Student as Developer: An Alternative Approach to Sustainability and Green Building High School Education Modules

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Abstract

An increasing focus in K-12 educational outreach is on science, technology, engineering, and mathematics (STEM) fields. A challenge in educating students about STEM topics is the ability to communicate the key concepts on a level that engages the students. Common approaches to K-12 students' experience with engineering education involve reading about engineering then completing worksheets or designingartifactsfor competitive purposes. Less common is an approach that has students design materials for other peer learners.

Through partnership between the University of Pittsburgh's Learning Resources and Development Center (LRDC), Swanson School of Engineering (SSOE) and the Quality of Life Technology Center (QOLT), the NSF RET competition provided rising tenth grade high school students with the opportunity to serve as interns at the Mascaro Center for Sustainable Innovation (MCSI). The interns, from a parochial school in Western Pennsylvaniaspent five weeks learning about sustainability and green building, for the purpose that each student would then develop a week long education module.

The interns were tasked with development of a sustainability and green building module for high school students in the hope that students would share the best ways in which they learn. The interns were asked to free think, any possibilities, to teach students about sustainability, while linking the topic to one of the following content areas: math, science, or history. The internship provided them with a unique opportunity to develop content for a high school class, while learning about sustainable engineering topics. This paper discusses lessons learned with this less common approach to engineering education with respect to features of the design that seemed to work well and features that require strengthening as well as additional outcomes from the internship.

Introduction

The National Science Foundation (NSF) Research Experience for Teachers program is but one instance of industry, government, and university-based programs that seek to insert engineering into K-12 classrooms through providing engineering research experiences to K-12 teachers.There are diverse goals for Engineering Education efforts commonly including: increasing public appreciation of engineering research, especially new areas of research, such as nanoscience or tissue engineering; increasing public appreciation of engineering work; increasing student science and math performance; and increasing the supply of future engineers overall and with greater gender, socio-economic, and racial diversity. The LRDC/SOE RET site focus is to increase the supply of future engineers and the diversity of such engineers by increasing math and science performance of traditionally underrepresented student. Authentic engineering design presents an effective platform to attain this goal.

A number of different RET models have been proposed and these vary primarily in the extent to which engineering research or K-12 activities are emphasized. As shown in Figure 1, many RET sites either have a strong focus on engineering research (Fig. 1A) or a strong emphasis on K-12 academic year development (Fig. 1B). In those sites with a strong research component, teachers are placed within a team and perform deep scientific research on a somewhat narrow engineering topic. The research lab experience is rigorous and demanding, and helps the teachers to build content knowledge in that particular domain, however, this experience does not change teacher beliefs that their students could engage and be successful in similar rigorous and demanding practices. In addition, since the focus of these sites is on teacher development, there is no real effort to ensure that the knowledge that teachers obtain gets translated into the classroom during the academic year activities.

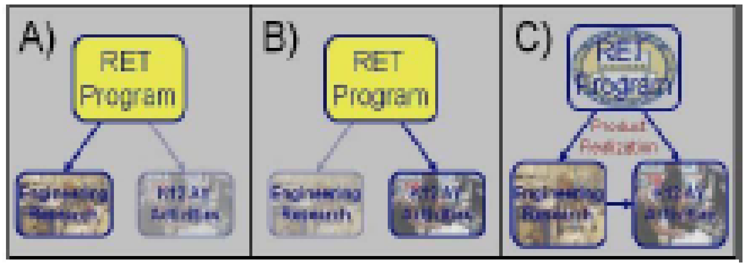

Figure 1: RET Site Examples

In contrast, the RET sites that focus on K-12 academic year activities (Fig. 1) develop in-depth curricular materials that can be implemented in K-12 science and math curricula. In these sites, RET participants often do little hands-on research and are exposed to engineering projects through presentations or observing others doing research. This approach may give the impression that teachers are capable of developing curricular materials but only engineers are capable of solving authentic engineering problems. This `look but don't touch' model potentially reinforces the belief that their own students cannot be successful engineers. With this RET model, participants are likely to gain a limited perspective on the field of engineering and not very likely to be able to convey to their students what engineers actually do.

