AC 2011-319: INFUSING NON-TRADITIONAL ENGINEERING PROJECTS INTO TRADITIONAL CLASSROOMS: WHERE DO THEY FIT? HOW ARE THEY ASSESSED?

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Infusing Non-Traditional Engineering Projects into Traditional Classrooms: How Do They Fit? The Case of the Build IT Underwater Robotics Project

Abstract

The pivotal 2009 National Academy of Engineering report on engineering in K-12 education states that the presence of engineering in pre-college education is an important phenomenon because of engineering's impact on K-12 STEM education. The NAE report then explores a number of questions about the ways in which engineering is taught in K-12 classrooms, including issues such as the curricular and instructional resources used, interaction with other STEM subjects, and teacher preparation. This paper explores these and related questions surrounding the adoption of non-traditional engineering projects into diverse middle and high school classrooms from the perspective of an engineering, science, and IT-focused project that features a challenge-based underwater robotics curriculum using LEGO®, Mindstorms and the NXT-G programming device. Data from teachers who implemented this project over two years suggest that their rationales for undertaking a complex engineering design curriculum include opportunities to expose students to engaging activities that simultaneously meet curricular objectives and that address certain 21st century skills. Their challenges include their own level of relevant content knowledge and IT experience, as well as time, facilities, equipment, and classroom management constraints. Teachers' feedback formed the basis for the development of streamlined curricula, just-in-time online learning modules, and other resources to aid implementation and enhance learning. Lessons learned from this project are informing the development and implementation of a scale-up project in four U.S. cities in girl-focused informal education programs and in disadvantaged schools.

Background

The 2009 National Academy of Engineering report, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, states, "The presence of engineering in K-12 classrooms is an important phenomenon, not because of the number of students impacted … but because of the implications of engineering education for the future of science, technology, engineering, and mathematics (STEM) education more broadly."[1] This pivotal publication then identifies a number of basic questions that at present remain unanswered: How is engineering taught in K-12? What types of instructional materials and curricula are being used? How does engineering education "interact" with other STEM subjects, including how has engineering instruction been incorporated into science, technology, and mathematics classrooms?

The National Academies report reviewed a variety of K-12 engineering curricula with the goal of describing the curricular objectives and the engineering content and skills addressed.[i] The study found that, from the *perspective of the curriculum developers*, "the reasons for including engineering content…are as diverse as the materials themselves," and that "teaching engineering

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[i] Researchers selected 34 K-12 engineering curriculum packages based on such criteria as the engineering content and skills included and the level of widespread use and longevity of the curriculum. Of these 34, 15 were examined in depth. See p.74 of 2009 National Academy of Engineering report, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*.

is not always a first-order objective."[2] Table 1 includes the variety of explicit objectives of the engineering curriculum programs reviewed by the committee:

Table 1:
Stated Curricular Objectives of Prevalent Engineering Curricula

- Enhance the study of science or mathematics or both
- Develop problem-solving skills through interdisciplinary learning experiences
- Connect science and mathematics to real-world problems and demonstrate their application in technical careers
- Teach technological literacy
- Develop design, creativity, iterative design, and critical thinking skills
- Increase awareness of the engineering disciplines and careers from an early age
- Provide rigorous curricula to prepare students to pursue engineering or engineering technology programs in college
- Reverse poor test scores in mathematics and science
- Demonstrate practical applications of mathematics

Welty et al. used a "beads and threads" model to analyze engineering curricula. The core engineering concepts and skills are represented by four "threads" that run throughout the various curricula, while the context or vehicle through which these concepts and skills are packaged are the "beads." Three of the threads that the analyzed curricula addressed, to varying degrees, were the three knowledge domains used in engineering design, specifically, **mathematics, science,** and **technology**. The fourth thread, the **engineering design process (EDP)**, encompasses specific aspects of engineering design, including analysis, constraints, modeling, optimization, and systems.[3,4] The "beads" or "packaging" used to deliver engineering content generally focused on technologies of interest to students, such as cell phones, digital video, water-bottle rockets, and robotics.

This conceptual model for analyzing engineering curricula provides insights into the variety of approaches and curriculum pathways through which engineering concepts and skills are and can be delivered in K-12 classrooms, as well as the varied learning objectives of such curricula. It also provides a glimpse into the types of teacher expertise needed and the challenges encountered in effectively delivering engineering curricula.

