
AC 2011-686: MAKING ELEMENTARY ENGINEERING WORK: LESSONS FROM PARTNERSHIPS AND PRACTICE THE SYSTEMIC PROJECT, MARYLAND

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Making Elementary Engineering Work: Lessons from Partnerships and Practice—The SySTEMic Project, Maryland

Increasingly, engineering concepts and skills are being introduced to elementary students. Incorporating this new discipline—one that few elementary educators are knowledgeable about or comfortable teaching—into an already-packed curriculum presents challenges. This paper will draw upon the experiences of educators within “The SySTEMic Elementary Engineering Project: A Partnership among Harford County Public Schools (HCPS), Engineering is Elementary (EiE), and Towson University (TU)” (hereafter, the SySTEMic Project). Specifically, the paper will first present the aim and basic features of the project. This will be followed by a discussion of: (a) the development of the tripartite HCPS-EiE-TU partnership, (b) the project’s focus on and development of science-technology-engineering (STE) integrated units of instruction, (c) the challenges of implementing engineering instruction at the elementary level, and (d) the aspects of the SySTEMic Project that might be transferrable or scalable to other districts. The paper concludes by summarizing SySTEMic Project research conducted thus far not only to inform future directions for the SySTEMic Project, but to contribute to the research literature on factors that may support or challenge elementary teachers’ implementation of engineering instruction.

SySTEMic Project Introduction

The aim of the SySTEMic Project is to teach one STE unit of instruction in each of 1st through 5th grades to all children in HCPS by 2012-2013 (Table 1). HCPS is a countywide district in Maryland, having a total of approximately 40,000 P-12 students, with about 15,000 in grades 1 through 5. The STE units, discussed in more detail in the third section of this paper, are blends of modified district science and EiE units, and take approximately 12 to 14 hours of instructional time. The project is currently in its second full year (2010-2011), which is the full implementation year for 3rd and 4th grades, and the pilot year for 1st and 2nd grades.

Of the 33 elementary schools in HCPS, 8 have participated as pilot schools. Pilot schools are where each STE unit within the SySTEMic Project is taught one year prior to full implementation in the district (i.e., during the pilot year), enabling the pilot teachers to provide feedback on the STE unit prior to full implementation. The pilot schools represent a diversity of size, socio-economic status and ethnicity of the student body, and geographic location within the district (Table 2).

Pilot year teachers include both classroom teachers and enrichment (a.k.a., Gifted & Talented or G&T). Classroom teachers represent the front lines of the effort to teach the STE units. Enrichment teachers, approximately one per school, were involved as a means of support to classroom teachers. These teachers are well suited to provide such support since many of them have prior experiences with engineering design challenges in after school activities like Destination Imagination, FIRST Lego League and the state’s Engineering Challenge competition. Further, their involvement helps them to develop extensions for the integrated units. Thus far in the project, enrichment teachers have co-planned and co-taught parts of the STE units—most especially the engineering lessons in each unit—with many classroom teachers, and assisted with the preparation of instructional materials.

Table 1: STE units—which are blends of modified district science and EiE units—for pilot and full implementation years for 1st through 5th grades. TBD = to be determined.

	3 rd Grade	4 th Grade	1 st Grade	2 nd Grade	5 th Grade
STE Unit =	Motion, Energy & Mechanical Engineering	Rocks, Minerals & Materials Engineering	States of Matter & Chemical Engineering	Pollination Partners & Agricultural Engineering	TBD
(Modified) District Science Unit	Energy in Motion	Rocks & Minerals	Solids, Liquids & Gases	Growth & Change	Energy Around Us
+ EiE Unit	Catching the Wind: Designing Windmills	A Sticky Situation: Designing Walls	A Work in Process: Designing a Play Dough Process	The Best of Bugs: Designing Hand Pollinators	An Alarming Idea: Designing Alarm Circuits
Pilot Year	2009 - 2010		2010 – 2011		2011 – 2012
Year of Full Implementation	2010 - 2011		2011 – 2012		2012 – 2013

Table 2: SySTEmic Project pilot schools.

School	STE Units Piloted or to be Piloted	School Characteristics			
		Size of school	School setting	Title I?	Approx % Minority students*
A	1 st – 5 th	Medium	Rural	No	10%
B	1 st – 5 th	Medium	Rural	No	5%
C	1 st – 5 th	Small	Rural	No	15%
D	1 st – 5 th	Medium	Small city	Yes	60%
E	1 st – 5 th	Large	Suburban	No	15%
F	1 st – 5 th	Medium	Small city	Yes	50%
G	1 st – 5 th	Large	Suburban	No	15%
H	1 st , 2 nd , 5 th	Medium	Suburban	No	25%

* Rounded to nearest 5%; Minority includes: American Indian/AK Native, African American, Asian/Pacific Islander, & Hispanic.