A third approach to RET programs that we have developed tries to create a strong linkage between the engineering research and K-12 activities (Fig. 1C). In our case, concentrating on the process of product realization has facilitated the strong linkage. Product realization can effectively be achieved as part of actual engineering researchby a broad cross-section of teachers, and thus allows teachers to experience first-hand what engineers actually do. Product realization, as a process, is also something that can be directly incorporated into a significant chunk of the K-12 curriculum, perhaps more so than particular pieces of engineering research content. In other words, the process of product realization becomes the bridge between research and the classroom.

The Mascaro Center for Sustainable Innovation (MCSI) at the University of Pittsburgh is a center of excellence in sustainable engineering focusing on the design of sustainable neighborhoods. MCSI focuses on collaborative engineering and innovative research, translating the fundamental science of sustainability into real products processes. In addition to MCSI's sustainability research, extensive outreach programs work with local schools, afterschool programs, community organizations and non-profits to increase awareness of sustainability and green building concepts.

The LRDC/SOE RET and MCSI internship provided a unique opportunity to develop module content with direct input from rising tenth grade students. The interns, from a parochial school in Western Pennsylvania, served as MCSI interns for five weeks, learning about sustainability and green building, for the purpose that each student would then develop a week long education

module. The interns were tasked with development of a sustainability and green building module for high school students in the hope that students would share the best ways in which they learn. The interns were asked to free think, any possibilities, to teach students about sustainability, while linking the topic to one of the following content areas: math, science, and history. The internship provided them with a unique opportunity to develop content for a high school class, while learning about sustainable engineering topics. This paper discusses lessons learned with this less common approach to engineering education with respect to features of the design that seemed to work well and features that require strengthening as well as additional outcomes from the internship.

Background

Methods of K-12 Engineering Education

We distinguish five common approaches for bringing engineering to K-12 students, which we discuss from the basis of the limited research literature that exists and our observations of many different programs. The first two approaches involve staying out of formal K-12 classrooms. The first is to hold a variety of forms of informal programs in the summer, at weekends, or after school. The second is to hold a variety of forms of engineering competitions, the most popular of which these days are robotics competitions, such as the FIRST Lego League. These out-of-school efforts likely do well in promoting interesting in engineering, however, they are difficult to organize with equitable access because they depend upon community intellectual experience with Engineering) and financial resources, which are rarely held or distributed equitably. Furthermore, complete separation between engineering outreach and formal K-12 classroom experiences gives the impression of an irrelevance of formal mathematics and science for engineering applications, and we risk developing students with an interest in engineering but no ability to survive college engineering training.

A third approach is through formal engineering curriculum units that vary in length from one week to multiple years of coursework such as Project Lead the Way, and the Infinity Project, followed separately from other curriculum content, or integrated with mathematics or science curricula e.g., such as in FOSS, or STC middle school science curricula. Here there are a number of interesting tradeoffs. Longer curricular units may be harder to insert into the already packed and highly constrained curricula, but may be more likely to produce meaningful levels of changes in students. Our approach involves a compromise of focusing on six to eight week-long units that are easier to insert into the timetable than full year curriculum units but are long enough to produce meaningful levels of change in students.[1] Another challenge of formal engineering curriculum units is teacher professional development. Most K-12 teachers have little experience with engineering, in addition to commonly having weaknesses in science and mathematics knowledge, and thus they require significant professional development in order to successfully implement engineering curriculum material. Again there is an equity complication: the students with the greatest needs often have the teachers with the weakest knowledge and skills.

A fourth approach involves various forms of professional, faculty, or student engineer visitations into classrooms, conducting demonstrations, guest lectures, or as teaching assistants. This approach is very commonly ad hoc, based on engineers directing attention to their own children's schools, and thus raising further equity of access issues. This approach also has more structured instances with industry, professional organizations, and university organizations. For example, the U.S. National Science Foundation's (NSF) GK-12 Program provides funds for engineering graduate students to spend 15 hours per week in K-12 classrooms for an entire year. These structured programs can strive towards equitable access, however, by not focusing on teachers or the curriculum, there is relatively little residue left in the school of these classroom visitation programs once they leave the classroom. The teacher is left mostly unchanged and is not given tools to build upon this foundation or continue the work in later years.