Challenges in Integrating Engineering into the Classroom

Research on the integration of innovative curricula has indicated that curriculum change ultimately rests on the classroom teacher. For example, in several studies on the integration of new science curricula, researchers found the following barriers: lack of equipment, lack of support from a professional development team, lack of time to plan and teach the lessons, insufficient teacher content knowledge, and teacher beliefs about the teaching and learning and the innovation to be implemented that were incompatible with success.[5, 6]

In terms of engineering curricula specifically, researchers have found additional constraints. For instance, Hutchinson, Bryan, and Bodner found that teachers' assessment of how well the lessons fit into pre-existing curricula and their own level of content knowledge on the topic were also important. [7] Custer and Daugherty found that many engineering-oriented professional development programs are designed to include teachers from a variety of academic disciplines—generally mathematics, science and technology education—but that schools' scheduling, curricular, and assessment constraints hinder the development of cross-disciplinary teams, as do the teachers' varying levels of science, technology, engineering, and mathematics ability.[8] These researchers expanded on this challenge, noting that among the diverse group of teachers involved in teaching engineering, either explicitly or as a component of other subjects, "a shift toward engineering will represent a substantial change in both content and approach…involve[ing] learning more mathematics and science…learning how to interact with colleagues in other disciplines to…rethink and repackage traditional content…and …rethinking teaching methods and learning to facilitate hands-on, open-ended design experiences in which students and teachers work together to solve real-world problems." [9]

Other concerns raised by teachers engaged in engineering professional development include their own content knowledge in science and mathematics; their technical knowledge, particularly with the use of specialized software applications and other tools; practical issues such as time for professional development, lesson planning, and time within the curriculum; and their ability to implement the curriculum with fidelity. Resources, including materials and equipment, as well as lack of administrator and institutional support for STEM in the context of high stakes testing and education funding priorities, were also cited as challenges, along with students' lack of mathematics background and low levels of reading comprehension.[10] And while it might seem that these concerns would abate at the secondary level, in fact many secondary teachers are specialists in their content areas and teaching engineering challenges them to learn new content, new ways to implement lessons, and new assessment methods.[11]

Why Teachers Adopt K-12 Engineering Curricula

If there are so many challenges, why do K-12 educators' participate in professional development on engineering curricula and adopt engineering curricula? The reasons are less well-documented in the literature, but they include a desire to increase their students' technological literacy; expose them to engineering technology as educational and career pathways from an early age; make science and mathematics relevant by providing real-world applications; and provide college credit for entry into engineering and engineering technology programs. [12, 13] Other reasons include fostering interpersonal "process skills" such as teamwork, communication, documentation, ethics, and aesthetics,[14] and providing a vehicle to increase student motivation and reduce anxiety in STEM subjects.[15]

Robotics-based engineering projects pose both special challenges and special learning opportunities in K-12 classrooms. Robotics has been demonstrated as an effective vehicle to teach STEM concepts at many levels. The theoretical foundation for using robotics in education has been put forth by Jonassen, who classified them as "mindtools," and described robotics experiences as cognitive tools that can enhance the learning process.[16] Others have argued that robotics enables students to creatively learn computer programming, mechanical design and construction, problem solving, and collaboration,[17, 18] as well as provides an opportunity to explore open-ended problems that require integrative thinking.[19] Riskowski et al. have gone a step further and identified three components that engineering design brings to the study of science (in this case, in middle school settings): (1) **interaction:** engagement and relationship-building among groups to design-build-test an apparatus, whereby the individual contributions to a collective product or process is paramount; (2) **artifact development:** developing an artifact fosters the display of the groups' communal knowledge as embodied in the artifact; and (3) **critical analysis:** a process of individual, small-group, and large-group (whole class) continual learning as designs are critiqued and improvements are suggested/tested.[20] Designing robots includes all of these.

Posing open-ended design challenges in the context of designing and testing robotic devices is also consistent with theories of problem-based learning (PBL). A growing body of research suggests that PBL, engineering curricula, and "design-based science" are effective means of increasing students' conceptual understanding of science (and mathematics), their long-term retention of learning, and their abstraction or transfer of learning. Several studies conducted at the middle school level indicate that design-based activities result in significant gains in student understanding of science concepts [21, 22] and science skills,[23] and decrease the achievement gap between some demographic groups.[24, 25, 26] Studies conducted in high school science classrooms using design-based curricula also provide evidence that these activities result in significant gains in student understanding of science concepts [27, 28] and may decrease the achievement gap between some demographic groups.[29, 30] In addition, several studies[31, 32, 33] have documented the impact of educational robotics on student learning of STEM concepts in informal learning environments.

The Build IT Underwater Robotics Project

The Build IT project is a problem-based learning (PBL) curriculum that utilizes an underwater robotics project as the context to engage students in hands-on and conceptual learning of engineering and science content and certain 21st century skills. The curriculum spans approximately 30 "regular" class periods, draws upon multiple content domains, and requires the extended use of a pool or tank to test the performance of student-designed remotely operated underwater vehicles.