The number of pilot year classroom teachers per grade level has varied in the SySTEMic Project. During the first full year of the project, 15 3rd grade and 13 4th grade teachers volunteered to participate in 7 pilot schools. For the second year, district leaders asked that all 1st and 2nd grade classroom teachers in the 7 pilot schools be involved in the pilot. An additional school, eager to be involved in the project, signed on to become a pilot year school for 1st and 2nd grades. Overall, 27 1st grade and 27 2nd grade teachers have participated in the 1st and 2nd grade pilot year. It is anticipated that approximately 25 5th grade teachers will participate in the 5th grade pilot year. Once STE units move to full implementation, all grade level teachers in all 33 elementary schools in the district—approximately 140 1st, 140 2nd, 140 3rd, 130 4th, and 130 5th grade teachers—will teach the STE units with some support from enrichment teachers within those schools.

Prior to teaching the STE units, both classroom and enrichment teachers receive professional development (PD) to learn both unit content and pedagogy. PD has ranged from 6 hours (1st & 2nd grade units) to 9 hours (3rd & 4th grade units) for each STE unit. Enrichment teachers participate in PD for all STE units. Classroom teachers attend a single session for their grade level only.

PD in preparation for the pilot year for each STE unit is led by the author, yet when moving towards full implementation, a subset of pilot year teachers—called “master teachers”—lead the PD process. After teaching the STE unit to one or more classrooms of students during the pilot year, master teachers volunteer to co-teach PD sessions. The author and Elementary Science Teacher Specialist meet with master teachers for approximately 6 hours to prepare them to lead PD. The involvement of master teachers is important in growing expertise for STE unit instruction in the district. Further, master teacher participation adds credibility to full implementation PD beyond what the author can provide—i.e., they are classroom teachers who have successfully taught the STE units to children and who have examples from real classroom practice to share as they lead PD. Thus far in the project, all 3rd and 4th grade teachers in HCPS have received PD led by seven 3rd grade and eight 4th grade master teachers, respectively. Master teachers co-taught two sessions to, on average, about 25 teachers per session.

After each STE unit has been taught during the pilot year of instruction, the Elementary Science Teacher Specialist and author meet with grade-level teachers to review the STE units lesson by lesson. Teachers provide feedback to increase clarity, reduce redundancy, and otherwise improve the STE unit curriculum. Thus far, this process has occurred for the 3rd grade unit (after the pre-pilot year) and the 4th grade unit (after the pilot year). The revised STE units are used during the full implementation year for the project.

Figure 1 depicts the roughly two-year long process from STE unit development to full grade level implementation of the unit in the SySTEMic Project. The 4th grade unit followed this process exactly, as will the 1st, 2nd, and 5th grade units. The 3rd grade unit followed this process in a slightly different way. The 3rd grade unit was first taught and then revised in a very small pre-pilot (at the end of the 2008-2009 school year), after which the unit was taught during the full pilot year (2009-2001). The pre-pilot involved two pilot schools. In each, a classroom and enrichment teacher worked together to co-teach the STE unit to one classroom of children.

Funding for the SySTEmic Project has come from three major sources: 1) a STEM (Science, Technology, Engineering & Mathematics) Workforce One Maryland Program grant through the Maryland Department of Labor, Licensing & Regulation; 2) a National Dissemination through Regional Partners (NDRP) grant funded by the Bechtel Foundation, awarded to EiE, and disseminated via subawards to NDRP Hub Site partners by EiE; and 3) a Maryland State Department of Education (MSDE) STEM grant. Largely, these grants have funded PD expenses, curriculum materials, kit materials, and the author's time to develop STE units and deliver PD.