The fifth approach of improving K-12 Engineering Education is professional development programs for K-12 teachers, be they elementary generalists, or secondary math, technology, or science specialists. These programs typically occur in a front-loaded fashion, with teachers getting most or all training prior to start of implementation of new engineering approaches in their classrooms (e.g., in the summer or at a regional, national, or international teacher conference). Such front-loading provides little incentive or support for classroom implementation. Another feature of such programs is that they are carried out as a volunteer effort on the teacher's part, rather than mandated participation by the schools. It is known that stronger teachers are more likely to volunteer for extra professional development opportunities,[2]

1B. Reynolds, M.M. Mehalik, M.R. Lovell and C.D. Schunn. (2009). Increasing Student Awareness of and Interest in Engineering as a Career Option through Design-Based Learning. International Journal of Engineering Education, pp. 1-11.
2 L. Desimone, A. C. Porter, B. F. Birman, M. S. Garet, and K. S. Yoon, The Newsletter of the Comprehensive Center Region VI, 8, 2005, p. 3.

and equality of access issues can arise, unless selection for admission into such programs explicitly addresses equity issues. A variation of the professional development approach that we explore in this paper is the NSF's Research Experience forTeachers (RET) program, in which teachers are paid to participate in engineering research and then must bring some aspect of that experience back into their class- rooms. By working with teachers, the theory is that the impact of the program will be felt for years to come, however, teachers often struggle with finding good integrations between their research experiences and classroom implementation.

Internship approach

Designing materials for other learners may have potentialas another strategy for K-12 engineering education. While conceptually, "*student as teacher*" has been consider in the reciprocal teaching model, "*student as developer*" has received little attention.Design-based learning shifts the role of the student from "consumer" to "designer" in an effort to teach science. While students remain consumers of a "prescribed" curriculum, the design of the unit gives them a sense of autonomy to "design a product that meets a need in your own life." This approach has shown to increase student engagement and motivation for learning science. We considered using a parallel approach by placing students in the developer role to create a module to teach sustainability to their peers. The goal of this approach was to deepen student understanding ofsustainability and sustainable engineering. The methodology built upon the previous stated approaches, specifically, we considered how curriculum typically is disseminated from the developer to the user to the audience. Traditionally, curriculum is created by an external source (*developer*) and imported into the classroom. The teacher (*user*), an internal classroom source, is tasked with translating and communicating the developed curriculum to the students (*audience*). The LRDC/SOE RET model integrates the role of developer and user through teacher experience. Teachers develop curricular material, which translates their own engineering experience into classroom learning. In this way the teacher assumes a dual role of developer and user for their students who remain in the role of audience (Table 1). The student as developer approach, as shown in Table 1, explores how shifting the role of a student impacts student learning. The primary step in this approach places the student in the role of developer while the teacher and student peers remain in the traditional role of user and audience, respectively. This approach follows the traditional model, but serves to establish a baseline to understand student efficacy.

Table 1: Comparison of Curriculum Development Models

Traditional	External Source →	Teacher →	Students
LRDC/SOE RET	Teacher	→	Students
Student as Developer	Student →	Teacher →	Peers

Previously our RET student intern experiences were to further the designs that they began in the classroom to deepen their engineering understandings, however, with this approach the learning resided only with the interns themselves. The student as developer approach seeks to be a bridge between individual student learning and classroom/peer learning by tapping into the ways in which students communicate and understand. Rather than a top down approach from external curriculum developer to students, this approach may be a more organic way to access student interests and understandings about sustainable engineering topics.

