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Leading by Example for Engineering Design (LEED) to Meet Next Generation Science Standards in Middle and High School Science and Math Classes

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Leading by Example for Engineering Design (LEED) to Meet Next Generation Science Standards in Middle and High School Science and Math Classes (Work in Progress)

Abstract
The Next Generation Science Standards (NGSS) have been recently developed based on the National Academies *Framework for K-12 Science Education*. The NGSS will be adopted across many states and school districts in the next several years. A notable feature of the NGSS is the call for the integration of the engineering design process in K-12; stemming from the national need to train future engineers for sustained innovation and security.

In this paper we discuss our experience in running a Workshop for lead science teachers from middle and high schools in which university engineering faculty worked with groups of teachers to development engineering design content in the form of design projects. In this pilot project sponsored by the Department of Education through the state Department of Education we operated four Saturday workshops, where 16 teachers worked with university faculty including the college science education coordinator and four faculty from various engineering disciplines. These workshops are training-oriented, and provide significant time for teachers and engineering faculty to work on projects. These projects will serve as cornerstone engineering design projects at their schools and serve as examples for other teachers. The completed projects will be disseminated at a LEED conference where all members of the ______ Science Teachers Association and the _____ Council of Teachers of Mathematics will be invited. This will broaden the impact of this grant statewide with the delivered cornerstone-example projects.

The teachers were surveyed to determine their perception of their ability to teach engineering in the K-12 classroom after the workshops and prior to classroom implementation. The results of this survey are presented.

Introduction

The Next Generation Science Standards (NGSS)[1] have been recently developed based on the National Academies *Framework for K-12 Science Education*.[2] The NGSS will be adopted across many states and school districts in the next several years. A notable feature of the NGSS is the call for the integration of the engineering design process in K-12; stemming from the national need to train future engineers for sustained innovation and security. Another notable feature of the NGSS is the cross-cutting concepts for science education. The structure of the NGSS presents the opportunity to meet the standards by integrating engineering design tools, skills, and processes to teach cross-cutting science concepts.

In a collaboration of the College of Mathematics and Science at the University of ___________ and the _____ School District - along with six other partner school districts, we are operating a program funded by a Department of Education (DOE) Math and Science Partnership (MSP) Mini-Grant. This program is to train teacher-leaders in the process of implementing engineering design projects in high school and middle school science and math classrooms. The focus of the program is on both training teachers in the engineering design process and how it can be implemented, and in the leadership skills that will enable them to impact school district-wide curriculum change (not just their own classrooms). In this offering of the program we are operating three one-day workshops, where 16 teachers work with university faculty including the college science education coordinator and four faculty from various engineering disciplines. These workshops are training-oriented, and provide significant time for teachers and engineering faculty to work on projects. These projects will serve as cornerstone engineering design projects at their schools and serve as examples for other teachers. The completed projects will be disseminated at a LEED conference where all members of the ______ Science Teachers Association and the _____ Council of Teachers of Mathematics will be invited. This will broaden the impact of this grant statewide with the delivered cornerstone-example projects. One additional feature of our work is the creation of a statewide network of high school and middle school science and math teachers and engineering faculty, which is is a necessary ingredient to implement engineering design to meet the NGSS.

Background

Training future engineers is critical for sustained innovation and security in the United States.[3,4,5] This need has led to many initiatives in higher education to improve retention of engineering and other Science, Technology, Engineering, Mathematics college students. The need to retain and recruit engineering students now extends formally into Kindergarten - Twelfth Grade (K-12) through the Next Generation Science Standards (NGSS).[1] In the NGSS, engineering design (ED) was chosen to be an integral component. ED is a new concept for K-12 teaching, and teacher leaders are needed that will implement ED in classrooms and assist other teachers in this integration. Some challenges to implementing ED in K-12 are the lack of time/space in the curriculum to add time-consuming projects, lack of physical resources, and perhaps most important, lack of practical experience in engineering design.

Very few teachers have engineering degrees, making the connection between teachers and engineers very important for ED integration. This project was carried out as a pilot to use teacher training workshops and a follow-up conference to address the core issue of teacher experience in ED and in leadership of curriculum change to assist other teachers in ED implementation.