Over two years, 65 middle and high school teachers from 30 socio-economically and academically diverse schools implemented the Build IT curriculum in a variety of classroom settings, including science, mathematics, technology education, pre-engineering, and computer science courses. The curriculum uses LEGO Mindstorms kits, the NXT programmable brick, and related equipment. This paper illustrates the ways in which this very diverse group of teachers, with students from across a wide academic spectrum, integrated Build IT into a variety of courses; how and why they overcame the heavy logistical demands associated with the project; how they justified the additional support and time required to do the project; and their perceptions of academic and 21st century achievements gained by their students through the project.

In the "bead and thread" analogy, the bead is the underwater robotics curriculum and the threads are the specific science and engineering design concepts introduced in the curriculum.

This paper will focus on teacher perceptions of the benefits and challenges on implementing this curriculum and, in the final section, relate this project to the existing literature on these benefits and constraints. Previous papers have reported on the program's professional development model for teachers; the model's efficacy[34]; and on classroom implementation models and effects on student learning.[35, 36] We have elected to include this type of data, rather than student outcome data in this paper as *a way to understand teachers' choices and decision-making about adopting non-traditional curricula* (and because student outcome data has previously been published).

Content Learning Objectives and Curriculum Design

The goals of the Build IT project were to increase middle and high school student and teacher interest and achievement in engineering, science, mathematics, and information technology.

Build IT exposes students to the concepts of buoyancy, Newton's Laws, momentum, density, gear ratios, torque, forces, energy, volume, mass-weight distribution, and simple machines. During the first year of the project, teams of students in each classroom used LEGO components, wire-guided switches, motors, and other equipment to design, construct, and control robots to maneuver in a 3-4 foot deep pool and complete a series of five increasingly complex challenges, each of which ends in a timed competition: (1) a straight-line challenge, in which the remotely operated vehicle (ROV) must travel the diameter of the pool's surface using one motor; (2) a slalom challenge, which adds a second motor and requires the ROV to navigate a Figure 8 course on the pool's surface; (3) a vertical challenge, where a third motor and other devices can be added to control the ROV's buoyancy in a vertical water column; (4) a grabber challenge, where a "claw" is added to allow each ROV to pick up objects; and (5) a final challenge, in which teams compete against each other to collect and deposit wiffle balls into underwater goals (see above photo). In the second year of the project, students learned icon-based programming using the NXT-G in order to complete the same set of challenges. The culminating event of each school year was a statewide competition in which teams from all partner schools competed against each other in middle and high school categories for the following prizes: Overall Winner, Most Innovative Design, and Speed. Equipment requirements included use of an eight-foot diameter pool set up in a secure area for varying durations of from three to more than 10 weeks (so that students could test their ROVs and compete in the design challenges). In addition, in the second year, students needed access to computers to program the motion of their ROVs and troubleshoot their performance.

As noted previously, the curriculum was taught in a wide variety of classes, including "regular" science, technology and technology education classes, with selected groups of students, with academically homogenous as well as academically diverse groups, with gifted students, and with special education students. Most of the high school teachers taught the curriculum in existing

Physics and Engineering classes, while the middle school teachers either integrated it into existing science or technology education courses or taught it as a special robotics class:

Table 2:
Titles of Courses in which Build IT/NXT Curriculum Was Taught

Course title	Type of course	Existing/Created
Middle school		
STEM Science	Middle school science	Existing
Grade 8 Physical Science	Middle school science	Existing
Robotics	Middle school science	Created
LEGO Robotics Enrichment	Middle school science	Created
Robotics	Middle school science	Created
Science	Middle school science	Existing
Robotics	Pre-Engineering/Engineering	Created
7th Grade Computers	Technology Education	Existing
Robotics	Industrial Arts	Created
Technology Education	Technology Education	Existing
Build-IT Underwater Robotics	Technology Education	Created
Build-IT Special Program	Build-IT special program	Created
Build-IT Enrichment	Build-IT special program	Created
Robotics	Build-IT special program	Created
High school		
CP Physics	High school physics	Existing
Honors Physics	High school physics	Existing
AP Physics	High school physics	Existing
AP Physics	High School physics	Existing
Pre-engineering	Pre-Engineering/Engineering	Existing
Introduction to Pre-Engineering	Pre-Engineering/Engineering	Existing
Robotics	Pre-Engineering/Engineering	Existing
Marine Engineering	Pre-Engineering/Engineering	Existing
Introduction to Engineering-PLTW	Pre-Engineering/Engineering	Existing
Digital Electronics - PLTW	Pre-Engineering/Engineering	Existing
Robotics Engineering	Technology education	Existing
Engineering Design Technology	Technology education	Existing
Systems Engineering I	Technology education	Existing
Introduction to Programming	Computer science	Existing
AP Computer Science	Computer science	Existing

The amount of time spent on the curriculum, as well as the intensity, also varied greatly. Most of the classes met several times a week during normal class time, but a few middle schools met only once a week for a full or half day.