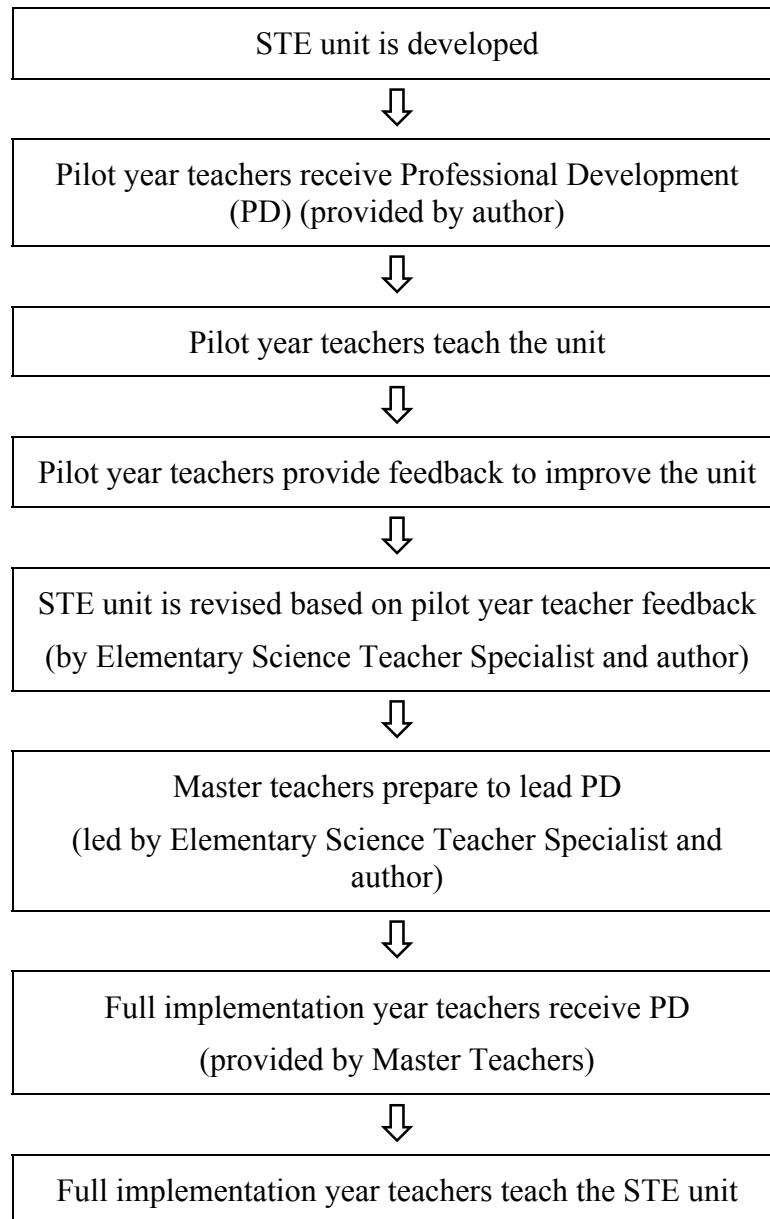


Figure 1: STE unit development and dissemination in the SySTEmic Project (a 2-year process).

In addition to these funding sources, HCPS has made an extremely important financial contribution to the project in that it has enabled 3rd & 4th grade full implementation PD to occur on inservice PD days during the regular school year. This contribution is substantial; the cost for teacher pay to come to summer inservice would be approximately \$30,000. Project leaders suspect that the district will similarly support 1st, 2nd and 5th grade full implementation PD; this has not been confirmed by the HCPS district leaders. See Table 3 for a summary of how external funding sources and the HCPS PD contribution have supported PD expenses, kit supply costs, curriculum costs (i.e., to purchase EiE curriculum), and unit development expenses (i.e., the author’s time to develop STE units).

Table 3: Major contributions that funding sources have made or will make to the SySTEmic Project. “Unit Dev.” = unit development expenses (author’s time). TBD = To be determined.

Funding Source	PI (Subaward) Institution	Pre-Pilot	Year 1	Year 2	Year 3	Year 4
		2008-2009	2009-2010	2010-2011	2011-2012	2012-2013
		3 rd grade pre-pilot	3 rd & 4 th grade pilot	1 st & 2 nd grade pilot; 3 rd & 4 th grade full	5 th grade pilot; 1 st & 2 nd grade full	5 th grade full
Workforce One Maryland Program Grant	TU (HCPS)	PD Kit supplies Curriculum Unit Dev.	PD (Sum 09) Kit supplies Curriculum	Kit supplies Curriculum	-	-
EiE – NDRP Grant	EiE (TU & HCPS)	-	PD (Fall 09)	PD Kit supplies Curriculum Unit Dev.	-	-
MSDE STEM Grant	HCPS (TU)	-	-	-	Unit Dev. PD	-
HCPS PD Support	HCPS			PD	TBD	TBD

Partnerships

The tripartite partnership among HCPS, EiE, and TU developed in two stages. The first stage involved the growth of the HCPS-TU partnership, and the second entailed formal partnering between HCPS-TU and the EiE program beyond the use of EiE curriculum.

Stage I: Development of the HCPS-TU Partnership

Since this paper highlights the development of partnerships, it is appropriate to begin with a history of the HCPS-TU partnership that includes a combination of coincidental encounters with EiE, a purposeful attempt to build such a partnership, and collaborative work towards funding that was a catalyst to grow both the SySTEMic Project leadership team and vision (see Table 4 for details). The first meeting between the author, who works at TU, and HCPS science leaders was in April 2008. Prior to this time, the author—a former engineer, high school pre-engineering teacher, and science teacher educator—was building scholarly and outreach activity in the area of elementary engineering via EiE curriculum. Shortly before contacting HCPS to inquire about the district’s interest in using EiE, the Elementary Science Teacher Specialist for HCPS attended a presentation by EiE at the 2008 National Science Teachers Association (NSTA) meeting. After email exchanges sharing mutual interest in EiE, the author was invited to present at the HCPS Science Facilitators meeting. Shortly thereafter, the author, Elementary Science Teacher Specialist, Assistant Supervisor of Science, and Coordinator of Gifted & Talented (G&T) education were working feverishly to write a proposal for the Workforce One Maryland Program due at the end of May.

The key components of the SySTEMic Project described in the previous section of this paper were envisioned in those April and May 2008 meetings and emails as the team worked towards proposal submission. Elementary engineering education would be made available to all children, not a select few. The effort would be systemic—reaching each elementary grade level from 1st through 5th—not sporadic or focused on one grade level. The project would employ a gradual implementation model, beginning in 3rd and 4th grades with a few schools, and then growing gradually to include more teachers, grade levels, and schools as expertise for managing the project and teaching engineering to children would grow. Enrichment teachers would provide support to classroom teachers, and would find ways to enhance and extend children’s learning about engineering. Pilot year teachers would be trained by the author, yet master teachers would lead professional development to disseminate the project beyond the first year. Materials to support the STE unit would become part of the district’s current science kit management system.