The NGSS derives from an effort an effort by the National Academies of science and engineering practitioners and educators to develop a viewpoint from which to develop the best direction for science education in K-12. The result was a report published by the National Academies Press in 2012: *A Framework for K-12 Science Education*.[2] The principal components to revitalizing science education put forth by the Framework[2] were Science and Engineering Practices (SEP), Crosscutting Concepts (CCC), and Disciplinary Core Ideas (DCI). The NGSS takes the framework and makes specific grade-level and discipline-oriented recommendations on how to integrate the proposed Framework[2] into practice in K-12 education. In particular the NGSS assigns performance expectations for each

DCI at each grade level: elementary school (ES), middle school (MS), and high school (HS). *The performance expectations are the way in which the Framework [5] proposes to integrate SEP into the classroom.* Even though the NGSS are science standards, the Framework makes it clear that engineering and technology practices "... are featured alongside the natural sciences for two critical reasons: (1) to reflect the importance of understanding the human-built world and (2) to recognize the value of better integrating the teaching and learning of science, engineering, and technology."[2] So the NGSS reflects this integration and *places engineering and engineering design as central to learning science in K-12*.

Implementation of LEED Workshops

The initial implementation of LEED workshops consisted of four workshops in the Fall 2013 at the University of __________ (___) with 16 lead teachers from the partner schools, including 5 middle school (MS) and 11 high school (HS) teachers with primary teaching duties in the following STEM disciplines: biology, chemistry, mathematics, physical science, and physics. The teachers were allowed to self-select into groups with common or related engineering design projects. ___ engineering faculty from the ___ Department of ____, consisting of two mechanical engineers, one electrical engineer, and one biomedical engineer, worked with these groups of teachers. The goal of the project-related activities was to develop an example student design projects along with a plan for implementation by the end of the four workshops.

The four Saturday workshops were spaced over the course of seven weeks in the Fall 2013. Teachers, grant investigators (___, ___, and ___), and engineering student assistants (____ and ____) were present from early morning to mid-afternoon for each workshop session. Engineering faculty were present for each meeting as well; co-author ____ served as the lead engineering faculty mentor and was present for the first session, while all participating engineering faculty (____, ____, ____, and ____) were present for the last three meetings.

In the first workshop, presentations were given by one of the co-authors (____) on the Next Generation Science Standards and the engineering design process. Another co-author (____) led a discussion on leadership in curriculum change. As groups were formed for projects, each group was ask to design and build a *spaghetti bridge*. This was a team-building as well as a hands-on design exercise. Finally, possible design projects were discussed with the groups who began brainstorming student design projects. It is important to point out that a strong focus was placed on *ensuring that the design projects would reinforce and/or introduce science concepts that were (1) appropriate for grade level in the NGSS, (2) appropriate to the courses the teachers oversee.* Co-author _____ assisted teacher groups in developing detailed Action Plans for implementation of the projects.

In the second workshop, each teacher group spent the morning working with the proper discipline-specific on their project plans by documenting how their projects would connect to the NGSS cross-cutting concepts. Co-author _____ served as the lead engineering faculty member and worked with each group and other engineering faculty to ensure that the project plans were directed at a suitable design problem. The lunch activity included a professional development presentation given by ____, and the testing and subsequent breaking of the spaghetti bridges built by teachers in the first meeting. By the end of the second meeting project plans and supply and material lists were developed by each group. The goal was to have all needed supplies by the final (fourth) meeting so groups could construct and/or test parts of or the entire design.

The third workshop was oriented toward diving down into more details regarding the design project and how it could be used with students. Each teacher group although similar in STEM discipline varied somewhat and also each group had somewhat different grades of students as the target population. So even though the projects were similar across groups there needed to be some tailoring of the projects for each teacher to ensure it would fit the science concepts and student level. On the third day any forgotten materials, supplies and equipment were requested so that all needed materials would be available for the final meeting.