Table 3:
Number of Meetings per Week

	High School %	Middle School %	Total %
4-5 times	69%	50%	59%
2-3 times	23%	21%	22%
1 time	0%	21%	11%
Varied	8%	7%	7%
Total	100%	100%	100%

In addition, the high school implementations were more intense, taking place over shorter periods of time than the middle school implementations, some of which went on for many weeks:

Table 4:
Number of Weeks Project Lasted

	High School %	Middle School %	Total %
1-5 weeks	62%	43%	52%
6-10 weeks	31%	14%	22%
More than 10 weeks	8%	43%	26%
Total	100%	100%	100%

The teachers also varied greatly in their preparation for teaching the concepts embedded in the curriculum. Thus, although they were almost all experienced teachers (65 percent had taught for five or more years), only 42 percent reported that they taught Newton's Laws, only 23 percent taught gears, and only 26 percent taught buoyancy. None of the middle school teachers and only 24 percent of the high school teachers reported that they taught the iterative design process, and while 57 percent of high school teachers reported that they had taken at least some programming, only 41percent of the middle school teachers reported that they had done so.

Teacher Perceptions on Benefits of the Build IT Curriculum

Since implementing Build IT required a major commitment of time from the teachers—to organize the materials, to learn the curriculum, to learn how to teach new concepts, to learn and then teach programming—we wanted to know if they felt that the effort had been worth it in terms of the benefits for their students. A survey administered to participating teachers at the end of the second year of implementation was returned by 27 of the 30 teachers who completed at least one implementation (i.e., with one class of students) that year. These teachers came from all 14 of the participating middle schools and from 12 of the 16 participating high schools. They were reporting on a total of 49 classes: 15 of the teachers taught the curriculum to one class, while 12 taught it in more than one class—some in as many as four.

In the year-end survey, 92 percent of high school teachers and 79 percent of middle school teachers gave the project an A or B in terms of how much they felt their students learned—and the few Cs were from three middle school teachers whose students had trouble with the programming and from a high school teacher whose students already knew the material. The ratings for enjoyment were even higher, with 94 percent of high school teachers and 93 percent of middle school teachers giving the curriculum an A or B in terms of how much they felt their students enjoyed it.

There were several learning goals, including to help students learn science concepts (in this case, the principles of gears and buoyancy), to learn programming, and to learn or reinforce math skills. The teachers were asked to assess their perceptions of student learning for these items on a 5-point scale, with 5 being the highest rating. The following table gives the percentage who gave a ranking of 4 or 5 for each of these. It shows that the teachers viewed the curriculum as most successful in teaching gears and buoyancy, somewhat successful in teaching programming, and less successful in teaching math. However, it should be noted that for some items at the high school level, the teachers did not feel it helped because their students already knew these topics.

Table 5:
Teacher Perceptions of Student Learning

	% of middle school teachers	% of high school teachers	% of all teachers
Learn the principles of gears	78%	100%	88%
Learn the principles of buoyancy	86%	85%	85%
Learn the basic principles of programming	57%	69%	63%
Gave them new math skills	15%	9%	13%
Reinforced existing math skills	31%	32%	32%

As noted above, the rankings were higher for engagement than for learning—but as teacher comments cited below show, many teachers recognize it as a necessary precursor. The rankings were also higher for the 21st century skill of group work and for learning the principles of iterative design. Again, it should be noted that many high school teachers believed their students already knew these skills; this at least in part explains the difference between the middle school and high school teachers' assessment of gains in presentation skills:

Table 6:
Teacher Perceptions of 21st Century and Engineering Design Skills Learned

	% of middle school teachers	% of high school teachers	% of all teachers
Engaged the students	93%	100%	96%

Learn to work well in groups	93%	85%	89%
Learn the principles of iterative design	79%	84%	81%
Gain presentation skills	67%	36%	52%

It is important to note that the rankings for learning the principles of iterative design increased from the first year as a result of a deliberate change of practice during the professional development workshops. In the background survey, none of the middle school teachers and only 24 percent of the high school teachers reported that they were currently teaching the iterative design process, and at the end of the first year, only 47 percent of high school and 29 percent of middle school teachers reported that they had built in explicit instruction on this topic. The results of the student assessments showed that, while the students clearly had engaged in that process, they did not know that they had done so.[35] At the end of the second year professional development staff and teachers discussed the need to make the process of iterative design more explicit in the lessons, 92 percent of high school and 71 percent of middle school teachers reported that they had deliberately taught the process—and, as the above indicates, most also felt that the students had learned it as well.