Framework for this approach

Our framework utilizes a similar structure as product realization to design curricular materials for classroom use. Over the past six years, the LRDC/SOE product realization process has been effective in impacting teacher classroom practice.[3] The LRDC/SOE RET framework includes an

3 Y. Doppelt, Y., C.D. Schunn, E. Silk, M. Mehalik, B. Reynolds, and E. Ward. (2009). Evaluating the impact of a facilitated learning community approach to professional development on teacher practice and student achievement. Research in Science & Technological Education, 27(3), 339-354.

experience for teachers, which results in development of a teacher generated artifact that isused in the classroom with students (*consumers*). Utilizing this framework the interns engaged in a process to deepen their understanding of sustainability concepts, and then generated an artifact that would be used by teachers in the classroom to teach sustainability concepts (Fig. 2).

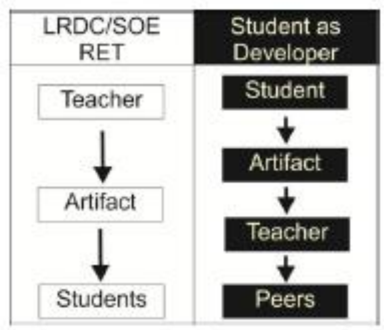

Figure 2: Internship Design Framework

Internship Design

The internship design included specific constraints designed to address the difficulty of integrating engineering education into existing curricula, a common shortcoming of the previously discussed K-12 engineering education methods. The internship required the interns to developa week-long module to communicate sustainability concepts. They could choose from four topic areas: green building, energy, water and green materials. Additionally, they were required to link the topic to one of the following content areas: math, science, and history. In this way, the interdisciplinary nature of sustainability would be naturally integrated and provide a lens through which to situate their module. In contrast to the content requirements, the students were not constrained in the methods (such as hands-on demonstrations, experiments, games, etc.) they could use engage students learning of the concepts.

The five-week internship was divided into steps that allowed the students to build components of the module, as shown in Table 2. The first week served as an introduction to sustainability and the topic areas. The interns were required to pick a content area and topic within the first week. The introduction week was framed to introduce the students to different teaching strategies and consisted of discussions, diagramming concepts and definitions on the marker board, and mapping product life cycles. This introductory week included a green building tour, as an example of a real-world application. Based on the introduction week the interns selected the following topics and content area: (1) Energy and Mathematics and (2) Green Building and History.

Table 2: Internship Schedule and Deliverables

Week	Topic	Deliverable
1	Define	Concept Module
2	Organize	Proposal Letter
3	Develop	Module Outline
4	Evaluate	Assessment Tool
5	Review	Symposium Presentation and Poster

The required deliverables included:a) a proposal letter written to the principal of a school to propose use of the module in a class; b) a detailed outline of the module, which also served as a teaching plan; c) an assessment tool(s); and d) a presentation and poster, which was presented at the MCSI summer Undergraduate Research Program (URP) symposium. Through iterative design, the interns refinedtheir modules and associated materials to achieve the final product. The interns were given the flexibility to work on the deliverables in any order, while the deadlines remained fixed. In addition to the green building tour, the students also participated and interacted with undergraduate and graduate students in several activities over the five weeks, such as a competitive jeopardy game on the four topic areas, which was moderated by two undergraduate research students.

Intern Modules

Students were unfamiliar with the subject of sustainability at the start of the internship. Linking their selected topic to a content area served as a lens to situate their module and supported their emerging understanding of the subject. Students' choice of a content lens reflected their interestsand tended to be their favorite school subject. For example, one of the female interns enjoyed mathematics and used that as a lens for her unit on Energy. Below is an excerpt from the module abstract (written by the student):

The module focuses on linking sustainability and energy to mathematics. The module explores renewable versus nonrenewable sources of energy, the advantages and disadvantages, ecological footprints, as well as meaning of "green." To link the sustainability concepts to the math content, the module will include the process of converting energy into electricity, through a series of equations to calculate the amount of energy generated by the various sources...

Mathematical models that describe energy conversionhelped this student make sense of sustainable energy concepts. Below is an example problem this student included in her module to help other students understand energy conversions. For example:

Example Problem: Energy from Fossil Fuels
Five tons of coal is used every day in Mike's town to generate electricity. Assuming that the process is 20% efficient, how much electricity is generated every day?