Independent partner strengths were instrumental during this envisioning and writing process. Each member of the team had a unique voice. The author had expertise in engineering education and science education, as well as in curriculum dissemination projects and teacher PD. The Elementary Science Teacher Specialist had 20 years of experience as a classroom teacher, and in her current role, knew the elementary science curriculum very well and was the district manager of the science kit replenishment system. The Coordinator of G&T Education and Assistant Supervisor of Science Education, both of whom had extensive experience as high school science teachers, had knowledge of K-12 science education in the district and how the SySTEMic Project could fit into and enhance that system. The coordinator further understood the important role that enrichment teachers could play. There seemed just enough overlap in expertise so that the team members could effectively communicate with one another, yet not so much that roles were redundant. Collaboration was not only enthusiastically embraced by the project team, it was also recognized by team members as being absolutely necessary for the success of the project.

Table 4: Early development of the HCPS-TU Partnership.

Date	Activities
Summer 2007	<ul style="list-style-type: none"> • Author finds EiE program online; becomes interested in using EiE
October 2007	<ul style="list-style-type: none"> • Author submits internal proposal to university to design and study a Summer 2008 Summer Engineering & Science (SEAS) Club
January 2008	<ul style="list-style-type: none"> • Author attends EiE Teacher Educator Institute • Author awarded SEAS Club grant
March 2008	<ul style="list-style-type: none"> • Elementary Science Teacher Specialist for HCPS goes to National Science Teachers Association (NSTA) convention and attends a presentation about EiE; becomes interested in EiE • Author asks a neighbor who works in HCPS central office if HCPS is interested in teaching engineering to elementary kids using EiE • Neighbor contacts Coordinator of Gifted & Talented (G&T) Education in HCPS, who becomes interested and contacts Elementary Science Teacher Specialist (after NSTA conference) • Emails are exchanged between the Elementary Science Teacher Specialist, Coordinator of G&T Education and Author • Author is invited to the HCPS Science Facilitator’s meeting in April
April 2008	<ul style="list-style-type: none"> • Author attends Science Facilitator’s meeting with aforementioned HCPS leaders and science facilitators from each elementary school; presents basic information about EiE and the SEAS Club plan • Author learns about a Workforce One Maryland Program grant proposal due May 31 • Author, Elementary Science Teacher Specialist, Coordinator of G&T Education, & Assistant Supervisor of Science (the “team”) meet multiple times to generate ideas for the Workforce One Maryland Program proposal
May 2008	<ul style="list-style-type: none"> • Author teaches an EiE unit to her students in a preservice teacher education course • Team meets about, writes, and submits the Workforce One Maryland Program proposal (Author, PI)
Summer 2008	<ul style="list-style-type: none"> • Author teaches 3 EiE units in SEAS Club • (Late August) Team, including new Supervisor of Science, learns that the Workforce One Maryland Program proposal was accepted (\$100,000)
Fall 2008 – January 2009	<ul style="list-style-type: none"> • Team meets multiple times to re-plan given that Workforce One Maryland Program funds are delayed
February 2009	<ul style="list-style-type: none"> • Workforce One Maryland Program funds are received

Both TU and HCPS provided a supportive environment for the project. These institutions understood the importance of answering local, state and national calls to increase the quantity and quality of STEM education, especially given the considerable STEM workforce expansion of two military bases in Maryland, one of which was in Harford County. HCPS's STEM-related efforts had been focused on high school and middle school levels, and the prospect of adding an elementary STEM effort was received positively by district leaders at the initiation of the SySTEmic Project. Further, the author's university is one that has a "metropolitan mission" in which scholarly and service-related work with school systems, especially with regard to the provision of teacher PD, is valued. Although no infrastructure existed at the university for engineering education (there is no college of engineering at the university), the author was free to use her unique background to pursue work that coupled science and engineering education.

Ironically, the lateness in funding from the Workforce One Maryland Program grant, which was frustrating to the project team, perhaps served to strengthen the HCPS-TU partnership. Multiple team meetings, now including the new Supervisor of Science for HCPS, occurred during fall 2008 and winter 2009 in which the following question was asked and answered repeatedly: "What is our plan if we get the funding *now*?" Original plans to run 3rd and 4th grade units at 7 pilot schools during the 2008-2009 academic year were eventually abandoned due to the logistical impossibility of doing so beginning in February 2009 when the funding was received and when the team also learned that funding could not be extended beyond the June 30, 2009 end date. Thus, a 12-month plan in the proposal was abbreviated to 6 months. The challenge brought the determined team together, and the SySTEmic Project was still productive. During the 6-month period: the 3rd and 4th grade STE units were developed; the pre-pilot PD, teaching, and reflection cycle was completed; many materials were purchased for the pilot years for all 3rd and 4th grade (and even some 1st and 2nd grade) pilot year classrooms; PD for the pilot year for most 3rd and 4th grade teachers took place; and an educational video about the project was created.