In general, the teachers felt that there were three immediate benefits of integrating Build IT. The first was that it motivated students to learn the subject matter, primarily because it involved them in hands-on learning; this was particularly emphasized by middle school teachers, where motivation is a major issue. The second was that it gave students the opportunity to engage in iterative problem-solving—to act like engineers; this was particularly emphasized by high school teachers. The third was that the students learned how to work in teams and even collaborate across teams; this was emphasized by middle school teachers, who have younger students, although both said that the project was helpful in teaching students to work in groups.

Teacher comments about project benefits fell into several major categories:

<u>Motivation/engagement</u>

- The greatest benefit, in my opinion, was in motivating them to study harder in science. With the Build IT program as a "carrot," the students paid greater attention, spent more time on-task in the more traditional activities in science just so they could participate in the program.
- The hands-on aspect of the class kept students engaged. There was also a lot of bonding that went on with the students who were in groups as they navigate the evolving group dynamic.
- The project engaged the students and got them interested in the course in a way that would likely not have occurred had we not done this project.
- It inspired some of the students to improve their grades (we used the trip as an incentive for behavior, etc.) and they looked forward to the class.
- Behavior problems were minimized because the students were totally engaged in the program.
- As long as students were engaged, there were little to no disciplinary issues. Some students who often struggle in some of the other classes were extremely successful with the hands on approach of Build It.

Iterative problem-solving

- Gives the students a real world experience of solving a problem or addressing a situation and then being able to test and redesign.
- The hands on aspect of design. Students can immediately test their designs, re-design and retest.
- It is an engaging, interactive class. They liked the freedom to learn and design an open-ended solution, enthusiastically entering into the room and getting busy with their work instead of sitting and listening. Each mini lesson was given when it was needed. After the class was over, the students said the presentation and learning to write technical documentation would help them in college.
- Teaching students to take a complex problem and break it down into pieces that could be accomplished. Doing iterative design. Design from principles rather than pure trial and error. Allows students to build tolerance for frustration. Promotes fault analysis.
- It is always a problem for students to figure out how to break down a complex problem into manageable pieces and to combine their skills to solve a problem. Persistence is also a problem. They tend to give up when the going gets rough. Build IT/NXT is an excellent way to teach students how to persevere in the face of a difficult problem and how to integrate their skills and knowledge to get a method of solution.
- All levels were challenged from the advanced to the low. The higher level students enjoyed working with each other and came to respect the "Mission Impossible" concept that you built the team based on the strengths of the other team members. They didn't have to wait for the weaker members to catch up but developed a respect for what the others brought to the group.

Teamwork/collaboration:

- Teaching students to work in groups. Students who were not confident of their ability discovered their capacity of thinking and applying. Students worked very well in groups to get higher grades on final challenges.
- Teamwork and accomplishing the tasks in different and creative ways are the greatest benefits because students evaluate and critique each other's robots.
- Although challenging, the students had to work together in groups to create a design and problem solve (become engineers).

Challenges

All the teachers faced multiple challenges in implementing the curriculum. In the first year, it was the logistics of the pool—finding a safe place to put a large pool that needed to be in place for many days, keeping the pool water clean—to sharing the LEGO kits among many students, and adapting the wiring to the water environment. The high school teachers had more issues with finding pool space, partly because many high school teachers do not have their own classrooms, while the middle school teachers were more concerned about safety. By the second year, only the high school teachers struggled with not having enough equipment, but this was because, based on the previous year's experience, the middle school teachers had solved this problem by reducing class size. On the other hand, only the middle school teachers had problems with managing the computers and with the programming, due primarily to their lack of familiarity with these skills. All the teachers tried various different ways of managing group work.

Challenges: Logistics

In the first year, the teachers had scrambled to find sites for the pool and to set up protocols for maintaining it. In the second year, some teachers continued to struggle with this, particularly at the high school level:

- Logistics of pool and scheduling students and teachers into same time slot. Pool also leaked this year. We just pushed on through and did the best we could.
- Access to a pool of water for testing. I bought a landscaping pool which has a capacity of approx. 100 gallons and was able to locate it in the classroom. Used a sump pump to pump the water out through a window.