The fourth workshop was a build-out and test day for each group. All supplies and materials that had been requested at that time had been received and were available. Lab space in the Department of _____ was used for the construction and/or testing for each group. Engineering student assistants (____ and ____) and engineering faculty assisted in bringing each project to a stage of completion where through either testing of equipment or construction, teachers were ready to implement design projects in their classes in the Spring 2014. One project team had been unable to decide on a project, but was able to redirect their efforts to choose a project and determine their needed supplies, which were ordered and received after the fourth workshop.

The budget for the grant was just less than $60,000 of which about $40,000 went to the partnering school districts to pay teacher stipends and commuting costs. The remaining $20,000 went to the University of _____ to pay faculty and student stipends and for equipment, materials and supplies (approx. 50% of budget for ___ was for equipment, materials, and supplies).

LEED Follow-up Conference

The initial planning for the grant included a conference to be held on the ___ campus where grant-participating teachers would present their final projects to other teachers that are members of the _____ Science Teacher's Association (_STA) and to the ____ Council of Teachers of Mathematics (_CTM). Funding for this conference could not come from the grant money due to timing, but one co-author (____) was able to secure support from textbook publishers and from the ______ Energy Resources Board (_ERB) who fund a number of energy and STEM education outreach initiatives across the state. This conference will take place in early February 2014.

Results of LEED Workshops

The primary result of the workshops were the detailed action plans for implementing science concept-linked design projects at the partner schools. An example of the first page of an action implementation plan is shown in Fig. 1. Other pages in the plan include steps for implementation, task assignments and contact information, and a proposed budget.

Table One shows some details for each of the project teams. Each project team was asked to document how their project would address NGSS Cross-Cutting Concepts (CCC) and Disciplinary Core Ideas (DCI) performance expectations (DCI-PE).

An additional set of results were measured using a survey instrument disseminated in 2012 called the Teaching Engineering Self-Efficacy Scale (TESS) for K-12 Teachers[6]. This survey was administered on the last workshop meeting. This instrument was not known to the co-authors at the beginning of the workshops, where it may have been used to measure the gain in the teacher's assessment of their ability to teach engineering over the course of the workshops. Note the TESS will be administered again after the teacher's have completed the projects in Spring 2014 so it will reflect the gain in perceived ability to teach engineering before and after actually implementing the planned projects. The results are broken down as is the TESS in the following categories of self-efficacy: content knowledge, motivational, instructional, engagement, disciplinary, and outcome. As mentioned, these results can be viewed as the expected self-efficacy of the teachers in these areas after the workshops, but *prior to carrying out the projects with their students*. The summary results are presented in Table 2.

Across all questions most responses were Strongly Agree (SA) and Agree (A), and the teacher's confidence, apriori to running the planned engineering projects, in engaging their students (58% SA), and in dealing with student disciplinary issues (41% SA) were particularly high. The one question block that showed the lowest teacher confidence (27% Neutral) was in the outcomes the students would have as related to teacher actions. The next lowest confidence exhibited by the teachers was in the Instructional category (15% Neutral) in which questions focus on the *teacher's ability to function independently in creating new engineering lessons and projects as well as assessing engineering work*. Overall the teachers exhibited a considerably high self perception of how they would implement engineering with their students: *87% of all responses were either SA or A*.

Two other surveys were used pre- and post-workshops but were not directly related to this paper and hence are not presented here.

Conclusions

Overall we view the workshops as a success as a pilot project to develop example engineering design projects that integrate engineering design, NGSS Cross-Cutting Concepts, and discipline content knowledge as appropriate to MS and HS grade-level bands and specific school needs.

The action implementation plans (as in Fig. 1) are valuable and may be shared with other researchers by contacting the first co-author (____). These plans will be improved for any future work by our group to guide teachers, through the seemingly complicated vocabulary and structure of the NGSS[1] and Framework[2] as discussed briefly in Appendix A. By revising these forms we can ensure that teachers will be clear about what specific cross-cutting concepts, disciplinary core ideas, and performance expectations (which include the science and engineering practices) will be met with a given project.

The need to have engineering faculty and/or practicing engineers involved in helping design projects is clearly at this point necessary. The teacher's confidence about creating additional content and assessing engineering work was relatively low as shown in the TESS, so continued involvement of these engineers is necessary.

