-HS Framework of Activities and Expected Outcomes

The Authors initially completed the framework activities for the Da-Vinci School and introduced the four-year engineering course sequence shown in Figure 1. The work in progress is focused on the activities associated with curriculum development, teacher development, student learning, and assessment.

Plan for developing the Piloting the ICE-HS Model: Timeline and Deliverables
The work in progress implements and pilot tests the curriculum development, teacher development and student learning dimensions of the ICE-HS framework for engineering in a public charter high school with a highly diverse student body. The research will measure the impact of the framework activities on student learning. The implementation plan institutes the deployment of the ICE-HS framework in three phases.

PHASE 1
The main activities include a teacher training workshop, deployment of the 9th grade pilot curriculum, and assessment of its implementation and preliminary results. The activities per semester are:

Summer 2011
Teacher Development: The cohort of high school teachers will participate in at least two intensive workshops, one on Inquiry pedagogy conducted by the educational consultants, and another on the engineering design educational model conducted one of the authors.

Curriculum Development: The Authors and high school teachers will meet weekly to develop a schedule of lesson plan topics for 9th grade Introduction to engineering processes and disciplines class and to link the lesson plans with the units, assign a sequence, assessments and pedagogical deliveries.
Student Learning: The authors will design a process for organizing key academic indicators of the school district (enrollment, grades, any appropriate state test scores and additional standardized measures to be collected in the students' junior year). There will be pre-surveys indicating baseline data for the project, with post-surveys being administered at the end of each fall and spring semesters.

Fall 2011 and Spring 2012
Teacher Development: The educational consultants/coaches will provide in-class teacher coaching bi-monthly each semester. Authors will meet with teachers monthly via conference calls or virtual meeting to institute accurate application of the engineering course design framework.
Curriculum Development: The authors, high school teachers, and graduate students will have bimonthly meetings to address implementation issues regarding the 9th grade Introduction to Engineering Processes and Disciplines class.
Student Learning: At the beginning of the fall semester, the authors will assist the PI in administering a web-based pre-survey to Year One 9th grade students. The survey will capture their learning experiences, current knowledge and skills, and attitudes toward STEM careers. At the end of both the fall and the spring semesters, the authors will administer a post-survey to 9th grade students for comparison of their self-assessed gains in knowledge and understanding, skills and STEM career interests.

PHASE 2
Summer 2012
Teacher Development: The cohort of high school teachers will discuss lessons learned from Phase 1 with educational coaches and authors.
Curriculum Development: The authors and high school teachers will meet weekly to consider changes to the 9th grade course and to develop a schedule of lesson plan topics for the 10th grade Introduction to Engineering Disciplines course. The authors will link the 10th grade class lesson plans with the units, assign a sequence, assessments and pedagogical deliveries.
Student Learning: The Author will report the analysis of findings from the Year One academic indicators and from the surveys of student's self-assessment of their learning and STEM attitudes, with review and comments regarding options for adaptations from the External Evaluator. The Research Team will meet and make adjustments for the following academic year.

Fall 2012 and Spring 2013
Teacher Development: The educational coaches will provide in-class teacher coaching bi-monthly each semester.
Curriculum Development: The authors, high school teachers and graduate students will have bi-weekly meetings to address implementation issues for the 10th grade Introduction to Engineering Processes and Introduction to Engineering Disciplines course and to work on standardizing the 9th grade course.

Student Learning: At the beginning of the fall semester, a pre-survey to Year Two 9th grade students will capture their learning experiences, current knowledge and skills, and attitudes toward STEM careers. At the end of both the fall and the spring semesters, the authors will administer a post-survey to both 9th and 10th grade students for comparison of their self-assessed gains in knowledge and understanding, skills and STEM career interests.

PHASE 3

Summer 2013

Teacher Development: The cohort of high school teachers will discuss lessons learned from Phase 2 with educational consultants/coaches and authors. The workshops will be scheduled based on teacher feedback from 2012-13, collected and provided by the school district evaluators.

Curriculum Development: The Authors and high school teachers will meet weekly to consider changes for standardization and replication of the 9th and 10th grade courses. The authors and graduate students will interview teachers and help define the steps for the Select, Adapt, and Integrate process for using the research-based modules and materials.

Student Learning: The authors will report the analysis of findings from the Year Two academic indicators and from the surveys of students' self-assessment of their learning and STEM attitudes. The Research Team will meet and make adjustments for the following academic year.