To summarize, beyond having Workforce One Maryland Program funds to pay for project costs, there were six essential factors for the success of the HCPS-TU Partnership. This SySTEmic Project partnership had:

1. A co-constructed vision.
2. Access to high-quality EiE curriculum.
3. Team members with unique strengths and a shared language.
4. A collaborative spirit—an understanding that working together would produce the best outcome.
5. A supportive context in which the project could flourish, such that both partner institutions valued the time and resources team members put forth for the project.
6. Team members who were both determined and flexible.

Stage II: Development of the HCPS-EiE-TU Partnership

In the first stage of the project, EiE was an essential part of the SySTEmic Project, but

perhaps not yet a full partner. A common interest in EiE brought the author and district leaders together, leading to the HCPS-TU partnership. The strength of EiE for HCPS and TU in this first stage was in the quality of the EiE curriculum. EiE units were well tested, the teachers' guides were well written, and the associated kits included simple, elementary friendly and typically inexpensive materials. The quality of the EiE curriculum was likely to have been one reason for that the SySTEMic Project was awarded the Workforce One Maryland Program funding—funding that was responsible for initiating the project.

In the fall of 2009, EiE invited the author to become a Hub Site Partner in their National Dissemination Regional Partners (NDRP) project funded by the Bechtel Foundation. The request was made because of the author's work using EiE in multiple domains, including in her preservice teacher education courses, in a summer science and engineering club for children that she led, and—most especially—her work with HCPS in the SySTEMic Project (see Table 4). The NDRP project involved working with a school district to provide EiE PD for teachers, gather student and teacher data during the school year, and offer follow-up PD sessions to get teacher feedback after instruction. HCPS was an eligible district and a natural choice for the first author given the work that had already begun with the Workforce One Maryland Grant. A formal HCPS-EiE-TU partnership emerged, in which EiE provided additional support for PD, materials, curriculum, and the author's time.

The NDRP project was critically important in enabling the SySTEMic Project to have enough funding to complete the 3rd & 4th grade pilot year, and to fund a majority of the 1st and 2nd grade pilot year expenses. Furthermore, participation in the NDRP project engaged SySTEMic Project teachers in collecting pre-post student data, creating awareness for teachers and administrators that there are measurable learning goals in engineering education. The first author was able to share SySTEMic Project successes and challenges with others in the NDRP at the EiE Symposium in June of 2010, creating additional connections between her and others involved in engineering education across the country.

This Stage II, tripartite partnership was possible because of four characteristics of the SySTEMic Project. The SySTEMic Project had:

1. A vision that was consistent with that of the EiE project (e.g., engineering for all children, and using hands-on, project-based engineering design instruction that builds on science concepts and is set in a meaningful context);
2. A strong collaborative relationship in place involving a PD provider (author) and a school district (HCPS);
3. Access to a pool of willing teachers and administrative support and;
4. An independent record of acquiring funding (i.e., through the Workforce One Maryland Program).

In December of 2010, the formal partnership between HCPS-TU and EiE via the NDRP project came to an end. The SySTEMic project, however, continues with added strength because of this partnership. Funding through the NDRP program helped to grow the SySTEMic Project,

and led to additional funding through the Maryland State Department of Education, an agency that seems excited by the project's approach to elementary engineering education.

The major partners in the SySTEmic Project—HCPS and TU—still work together collaboratively, writing grants and letters of support for one another to sustain the project, delivering PD, and managing the logistics of writing and revising STE units and providing STE unit supply kits to a growing number of teachers in the district. STE unit and kit development—a process of integrating science, technology, and engineering lessons and materials—is the focus of the next section of the paper.

Integration

The SySTEmic Project is somewhat unique among other EiE implementation projects in that the 'unit of focus' is not the EiE unit, but rather the STE unit. During the process of writing the Workforce One Maryland Program grant proposal, HCPS partners selected five EiE units to couple with five district science units (one per grade in 1st through 5th grades), respectively (Table 1). Coupling EiE and science units—typically teaching the EiE unit after science units have been taught—is a common EiE implementation approach. Indeed, one of the strengths of the EiE curriculum is in its explicit connection to and reinforcement of science concepts. STE unit development was, however, somewhat more complex than adding EiE units to the end of science instruction for three reasons discussed in this section: 1) time, 2) the need for STE unit connectedness and coherence, and 3) the need to produce a single STE unit kit of materials.

Time

Due to administrative decisions in HCPS regarding the need to emphasize heavily tested subjects, language arts and mathematics, the time for science and engineering instruction is limited. Both science and engineering are taught during designated "science time" in the elementary school day, which amounts to approximately 2.5 hours per week for 4th and 5th grades, and 1.25 hours per week in 1st through 3rd grades. The original district science units took approximately 8 to 10 hours of instructional time, and EiE units typically take a similar amount of instructional time. What the project could not do was simply add the original science unit and EiE unit together, as it was unrealistic for teachers to be able to spend 16 to 20 hours of instructional time teaching the unit. Thus, unit development involved designating the storybook portions of the EiE unit (about 1.5 hours) as language arts time, and removing some material from the original science unit.