In the second year, scheduling and classroom management were issues for a few high school teachers and for many of the middle school teachers. Quotes from their survey responses show their frustrations, but also the lengths to which they went to devise solutions:

- Scheduling was a major hurdle this year. There existed no overlap time between the two [cooperating] classes and that greatly lessened the time that the CS kids could work cooperatively with the Physics students. We ended up running “in-school” field trips but I do not feel this was adequate time for the students to help one another with their tasks.
- Time was an issue last year as well as this year. To try and resolve the problem, students were taken out of their regular classes for the entire day and worked on the Build IT project. Their regular work had to be made up for homework. We did this for 3 days for about 4 weeks. My colleagues were very supportive and I think it worked out better because students were able to focus on lessons and complete tasks than during a 50 minute class as we did last year.
- Our greatest challenge was time in Year 2. In Year 1, [my co-teacher] had the class built into his Industrial Arts rotation, so the entire 7th grade (about 90 students) went through the program and the class was 42 minutes per day, 5 days per week, for 10 weeks. In Year 2, robotics was squeezed into a once a week, 30 minute period, and it was very difficult to have continuity. Some weeks the class was cancelled due to assemblies or special activities. This made it very difficult for the students and frustrating for me.

Challenges: Programming

One question on the second-year survey asked specifically about challenges with the NXT programming. A few of the teachers had to deal with old or locked-down school computers or with teaching in ad hoc and very inadequate spaces. Again, they went to great lengths to solve these problems as well:

Computers and location:

- Our laptops are old and it was a challenge to get the software loaded. Computers are locked out from loading software and only one staff member had the key to unlock. Batteries are shot and we had to be on power. Shower room we are in has no power. Security of computers. We can't save anything so we had to download programs to flash

drives at end of each day. No projection capability in shower room so it was difficult to demonstrate programming.
- We found that the program uses a lot of memory when the programs get very large. Our current computers are really not equipped to handle the program so we are looking into purchasing laptops with better configuration next semester.

In general, it was the middle school teachers who reported that their students had difficulties with the actual programming. Their responses suggest that they themselves needed more time to be able to teach programming effectively:

- The programming was the most difficult. More time was needed for the students to truly understand the nature of the system.
- We had some questions about programming, such as how we could use 4 motors and if a second NXT could be used but they were never answered.
- Not enough time spent just "playing" with the programming aspects. Our students have never had exposure to any programming language, so it was a challenge for them.
- Sat with the students and plugged through until the problems were resolved. If the teachers had more knowledge about the programming, it would have been easier.

However, some teachers reported no problems at all. For the high school teachers, this was because their students already had a background in programming, but for the middle school teachers, it seems to have been a matter of perseverance.

Challenges: Managing group work

During the teacher workshops, there were many discussions about the best ways to organize groups, with the teachers sharing ideas about such topics as whether to assign students to a group or let them choose, whether to rotate roles, whether to create academically heterogeneous or homogeneous groups, and whether to mix genders. In the second year survey, when the teachers were asked how they had organized their groups, they were split on all dimensions, except for gender, with most teachers having mixed gender groups. Middle school teachers were more likely to assign students to groups than high school teachers, but high school teachers did both in equal measure:

Table 7:
How Groups Were Organized

	% high school teachers	% middle school teachers	% all teachers
Teacher assigned students	54%	79%	67%
Students chose group	62%	36%	48%
Rotated roles	54%	29%	41%
Students chose role	46%	36%	41%
Academically heterogeneous	31%	29%	30%
Academically homogeneous	31%	21%	26%
Genders mixed	77%	43%	59%

Genders separate	15%	36%	26%
Combinations	15%	7%	11%

About one-third of the teachers reported that their management of group worked had changed from the first to the second year, particularly at the high school level, but what changed varied from teacher to teacher, with some becoming more prescriptive and some less so. All were struggling to help students make the groups more effective. Here are some examples:

- I had clearer expectations of what was required of each team to complete the project.
- Yes, I took the advice of other Build IT teachers and penalized teams that did not follow the roles they assigned themselves at the beginning of class. I made the leader choose the roles for that day. I checked that roles were rotated daily.
- Did more homogeneous grouping. Worked very well this year.
- I did some gender groups, other mixed groups, etc. I tried a little bit of every type of grouping. In groups with dominant male students, the girls often backed away. Although, in some mixed groups, there were some dominant girls and some of the boys backed away.

