Underwater LEGO Robotics as the Vehicle to Engage Students in STEM: The BUILD IT Project's First Year of Classroom Implementation

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Abstract

The BUILD IT project is a university-school collaboration to increase precollege student and teacher interest and achievement in engineering, science, mathematics, and information technology through a novel underwater robotics project that utilizes LEGO Mindstorms kits, the NXT programmable brick, and related equipment. The project is being implemented in 36 socio-economically and academically diverse schools throughout New Jersey for students in Grades 7-12. Through a series of increasingly complex challenges, BUILD IT exposes students to science, mathematics, and engineering concepts such as buoyancy, Newton's Laws, momentum, density, gear ratios, torque, forces, energy, volume, mass-weight distribution and simple machines. This paper describes the first year of classroom implementation in which teams of students in a variety of classroom settings 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, collect objects, and compete in a project-sponsored statewide underwater robotics contest.

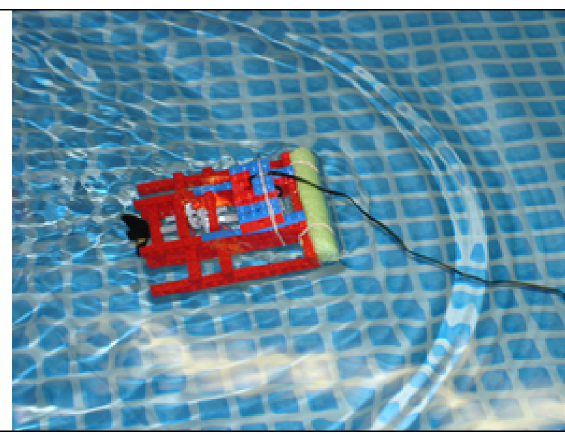
Introduction

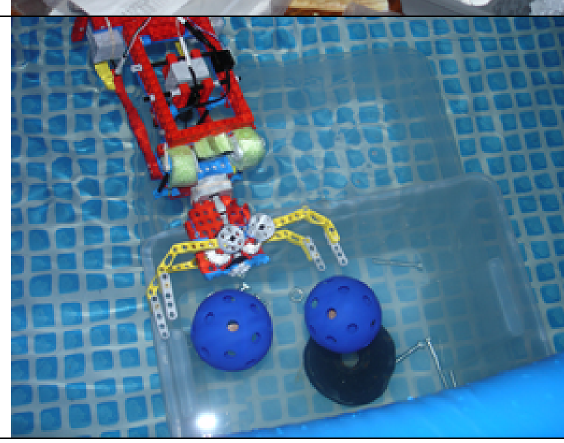
Robotics has been demonstrated as an effective vehicle for discovery-based learning[1,2,3]. Robotics education has proliferated in the K-12 arena, with exponential growth of schools involved in extracurricular robotics competitions such as US FIRST and FIRST Lego League, as well as in-school robotics courses for elementary through high school levels[4]. Most robotics curricula focus on the design and control of terrestrial robots, whose educational objectives include mechanics, electronics, programming, problem-solving, and the engineering design process[5],[6]. Several, including the BUILD IT project, introduce a further level of complexity to these educational activities through the use of an underwater medium in which to deploy robots[7,8,9,1011,11]. BUILD IT is a three-year, National Science Foundation-sponsored Information Technology Experiences for Students and Teachers (ITEST) project which presents a series of design challenges to middle and high school students in the context of an underwater robotics project. The underwater environment presents novel and more complex challenges, such as controlling for buoyancy and three-dimensional range of motion, not previously encountered, even by students experienced in other robotics curricula.

Two distinctive features of the BUILD IT underwater robotics project are its use of LEGO components, which allow for rapid construction and redesign, and which are durable with relatively low start-up costs; and its extended, in-school curriculum, spanning some 20-30 class periods. The length of the curriculum, as will be discussed, created some time pressures in certain types of classrooms, but allowed students to have intensive experiences with iterative design, problem-solving, presentation skills, and hands-on learning of integral science and mathematics concepts.