While reducing science content, the author and Elementary Science Teacher Specialist maintained a focus on inquiry-based instruction that favored conceptual development, and used the following criteria to determine what to cut or keep:

- What must be attended to in the Maryland State Curriculum?
- Do most children already understand this basic concept? Do we need to teach it?
- Is this concept cognitively appropriate for this age group?
- Are the models in this unit inaccurate or ineffective?
- Are the children doing overly repetitive testing or other activities?

- Can the procedures be simplified?

In many ways, removing and reducing science lessons has been an unnatural task for both the author and Elementary Science Teacher Specialist (who generally aim to increase science education experiences for children). However, thus far, anecdotal feedback from SySTEMic Project teachers indicates that children’s engagement with the science concepts is deeper and stronger with the STE units than with the original district science units.

Connectedness & Coherence

Another factor with regard to determining whether to keep or cut—or in some cases replace—science lessons is whether or not the science lessons contribute to a coherent, true story that the STE unit tells. Like a good book, the STE unit should make sense from beginning to end, building an understanding of science content in meaningful ways that transitions smoothly into learning about technology, engineering fields or the engineering design process. There is no one strategy for doing this, as evidenced by comparing Table 5 (the order of EiE lessons within EiE units) and Table 6 (the order of science and EiE lessons used in the four STE units that have been developed thus far).

Table 5: Short descriptions of lessons in each EiE Unit.

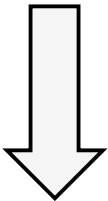
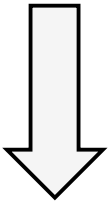
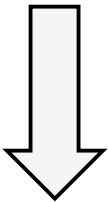
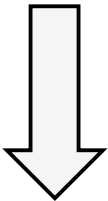
EiE Lesson	Description
Prep Lesson	<i>Technology introduction</i> —informs/reminds students that technologies are human-made solutions to problems.
Lesson 1	<i>Storybook</i> —tells a story about a child who encounters a problem and, with the help of an adult engineer, solves the problem; context of the story is similar to context of the engineering design challenge (lesson 4).
Lesson 2	<i>A broad look at the engineering field</i> —examines a broad aspect of the engineering field outside of the storybook or design challenge context.
Lesson 3	<i>Collection of data to support the engineering design challenge</i> —enables students to gather important information prior to beginning the engineering design challenge.
Lesson 4	<i>Engineering design challenge</i> —takes students through the engineering design process to solve a problem.

For example, the 3rd grade unit, Motion, Energy & Mechanical Engineering, begins with science lessons that develop students’ understanding of motion and force. Children pause to first consider that ‘technology’ includes many simple, everyday items (e.g., post-it notes, spoons), and then apply both their understanding of what counts as technology and the science language they developed to describe the motion and forces of simple technologies (e.g., glue sticks, egg beaters, and can openers) in EiE Lesson 2. They then consider that sails and sail materials are also technologies, and design sails for model boats in EiE Lesson 3. As they test their boats, they again use their understanding of force and motion to describe why and how the sailboats move. The unit then transitions to science lessons about energy, and how energy is transformed in technologies (e.g., fans, pinwheels, and solar cells). Students read the storybook, EiE Lesson 1,

about windmills, setting the stage for thinking about how the energy of the wind can be transformed using windmills and turbines. Students then engage in the final lesson of the unit, EiE Lesson 4, the culminating engineering design process lesson that involves designing windmill blades for a model windmill. During this lesson, students apply not only what they learned from designing sails, but also use science concepts developed in the unit (about force, motion, and energy) to describe the windmills whirring about with the blades they designed.

Part of developing this coherent story for students involves helping teachers to see the connections between the science and engineering lessons in the STE unit. These connections are made explicit in a “science connections” section of added activity sheets that the author writes to accompany EiE lessons in the STE units.

Table 6: Order of science and EiE lessons within four STE units developed thus far for the SySTEMic Project.

STE Unit	Progression of Lessons	
1 st Grade		<ul style="list-style-type: none"> • Science Lessons (solids, liquids, and gases) • EiE Prep lesson (modified from original)* • EiE Lesson 1 • EiE Lesson 3 • EiE Lesson 4 • EiE Lesson 2
2 nd Grade		<ul style="list-style-type: none"> • EiE Lesson 1 and Science Lessons (life cycle of insects, the life cycle of flowering plants, and pollination) are interwoven • EiE Prep Lesson (modified from original)* • EiE Lesson 3 • EiE Lesson 4 • EiE Lesson 2
3 rd Grade		<ul style="list-style-type: none"> • Science Lessons (motion, force) • EiE Prep Lesson (original)* • EiE Lesson 2 • EiE Lesson 3 • Science Lessons (energy) • EiE Lesson 1 • EiE Lesson 4
4 th Grade		<ul style="list-style-type: none"> • Science Lessons (minerals, rocks, weathering, erosion) • EiE Prep Lesson (modified)* • EiE Lesson 1 • EiE Lesson 2 • EiE Lesson 3 • EiE Lesson 4 • Final Science Lesson (local sources of rocks and minerals)