Step 1. Energy Generated = Amount of coal (tons) × Energy Conversion (Btu/ton)
Step 2. Electricity Generated = Energy Generated × Electricity Conversion (kWh/Btu)
Step 3. Efficiency = Electricity Generated × Efficiency (%) = kWh/ton

Once the basic conversion equations were established, the intern showed how to build on this withsubsequent energy sources, such as solar or wind turbines, taking into consideration pertinent features such as area.
Our male intern's favorite subject was history. He used a regional context to highlight his chosen topic on green buildings. Below is an excerpt from the letter he wrote to his principal:

The focus of the module is on the history of Pittsburgh and its movement toward green buildings and sustainability and leaders. I also think this will be a good way to teach high school students because of

Pittsburgh's leadership in the field of sustainability and green building…[this will] *give* [students] *a better understanding of Pittsburgh and its efforts for a better place to live*.

Considering local pioneers and their contribution to regional greenbuilding was a way for this student to relate his understandings to sustainability. Through exploration of local pioneers such as Carson, Heinz, and Lawrence, this student recognized the tenets of sustainable engineering as resource for solving local issues. In his module, accessing students' prior knowledge of local history supported the relevance of the need and how green buildings are effective solutions to these problems.

In both modules, students created curricular materials for teachers, which included lecture/review notes (PowerPoint to support classroom discussions), in-class worksheets (word searches, fill in the blank about, and well specified word problems), and homework assignments.

Lessons Learned

The outcomes from this approach yielded various levels of understanding regarding student learning. The framework for the approach served to establish a baseline to understand student efficacy. In the approach of student as developer (Fig. 2), the development of an artifact served as the process in which the interns deepened their understanding of sustainability engineering through the lens of a self-selected alternate discipline area. This supported the widely accepted belief that we understand at one level when we learn for ourselves, but at a different often deeper level when we have to "teach" that understanding to someone else. The open-ended nature of the task allowed students to choose the mappings based on their own interests and strengths. Also, development of the artifact was framed within a real world context, albeit communicated within a personal context.

To further explore the effectiveness of student as the developer framework, the approach needs to be expanded to parallel that of an LRDC/SOE RET, in which the student assumes the role of both developer and user, while the student peers remain as the audience. Potential future steps include structured assessment of student learning throughout the internship to provide a gauge of skill development, as well as the depth of knowledge in regard to the topic. The process of designing pedagogical materials also required more structure. The pedagogical model the students used is their own module is a translation of their traditional experience of learning and what worked for them. If we want them to generate a different pedagogical model we need to provide them with an experience of innovative teaching methods to fully grasp the potential impact on their own student learning.

Summary

In summary, this paper explores the less common approach that has students design materials for other peer learners. Rising tenth grade high school student interns, from a parochial school in Western Pennsylvania, spent five weeks learning about sustainability and green building. The interns were tasked with development of a sustainability and green building module for high school students in the hope that students would share the best ways in which they learn. The internship approach explored the potential of student as developer of materials for other learners as another strategy for K-12 engineering education. The internship design included specific constraints designed to address the difficulty of integrating engineering education into existing curricula, a common shortcoming of the previously discussed K-12 engineering education methods.

The goal of this approach was to deepen student understanding of sustainability and sustainable engineering. The student as developer approach explored how shifting the role of a student impacts student learning. The primary step in this approach places the student in the role of developer while the teacher and student peers remain in the traditional role of user and audience, respectively. The outcomes from this approach yielded various levels of understanding regarding student learning, including the process in which the students developed the module in relationship to their own understanding and the need to frame the topic and content within a real world context. To further explore the effectiveness of student as the developer framework, the approach needs to be expanded, in which the student assumes the role of both developer and user, while the student peers remain as the audience. Potential future steps include structured assessment of student learning throughout the internship to provide a gauge of skill development, as well as the depth of knowledge in regard to the topic.