Some challenges and observations for future programs are as follows:

1. Saturday workshops worked fairly well over a seven week period. Transitioning to a 4-5 day summer workshops may make sense for any future work so that teachers and engineering faculty can be at all meetings and progress can be made in a shorter time without significant gaps between meetings.
2. Engineering faculty were relatively unaware of the level that MS and HS courses and at first proposed overly ambitious projects - since our idea was to develop small scale projects that could be replicable at other schools in the state. A future offering of workshops should include an orientation to NGSS and example projects for engineering faculty so that expectations of MS and HS teachers and engineering faculty are met.
3. We believe the conference planned for Feb. 2014 will yield good feedback on the effectiveness of the workshops and allow for direct dissemination of projects to other teachers.
4. The TESS will be used again after teacher's have completed projects with their students and a gain will be calculated to assess the change in teacher self-efficacy for teaching engineering. Initially the teacher's had high confidence in how they would implement engineering with their

students: 87% of all responses to the TESS were either SA or A.
5. The connections of the both the university faculty and school district administrators to a statewide network of science teachers was critical to be able to recruit workshop participants and will be critical to hold a statewide conference.

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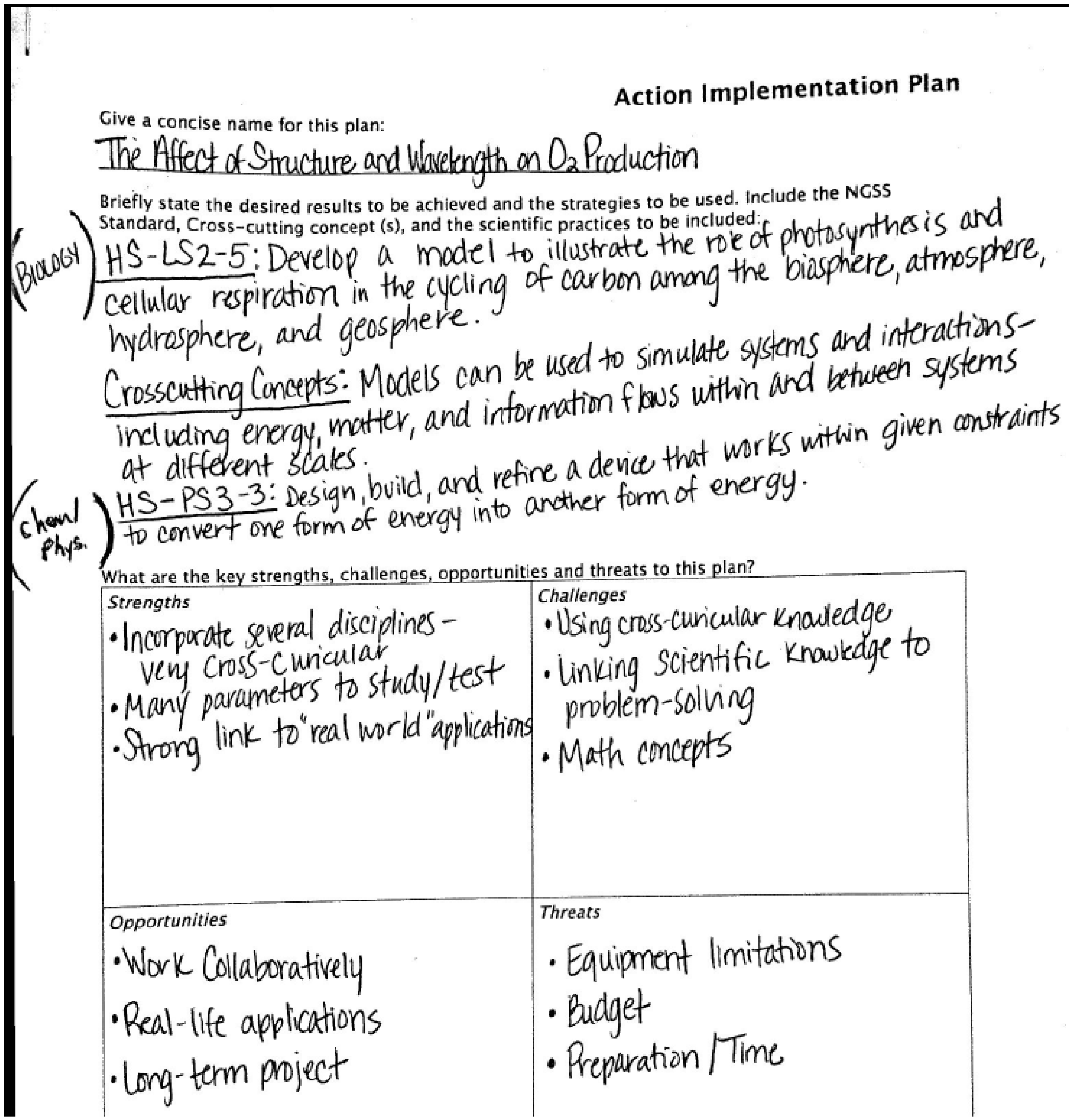
Table 1. Summary of Projects developed by teacher groups in the MSP program. Note full definitions of the applicable NGSS Disciplinary Core Ideas (DCI) Performance Expectations (PE) can be found on the NGSS website[1].