* *EiE Prep lessons have been modified, making them relevant to each unit and different for each grade level, lest they be redundant.*

Kit Development

The original district science units were kit based, and the EiE units are also kit based. Kits are large plastic tubs of all of the essential materials for the unit that are unlikely to be a normal part of the teacher's classroom. For the 3rd and 4th grade pilot year, teachers worked out of two kits—the original district science kit and the EiE kit. This proved to be a cumbersome process, particularly given that the science kit contained older materials no longer used in the unit. Since this time, the Elementary Science Teacher Specialist and her science kit warehouse assistant have designed unified, integrated STE unit kits for 3rd and 4th grade full implementation and the 1st and 2nd grade pilot year. These integrated unit kits do not include the older science materials no longer used in the science portion of the unit, and some engineering materials can be repurposed for science lessons (and vice versa). Integrated STE unit kits, like all other science kits in the district, then become a part of the district-sustained kit replenishment program whereby HCPS replaces consumable and other supplies in the kits as needed.

It should be noted that pilot year teachers not only provide feedback on the STE units, as mentioned earlier, they also provide feedback on the kit materials themselves. This feedback helps to shape the design of the integrated STE unit kits.

Challenges

The two biggest challenges for the SySTEMic Project are these: 1) time, and 2) money. Some teachers still have difficulty “fitting in” the STE-integrated units. Pressures to perform on high-stakes language arts and mathematics assessments crowds what little time for science there is. Some classroom teachers cannot dedicate more than a 30-minute block to science, making longer lessons like EiE Lesson 4 (the engineering design process) more difficult to teach as the lessons need to be broken into parts. Strategies such as regrouping for reading or mathematics (i.e., where groups of children go to other classrooms to learn these subjects with a more homogenous group) and pseudo-departmentalization (e.g., having one 3rd grade teacher teach the STE-integrated unit to all 3rd graders in a school) create less opportunity for teachers to creatively borrow time from other subjects. Teachers who wish to delve more deeply into the curriculum with students—to create extensions, to allow students to go beyond the content of the lessons, or to simply enable struggling learners more time to learn the content—find that the STE units can take well beyond the time estimates for the units. (The author would argue that this is time well spent; yet the fact remains that teachers must also attend to the more heavily tested subjects.) Finally, enrichment teachers are limited in the amount of time they can contribute to the SySTEMic Project; the support they can provide per teacher will necessarily reduce since the growth in the number of classroom teachers far exceeds that of enrichment teachers in the project.

The SySTEMic Project has been fortunate to receive funding from a variety of sources, however more money is needed to continue the project with the same level of support for kit supplies, curriculum materials (which must be purchased from EiE), and full implementation PD for 1st, 2nd, and 5th grades. Full implementation PD is likely to come from the HCPS district in the same way that it occurred for 3rd and 4th grades, and, if realized, would be a tremendous asset to the SySTEMic Project. Grant assistance that would support kit supply costs and curriculum

materials for the first year of full implementation would be helpful; ongoing replenishment costs can be sustained thereafter via the district's current means of replenishing kit supplies and keeping curricula current. As mentioned previously, the project team continues to search and apply for such funding.

Transfer & Scale

Although the SySTEmic Project was designed to address the particular context of the HCPS district, aspects of the project's work to gradually and systemically integrate engineering within science instruction at the elementary level may be generalized and used as a model for other districts to emulate. The creation of a leadership team to spearhead the effort is essential, and the previous bulleted list of essential factors for the success of the HCPS-TU partnership gives rise to the following suggestions for the leadership team:

1. Form a leadership team in which each member brings necessary expertise (i.e., of science curriculum, engineering curriculum, elementary teaching, professional development, knowledge of the district's politics and procedures, grant writing), has a shared interest in engineering education, and is willing to participate collaboratively.
2. Co-create a vision for the way in which the engineering will be introduced at the elementary level to the schools, teachers, and children in the district (e.g., Will it be a gradual implementation model with pilot schools? Is this for all children, or a select few?).
3. Locate an engineering curriculum. Not surprisingly, the author recommends EiE, as it has been extensively researched (and for many other reasons described earlier).
4. Determine how the engineering curriculum will relate to the science curriculum, and whether or not the science curriculum (or engineering curriculum) is in need of modification when the two curricula are coupled together.
5. Seek funding sources and write grants. Even if not funded, this process will help the leadership team articulate their vision, as well as the details of the project plan. Determine the extent to which there is district funding (even in the form of PD days) available to support the project.
6. Consider how to develop engineering education expertise within the district, for example, by creating a similar master teacher model for PD as was the case for the SySTEmic Project.

This team is likely to, but does not have to, include individuals from more than one institution. Having multiple institutions may provide an advantage with regard to seeking funding.