Fall 2013 and Spring 2014

Teacher Development: The educational coaches will provide in-class teacher coaching bi-monthly each semester. Authors will meet with teachers monthly via conference calls or virtual meeting to institute accurate application.

Curriculum Development: The authors, high school teachers and graduate students will have bi-monthly meetings to address issues for standardization of the 9th and10th grade class

Student Learning: At the beginning of the fall semester, a web-based pre-survey to Year Three 9th grade students will capture their learning experiences, current knowledge and skills, and attitudes toward STEM careers. At the end of both the fall and the spring semesters, the authors will administer a post-survey version to both 9th and 10th grade students for comparison of their self-assessed gains in knowledge and understanding, skills and STEM career interests.

Research Methodology

The expected outcome of the proposed research would be positive student attitudes towards STEM career opportunities. The research utilizes several measurement data sets. Each goal of the proposal is associated with measurable objectives. This section discusses the analysis used for the interpretation of the measurement data collected

Goal One: Teacher Development: The measurements include feedback from the school and district instructional coaches during each academic year. Based on the feedback the authors will decide if there is a need for additional coaching for the teachers. The critique will also help assess the increase or decrease in the teacher development. The authors will develop a report summarizing the teacher development workshops, their impact on teachers and the outcomes supported by the school and district instructional coach feedback.

Goal Two: Curriculum Development: The measurements include the school and district instructional coach feedback and the end of course grade. The Author will collect the feedback from instructional coaches four times in the academic year to help make changes to the 9th grade curriculum between Year One and Year Two and help deliver the final 9th grade curriculum in Year Three. Similar process will be followed for the 10th grade curriculum introduced in Year Two of the project.

Goal Three: Student Learning: The measurements include quantitative indicators - end-of-course grades; results of ACT and Accuplacer tests in the 11th grade; comparisons of results from the surveys, the beginning of the 9th grade and at the end of each semester thereafter; and results from surveys of 12th grade students (survey, PSAT and/or ACT career interest). In addition, qualitative measurements will include the random sample work of student portfolio, and their selection of a topic for their 11th grade capstone project as an indicator of increased interest in STEM learning and careers.

Baseline quantitative measurements data will be collected each year for the 9th grade class that has no exposure to the ICE-HS framework. The quantitative data will be tested using two sample t test to indicate a statistically significant difference in the population.

By the end of Phase 1 we will have the end of course grades, data from the pre and post survey for 9th grade students. These will be the indicators of success of the initial pilot implementation process. The qualitative data will help interpret the refinement needed for the next academic year's 9th grade class and the 10th grade curriculum development.
By the end of Phase 2 we will have base line data on the new 9th grade group and pre and post survey data will be the indicator of success of the refined implementation of the initial 9th grade students. For the 10th Grade we will have their end-of-course grade and the survey data as an indicator of success of the pilot implementation of the 10th Grade. The qualitative data will help interpret the final rendering for the next academic year's 9th grade class and the refinement needed for the10th grade curriculum development.
By the end of Phase 3, we will have the base line data on new 9th grade group and pre and post survey data will be the indicator of success of the final implementation of the 9th grade curriculum. For the 10th Grade we will have the end-of-course grade data for 10th grade students and the survey data as an indicator of success of the refined implementation of the 10th Grade. In addition, students who took the initial pilot 9th grade class will take the ACT and Accuplacer tests in the 11th grade. Statistical differences between the students who went through ICE-HS and the students who did not will indicate the success of the 9th and 10th grade.

Replication
This model is a process based model. The replications of such models are successful when there is a buy-in from the administration and the teachers towards the STEM program. The replication methodology would begin by doing the framework activities as shown in figure 2 with the new high school and generate the customized four year curriculum. The authors will then develop a support mechanism to help with the implementation of the curriculum through the teacher development and the curriculum development activities.

Discussion

This paper presents a framework to introduce, implement, and pilot test an engineering curriculum in a charter high school. The ICE-HS is based on systems approach and thus is implemented across three dimensions: Teacher Development, Curriculum Development and Student Learning. The customization and the flexibility of the framework are the key aspects of the framework. Instead of providing a prescribed solution to a high school ICE-HS attempts to develop process that will facilitate teaching engineering customized to a particular high school. This is a work in progress paper, there are plans to collect end of semester data and present some impact data during the conference. Future research with the ICE-HS framework include assessment of the framework, developing training for teaching engineering in high school and providing support infrastructure for teaching engineering in high schools.

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