In the first year, the limited amount of equipment for the larger classes had sometimes led to the presence of too many “idle hands”—a complaint that was heard from the students and recognized by the teachers. As with the other implementation challenges, here too the teachers worked to come up with a solution, primarily by making sure that everyone had something to do, even if it was housekeeping. Here are some examples:

- Students who were idle fixed the wires. Refill the pool when required (pool being on the third floor, they had to go first floor gym and get the hose and return).
- We would pull students out of the group to do “management tasks” like fixing a control box, cleaning the pool, or organizing parts when they weren't busy.
- Used the presentation part as way to keep all students involved. When students complete task, we had them work on the PowerPoint.

A second issue was controlling dominant team members, who had a tendency to take charge and do all the work, and getting students to share the more interesting roles or move out of their comfort zone and take on new roles (builder for the girls, programmer for many students). Over half the teachers reported that they had assessed teamwork, particularly at the middle school level, and designed various ways to control for dominant team members doing all the work. Here are some examples:

- Assigning roles in groups and changing roles at random times (sometimes during a class). For example: only one person, designated by a yellow t shirt, was allowed to manipulate the computer. Students were randomly selected to wear the shirt. You didn’t know who would be next so you had to pay attention. Also known computer geeks were not allowed to program, only advise verbally.

- By changing roles constantly, the group had to work as a team or they couldn't get anything done. They had to be aware of everybody's capabilities and how to use them. They had to communicate.
- I had each team member draw a circle graph depicting each team member's contribution to the project for each challenge and document the tasks completed. This was private and confidential. I then compared it with my observations and notes about each group.
- I had a score of 1-5, 5 being a good score and 1 being a low score. They were assessed on how they worked, if there was a problem how they solved that problem, and how they worked against other groups.

Challenges: Gender differences

Although only about a third of the teachers reported that they had seen gender differences during implementation, those who did felt that there was reluctance among the girls to get involved in the building (complaints of broken finger nails) and programming (too hard, too geeky). However, when the girls did get involved, the teachers felt they were more creative and did better.

- The girls were better planners while the boys tended to go in directly and attempt things more quickly with slightly less thought.
- Some girls picked the documentation job and were reluctant to build the robot since they did not have prior experience building with LEGOS, so they deferred to the boys. They were less apt to pick the programming for the same reason. In an all-girl group, they worked together to learn the new concepts. Their documentation was beautiful, thorough and well presented.
- The girls were actually more creative than the boys.
- Our girls really did better and were more interested in it than our boys.

It is noteworthy that the students (girls and boys) agreed with the teachers' assessment that they were both more creative and more focused than the boys.[35, 36]

Impact on Teachers and Schools Beyond the Built IT Program

Although it was not a formal goal of Build IT to change the culture of a school, or even of any one teacher's classroom practice, for many teachers participation in Build-IT did lead to other changes in their classrooms. For some, it was the curriculum itself that changed, while for others the change was in their use of project-based learning. Here are some examples:

- The Build It project is incorporated in the curriculum for 9th grade class. I use the techniques for group work with other projects in class.
- I have built a semester course with the Build IT project as the first marking period project.
- I included projects which students had to identify the math used in an engineering career of their choice. A choice made from materials I receive from my involvement with Build IT and the workshop provided for Guidance Counselors that was given last year.
- I have a better programming unit to teach to my students.
- This year, I will make "technology careers" a unit in my classroom.

- Made the classroom more student-centered.
- Clearer idea of good projects for the post-AP exam classroom.
- Yes, my classroom became more "hands-on," with more group work in more topics.
- It has in terms of how I facilitate group work and projects.

Having support at the school and community level is very important in allowing teachers to introduce any innovative curriculum, and was particularly important for Build IT because of the need for the pool and for additional equipment. The teachers reported that school administrators and some parents (particularly in the middle schools) had been very supportive of the project. In some cases, this support had been local—finding space, offering praise, allowing professional development days and field trips, and so on. In other cases, however, principals had also been instrumental in finding funds for additional equipment (particularly for more LEGO kits) and three of the high school teachers had made presentations to their school boards, often with their students.

It was therefore an important achievement of the project that, despite all the logistical and time-related difficulties, 22 of the 27 teachers who returned the survey at the end of the second year said that they planned to teach the Build IT curriculum after the project had ended, with over half saying they planned to do both the simpler ROV (from the first year) and more complex NXT (from the second year) versions. However, a few felt that they might have to drop the pool and do the entire curriculum on land. Those high school teachers who planned to do both wanted to use the ROV version as an introduction and the NXT version for advanced and AP classes, all in existing pre-engineering or physics classes. Most of the middle school teachers planned to do both versions--the ROV with a younger grade and the NXT with an older grade.