Project Title	***Brief Description***	***Classes (Level)***	***NGSS DCI -PE***
Rain Masters	Students will design drainage solution for a flooding basement a the students' school.	Physical Science & Algebra (MS)	MS-PS2 MS-ETS1-1-4
Glider Challenge	Students will optimize wing desig to maximize flight distance and decrease drift.	Earth and Physical Science (MS)	MS-PS2 MS-ETS1-1,2,3,4
The Effect of Greenhouse Design on O_2 Production	Students will design the optimum greenhouse (with constraints) usir spectrophotometer, O_2 sensor, and other supplies.	Biology and Chemistry (HS)	HS-LS2 HS-PS3 HS-ETS1-1-4
Runaway Ramp	Students will design a runaway truck ramp using motion sensors, Newton's Laws, and math.	Pre-Calculus, Calculus, Physics (HS)	HS-PS2 HS-ETS1-1-4
Beam Design	Students will design and construc a beam cross-section and calculate and measure deflection for a given loading.	Physics and Calculus (HS)	HS-PS2 HS-ETS1-1-4

Table 2. Results of the TESS at the conclusion of four MSP program workshops; prior to completing project with their students. Results are average percent responding at each level for indicated question blocks. Numbers may not sum to 100 due to rounding. There were no answers of *Strongly Disagree* even though this was an option to choose.

Self-Efficacy Category	***% Strongly Agree***	***% Agree***	***% Neutral***	***% Disagree***
Content Knowledge (Questions 1-17)	30	56	9	5
Motivational (Questions 18-20)	33	62	4	0
Instructional (Questions 21-25)	32	49	15	4
Engagement (Questions 26-29)	58	40	2	0
Disciplinary (Questions 30-35)	41	56	3	0
Outcome (Questions 36-41)	22	47	27	0



Action Implementation Plan

Give a concise name for this plan:

The Affect of Structure and Wavelength on O_2 Production

Briefly state the desired results to be achieved and the strategies to be used. Include the NGSS Standard, Cross-cutting concept (s), and the scientific practices to be included:

(Biology) HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

Crosscutting Concepts: Models can be used to simulate systems and interactions—including energy, matter, and information flows within and between systems at different scales.

(chem/phys.) HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

What are the key strengths, challenges, opportunities and threats to this plan?

Strengths	Challenges
• Incorporate several disciplines – very cross-curricular • Many parameters to study/test • Strong link to "real world" applications	• Using cross-curricular knowledge • Linking scientific knowledge to problem-solving • Math concepts
Opportunities	**Threats**
• Work Collaboratively • Real-life applications • Long-term project	• Equipment limitations • Budget • Preparation / Time

Figure 1. Sample Action Implementation Plan for a high school design project focused on scale modeling of a greenhouse. Note the direct use of NGSS Cross-Cutting Concepts[1] and the direct reference to the Disciplinary Core Ideas (DCI) performance expectations (HS-LS2-5 & HS-PS3-3 -- *see NGSS website[1] for full definitions*).