Summary of SySTEmic Project Research

Research on SySTEmic Project Students

The EiE team, through the NDRP project, collected pre-post student learning data related to the engineering portions of the STE-units. These data, disaggregated by state, have not yet

been made available for the SySTEmic Project team to analyze. Furthermore, with an extremely limited research budget—and despite an attempt to study the impacts of the SySTEmic Project on students via an unfunded National Science Foundation grant proposal—the benefits that students receive from STE-unit instruction has not been examined empirically. SySTEmic Project leaders trusted prior EiE research that demonstrated that not only did students exposed to EiE units learn more engineering, but also their science scores improved, as well. ¹

Research on SySTEmic Project Teachers

Funding from the aforementioned Workforce One Maryland Program and NDRP grants, as well as a grant from the Towson University Faculty Development and Research Committee (FDRC), has enabled the author to conduct mixed-methods research on factors that both support and hinder SySTEmic Project teachers' implementation of the STE units. This mixed methods research began with a qualitative investigation of the two early pilot sites teaching the 3rd grade STE units. The author visited these sites, logging approximately 20 hours of observation time at the two early pilot schools. Field observations and a qualitative analysis of pre- and post-teaching interviews with the two enrichment and two classroom teachers at the early pilot sites enabled the author and a colleague, Dr. M. Paz Galupo, to develop pre-, mid-, and post-teaching surveys to disseminate to the 36 2009-2010 3rd grade, 4th grade and enrichment pilot year teachers. The surveys included both open-ended and Likert scale questions that queried teachers about: their perspectives regarding the benefits of STE unit to students, their comfort level with the STE units, the quality of kit materials, co-teaching, their interaction with other teachers within their buildings who were also teaching STE units, the use of hand-held cameras to enhance instruction, and whether or not they see themselves as “teachers of engineering.” During the 2009-2010 academic year, these surveys were completed with an extremely high response rate (e.g., 100% for pre; 94.4% post). Additionally, the author spent well over 20 hours observing two 4th grade classrooms at two of the pilot schools, and conducted post-teaching interviews with 21 of the 36 teachers involved in the SySTEmic Project during the 2009-2010 year. Furthermore, 2009-2010 pilot year teachers completed pre-post PD surveys written by EiE, and 2010-2011 pilot year teachers (~60 1st and 2nd grade teachers and enrichment teachers) participated in a post-PD EiE survey.

Overall, pre/post PD surveys, pre-mid-post teaching surveys, interviews, and field observation data collected by the author (who does not have the support of a research team beyond occasional undergraduate help) has provided much for the author to share in conferences and through publication. The author has either already published/presented the following findings, or will do so in the near future:

- Teachers perceive PD to be an effective means of preparation (pre-post PD survey data). ²
- Classroom teachers value having other classroom teachers with whom to share ideas as they implement STE units for the first time. ²
- Classroom and enrichment teachers value their combined efforts via co-teaching to deliver hands-on engineering design processes that simultaneously engage students in deep, reasoned thought. ³

- Teachers see the STE units as being valuable to their students (more to be published).^{2, 4}
- Teachers have enhanced their instruction of the engineering design process via the inclusion of hand-held cameras (more to be published; presenting work at the 2011 NSTA Convention on March 12, 2011).
- Teachers identify time to prepare and time to teach within the daily instructional minute schedule as the largest factors that hinder their teaching of STE units (more to be published).²

Specific qualitative and quantitative findings of this research are beyond the scope of this paper, yet as indicated above, have been and will continue to be published and presented. The intent of this paper—as well as other papers in the “Making Elementary Engineering Work” set—was to provide something that focused empirical papers often do not: a “zoomed out” perspective of a project. Such perspective allows for things like the details of the development of partnerships to become transparent.

Conclusion

The SySTEmic Project has been successful because of the HCPS-TU partnership that created the project, and the contributions of high quality EiE curriculum and the partnership that EiE provided to grow the project during a critical time in its five-year trajectory to meet its goal of engineering for all 1st through 5th grade children in HCPS. The development of integrated STE units has enabled a sort of custom fitting of EiE for the district’s existing science curriculum. Although challenged by time and money (challenges that are probably not unique to this project), the transformation of the HCPS district to include engineering and technology at the elementary level continues with vigor. Together with other examples in the “Making Elementary Engineering Work” paper set, we can work to foster better implementation and sustained use of elementary engineering in HCPS and beyond.

REFERENCES

1. Lachapelle, C. P., Cunningham, C. M., Jocz, J., Kay, A., Lee-St. John, T. J., Mabikke, H. N., Phadnis, P., et al. (2011). *Engineering is Elementary: An evaluation of years 4 through 6 field testing*. Boston, MA: Museum of Science.
2. Lottero-Perdue, P.S., Herzog, M., Ryan, A., Baranowski, A., Cole, M. (2010). The SySTEmic Elementary Engineering Project: Reflections on growing an engineering education community of practice. *Proceedings of the P-12 Engineering Education Summit hosted by Purdue University*, Seaside, OR. August 11-13.
3. Lottero-Perdue, P.S. (2011). Classroom Teacher – Enrichment Teacher Pairs: Co-teaching as a means to implement elementary engineering education. *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Expo*, Vancouver, Canada. June 26-29.
4. Lottero-Perdue, P.S., Lovelidge, S., & Bowling, E. (March, 2010). Engineering for all: Strategies for helping all students succeed in the engineering design process. *Science and Children*, 47(7), pp. 24-27.

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