The BUILD IT curriculum was planned as a two-phased, scaffolded approach to engaging students in designing, building, and controlling robots in three dimensions, controlling for buoyancy and other features unique to the aqueous environment. In the first phase, known as the ROV Curriculum, the goal was to train teams of teachers from 36 schools (17 middle and 19 high schools), serving students of grades 7-12, to implement a series of lessons in which students worked in teams of 2-5 students to build, test, and control robots using LEGO bricks, motors, propellers, cables, wire-guided switches, and other materials. Phase 2, known as the NXT Curriculum, will replace the wire-guided switches with the NXT Intelligent Brick and has added Mindstorms sensors in order to create a programmable controller to manipulate the underwater robot. This adaptation is being implemented in classrooms during the 2008-09 school year, and will be discussed in future papers. It is also anticipated that advanced classes will be able to add an autonomous underwater vehicle (AUV) component during the final school year.

Preceding the school year implementation of the ROV curriculum, two identical two-week summer institutes were held during the summer of 207 for two cohorts of middle and high school teachers. During the first week of each institute, teachers were trained in the curriculum by being guided in a project-based, team-based approach in which they worked on all five challenges, culminating with a competition on the final day of the week[12]. The five challenges are outlined in Table 1. During the second week, teachers piloted the lessons with small groups of students in order to gain confidence and plan for implementation during the school year. Year 1 included two mandatory professional development days for participating teachers to share implementation successes and challenges, learn troubleshooting techniques (e.g., waterproofing motors), and culminated with an "IT Symposium and ROV (Remotely Operated Vehicle) Competition."

Table 1		
Straight Line Challenge	Use a single motor to build a vehicle that can travel the diameter of the pool on the surface as quickly as possible; optimize gearing to achieve best propeller speed.	

Slalom Challenge	Use a second motor to enable steering; maneuver on surface to complete a slalom course around two buoys in shortest time.	
Submerge Challenge	Use a third motor and other materials to control the vehicle's buoyancy in order to descend and rise vertically in water	
Grabber Challenge	Design a motorized mechanical manipulator which can grasp specified objects; build an electrical control system which uses four 4 switches to control 4 motors (left, right, vertical, grabber); each switch must have 3 positions (forwards, backwards, off).	
Final Challenge	Combine the products of previous challenges to produce a vehicle which can retrieve the greatest number of objects from the bottom of the pool within a specified period. Objects must be deposited in bins at various depths in the water to score points.	

School Year Implementation of ROV Curriculum

Teachers provided an estimated timeline and plan for how the lessons would be implemented in their particular school and classroom. In planning for classroom implementation, teachers had to consider a number of factors in the creation of the implementation schedule, including placement of the 8-foot diameter pools in a secure location; use and cleanup of materials; curriculum pacing and testing schedules; and others. Also, although the project was forecast to require approximately 20 standard class periods for full implementation, many teachers either needed to or wanted to extend the project beyond 20 periods. A number of classes implemented the project as one condensed block in a four-to-five-week marking period; others, due to scheduling or curriculum pacing issues, extended the project over several months, offering the class once a week. Further, some teachers were more constrained by time than others; in general, technology education teachers were more able to devote 20 or more class periods to the project than were science or mathematics teachers. Due to these factors, there were a wide variety of implementation plans and schedules among the participating schools.

The stated goals of the ROV curriculum used in Year 1 were: to introduce students, through a collaborative, iterative design experience, to concepts such as experimental design, motion and forces, balanced and unbalanced forces, rotational motion, machines, gear ratios, mechanics, electrical circuits, and buoyancy. Practical construction problems, such as how to prevent power cables from interfering with the boat's movement, also required that participants develop their problem-solving skills. The use of LEGO materials is a particularly effective tool, as has been documented elsewhere,[13,14] to allow rapid prototyping, testing, and redesign.

The data analyzed in this paper comes from teachers' applications, from their baseline surveys, from surveys returned immediately following implementation, to a final survey completed at the end of the year. Student data will be reported in a following paper.

A summary of findings regarding the ROV implementation follows:

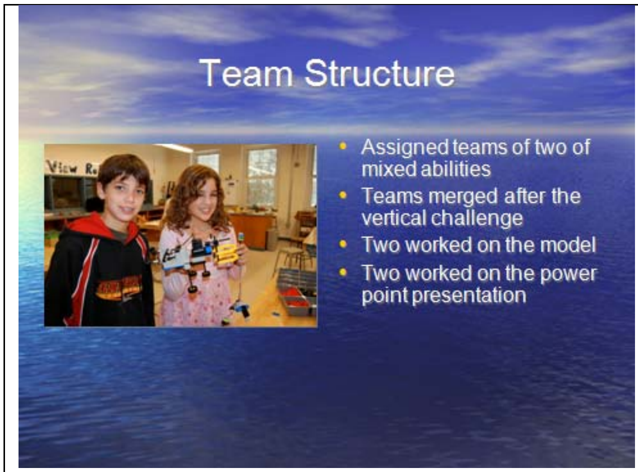
- Overall, the BUILD-IT curriculum was very well received by the teachers who taught it during the year.
- Fifty percent of the schools were in the A or B District Factor Groups, assigned to the lowest socioeconomic districts in the state.
- 36 teams, comprised of 71 teachers (teams of two except for one school) signed up to participate. Forty-one teachers (representing all 36 schools) began to teach the curriculum and 36 of these (representing 31 schools) completed at least one round. One-third taught it twice or more.
- Overall, 90 percent of the teachers gave the project a grade of A or B in terms of student learning and 87 percent gave it an A or B in terms of student engagement.
- Both middle and high school teachers reported that they were able to use curriculum to teach a number of concepts covered in the standard curriculum and on the state tests.
- Both middle and high schools teachers listed such other benefits as the 21st-century skills of teamwork, problem solving, the ability to deal with failure, and the ability to deal with real-world problems.

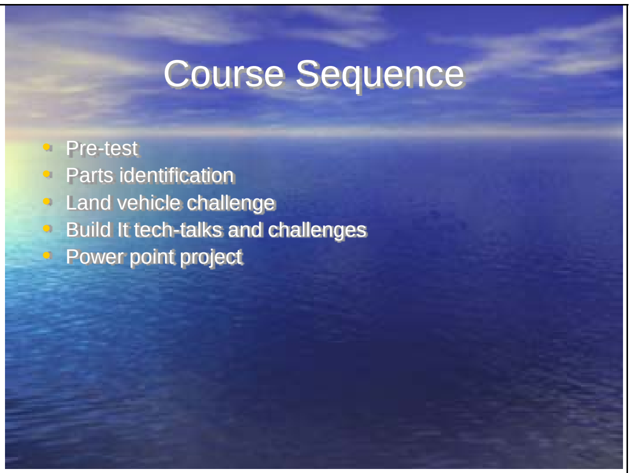
- The teachers also reported that their own awareness of engineering careers had grown as a result of the project, in particular by expanding their knowledge of the number of engineering fields.
- The main challenges the teachers faced were logistical, including setting up a pool and having enough LEGO materials for entire classes, and finding enough time to fit it into the curriculum.
- Almost all of the teachers found ways to resolve the problems they faced, or developed plans for doing so next year.

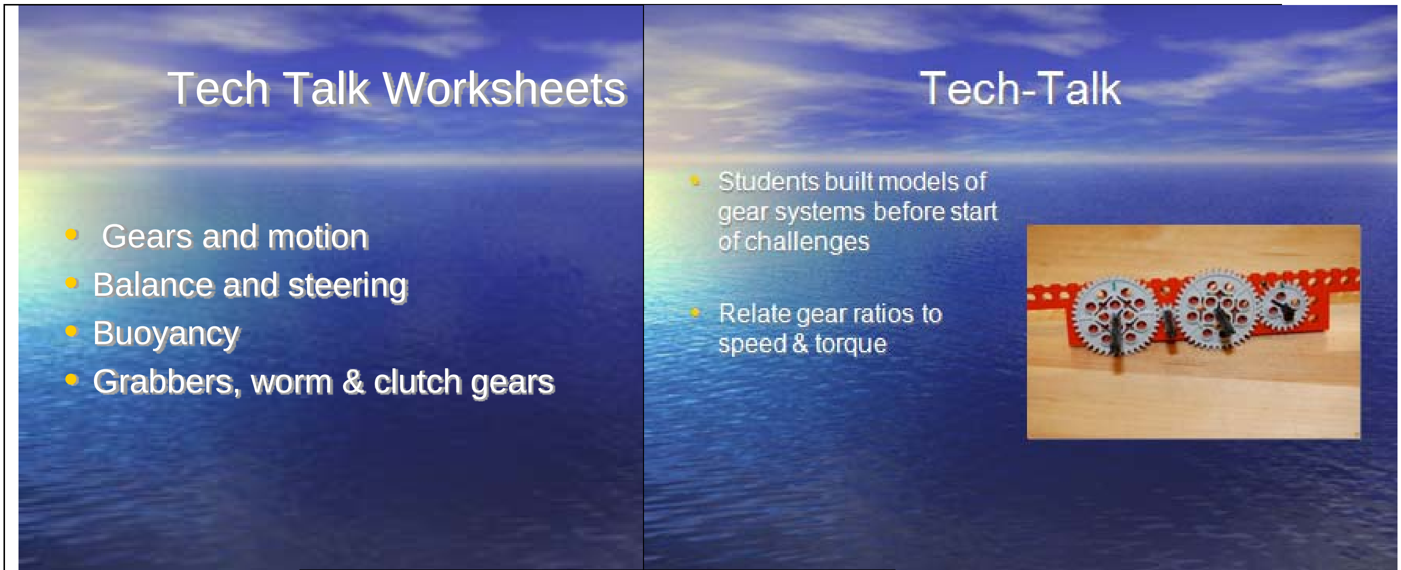
In terms of classroom implementation, two case studies provide insight into how the curriculum was implemented in very different settings:

<u>Case Studies</u>

The middle school described in this case study is a suburban school in an affluent community[15]. The participating teacher has 26 years of classroom experience, an undergraduate degree in Industrial Arts and Technology, and state teaching certifications in Industrial Arts K-12, Elementary K-8, and Middle School Math HQT. Industrial Arts and Technology is required for all seventh graders. Since he taught Industrial Arts/Technology, he relied on his fellow teacher in the project to help with teaching the science concepts. This teacher modified the planned implementation of curriculum, based on observations from the summer institute, in order to reduce potential challenges of students working in teams. The teacher team (the technology teacher, assisted by a science teacher) also added a "Challenge 0," or a land-vehicle challenge, to introduce and familiarize students with the LEGO parts and their functions before starting the water-based activities.







Artifacts of Middle School Classroom Implementation

Despite the fact that the school is a relatively good one, the students in this class were academically heterogeneous, ranging from special education students to slow learners to those the teacher considered not sufficiently challenged intellectually most of the time. The students' own estimation of their abilities was in line with this, with about 70 percent reporting that they found school either "easy" or "very easy," but a number reporting that they only received Cs in science and math.

Almost all (90 percent) of the students reported that they had already studied forces and motion, but only half reported that they had learned about electrical switches, only one-third had learned about gears, and only one or two reported that they had studied buoyancy. Assessments were drawn from a source on buoyancy[16], and supplemented with additional items that were developed by project faculty. The results of the pre-assessments corroborate this. Each assessment had three or four questions, depending on the subject, and although a higher percentage of students got more correct answers for gears than for the other two assessments, none of the results were showed a full understanding of the concepts involved:

Detailed student assessment data from this case study classroom has been previously reported[17]. However, to summarize, pre-/post-assessment data showed that the number of questions answered correctly had increased on all the tests. Also, despite the fact that the teacher rated the curriculum highly in terms of teaching buoyancy, the results of the post-test show that this was still a concept that his students struggled with.

Regarding group work, this teacher wrote in his post-implementation survey, "I thought the adults had trouble working in groups of four on one model, so I decided to start out with groups of two, so all the students were involved. I also knew to choose the groups carefully so one person wouldn't over-run the team and not wait too long to adjust the groups if there were major issues.” He had also encouraged the girls to be involved in all aspects of the curriculum, including the building, and had quickly adjusted groups that appeared to be dysfunctional.

The high school was very different from the middle school: the student body is 70 percent Hispanic and 20 percent African American, and the community is in the lowest income ranking for a New Jersey school. However, the school has an engineering track and is involved in Project Lead the Way, and the teacher came to teaching after a career as an electrical engineer.

The first class that used the BUILD IT curriculum was made up of sophomores in a pre-engineering track, and it was taught for 100-minute periods every day for 12 days. Almost all (93 percent) of the students reported that they had previously studied electrical switches, 60 percent said they had learned about motion, approximately half had studied forces and buoyancy, and about one-third had studied gears and gear ratios.

Like the middle school students, these students did much better on the post-assessments. This teacher added an Electrical Challenge to the curriculum, which may account for the high scores on the electricity post-assessment, but her students (like the middle school students) had the most trouble with the concept of buoyancy.

This teacher had also learned from her experience during the summer institute and had organized her groups carefully. She had assigned roles and played a more active facilitating role than she had in the past.

The high school students kept design logs as well.