It was the middle school teachers who expected to make the greatest changes. Four reported that the Build IT curriculum was going to be a formal part of the school's curriculum the following year:

- Everyone from the superintendent, two principals, the board of education and parents have been supportive and appreciative of the program. Beginning with this upcoming school year, robotics (NXT programming) is part of the Industrial Arts curriculum rotation. When the IA curriculum was updated during the summer of 2008, robotics and the associated NJCCC standards were included.
- I have been given permission to incorporate the STEM project initiatives in my class curriculum. My class will be a highly engaging pre-engineering project-based model. I have been allowed to develop my class curriculum and pacing schedule. I am being moved into a larger room and given a line item to supply this initiative.
- Definitely part of my curriculum now. Has also impacted our high school as parents from my last year's class are demanding engineering courses.
- I have added more of a career focus to my upper grade teaching and a connection to engineering whenever possible in my Science classes.

And two were developing entire programs:

- I am now offering a middle school program in pre-engineering. This is generating a lot of excitement with students, parents, and the community. The Build IT program was the inspiration.
- They are currently discussing plans to transition my middle school into a STEM magnet middle. They have asked about my networking with other teachers in the building to establishing cross-curricular thematic units based on STEM.

Additional Impact: Awareness of Engineering Careers

One additional goal of the Build IT project was to open the eyes of the teachers to the variety of engineering careers available to their students. This was done through discussions of engineering careers during professional development days, visits to some of the research labs at Stevens Institute for Technology (where the summer workshops were held), and a career awareness day attended by a guidance counselor from each school and some of the teachers.

Some of the teachers, particularly at the high school level, were themselves former engineers so their awareness was less likely to change, but about two-thirds of middle school teachers and one-third of high school teachers reported that it did:

Table 8:
Percent of Teachers Who Reported that Their Awareness of Engineering Careers Had Changed

	% high school teachers	% middle school teachers	% all teachers
Yes	38%	64%	52%
No	54%	14%	33%
Not sure	8%	21%	15%
Total	100%	100%	100%

Discussion and Future Research

The literature cited earlier in this paper listed a number of barriers that teachers face in integrating any innovative curricula into their classrooms and additional barriers they face in integrating engineering curricula. Each of these barriers was a potential factor in the implementation of Build IT. Although not all were resolved completely, most were resolved to the degree that the curriculum could be implemented. Those teachers who were convinced that the curriculum benefit their students persevered, coming up with creative ways to meet the challenges. At the same time, Build IT curriculum developers learned from the experience of the first year and not only adjusted the professional development sessions to provide more support for logistical issues but worked to streamline the curriculum and created additional support for learning in the form of tutorials, simulations, and videos that would help the teachers become confident teaching new material. Without these two components, it is unlikely that such innovative curricula can be introduced into schools.

Table 9:
Barriers to Innovation

Barriers to Adoption of Classroom Innovations	Resolution
Lack of equipment and other resources	Provided by the project; additional resources found by the schools
Lack of support from the professional development team	Two week summer workshops, with follow up professional development days and just-in-time classroom visits
Lack of time to plan and teach the lessons	Partly resolved by PD days, but still an issue
Insufficient teacher content knowledge	Partly resolved by PD days and creation of online resources. Still an issue to some extent
Insufficient teacher technical knowledge	Partly resolved by PD days and creation of online resources. Still an issue to some extent
Insufficient experience with problem-based learning	Not an issue, since PBL is common in middle schools and in high school physics and engineering courses
Students' lack of background knowledge	An issue, but counteracted by the ability of lower performing students to excel with hands-on learning
Teacher beliefs about the value of the innovation	Not an issue with this group of teachers, all of whom volunteered for the project and stayed with it for two years
Teacher assessment of how well the curriculum fits with pre-existing curricula	An issue, resolved by reordering existing curricula or creating new courses
School scheduling constraints	An issue, resolved by individual teachers with help from their administrations
School assessment constraints (standardized testing)	An issue, particularly for some middle school teachers

Lessons learned from this project may inform both curriculum developers and K-12 educators as to the benefits and challenges of adopting engineering in the traditional K-12 classrooms. The Build IT project has led to a national scale-up effort that is adapting the curriculum for use in other parts of the country in both traditional secondary classrooms in disadvantaged regions and with informal education providers focusing on girls, under the umbrella of the Build IT Scale Up project, and the newly-titled *WaterBotics* curriculum (www.waterbotics.org). Future research will report on efforts to distill "core elements of success," or those components of the curriculum and implementation that are directly linked to desired student outcomes, as well as the differences in implementation and outcomes in formal and informal learning environments.

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