Both these teachers found the curriculum fit well into their existing courses and both felt that it taught valuable skills in addition to concepts. Both felt that the hands-on aspect of the curriculum was motivating for their students. For the middle school teacher, there was also the additional important lesson that unsuccessful prototypes are not failures but steps toward a final solution.

Analysis of School Year Implementation

The project’s original goal was to enroll two teachers from each of 36 different schools, for a total of 72 teachers. Sixty-eight teachers attended the first summer institute and 71 were in place by the beginning of the school year (one school had only one teacher signed up). They came from 17 middle schools and 19 high schools. Fifty-percent of the schools came from the two lowest SES district classifications, while the remaining schools were distributed across SES classifications.

The project plan was for one teacher in each school to implement BUILD-IT with one class of at least 20 students in the first year and the second to implement it with one class of at least 20 students in the second year (when programming was introduced). In this first year, all the schools had teachers who started at least one implementation, and 14 of the 17 middle schools and 17 of the 19 high schools had teachers who completed at least one implementation. The schools that did not have any teachers who completed were with one exception schools in the lowest District Factor Group (DFG), which is a measure of socio-economic status[1]:

Number of schools with teachers who started and completed, by district factor group (A is lowest SES classification, while J is the most affluent):

Middle schools		
Classification	Started	Completed
A	8	6
CD--J	9	8
Totals	17	14

High schools		
Classification	Started	Completed
A	7	5
CD--J	12	12
Totals	19	17

In some schools more than one teacher began an implementation, so there were more teachers implementing than schools. In this first year, 42 teachers began the curriculum and 36 completed at least one implementation. Again, with one exception, those teachers who did not complete were in DFG=A schools. Overall, middle school teachers were slightly less likely than high school teachers to complete, while teachers in A schools were also somewhat less likely to complete than teachers in other district factor groups:

Number of teachers who started and completed, by district factor group

Middle school teachers			
Classification	Started	Completed	Percent
A	9	7	78%
CD--J	9	8	89%
Totals	18	15	83%

High school teachers			
Classification	Started	Completed	Percent
A	9	6	67%

[1] District Factor Groups (DFGs) are used by New Jersey and represent an approximate measure of a community's relative socioeconomic status (SES). Classifications range from A (lowest economic category) to J (most affluent). For more information on how they are calculated, see http://www.state.nj.us/education/financie/sf/dfg.shtml.

CD--J	15	15	100%
Totals	24	21	88%

However, although not every teacher taught the curriculum in his or her own classroom, all but two of the non-implementing middle school teachers and all but five of non-implementing high school teachers collaborated in some way with the implementing teacher. In some cases, this was co-teaching, in some cases it was assisting, and in still other cases, it was planning. As a result, the total number of teachers at least involved during the year was 64, or 90 percent of all teachers who signed up.

In addition, while some attrition among teachers reduced the total number of implementers, the fact that six of the middle school teachers and nine of the high school teachers taught the curriculum to more than the one class greatly increased the number of students reached, so that by the end of the year, the curriculum had been successfully taught to a total of 69 classes: 33 classes of middle school students and 36 classes of high school students.

Middle school teachers were slightly more likely than high school teachers to teach the curriculum only once, but also more likely to teach it four or more times. For example, those teachers who felt least comfortable with the materials often chose one class that they felt could do the work, while those who felt more comfortable taught it to all their classes. However, teachers in DFG=A schools were somewhat more likely to teach the curriculum only once than teachers in other district factor groups, presumably because of time pressures, while teachers in the higher achieving schools were more likely to teach it more than once:

Number of times taught by school district factor

	Once	More than once	More than once as %
A	8	5	63%
B-J	13	10	77%
Total	21	15	72%
As %	58%	42%	

The sections that follow analyze the teachers' responses to a post-implementation survey, completed immediately after the curriculum had been taught, and a final year-end survey. Thirty-one teachers returned the post-implementation survey and 38 returned the final survey; 36 of the 38 completed at least one implementation.

Most of the teachers who returned the post-implementation survey reported that they were able to have their students complete the entire set of challenges, and a few even added challenges of their own—for example, an electrical challenge, a head-to-head competition, an underwater Figure 8 challenge (Figure 8 combined with vertical motion), a land vehicle challenge, and Year 2 AUV challenge:

Challenges completed

	High	Middle	Total	High %	Middle %	Total %
Straight line challenge	16	14	30	94%	100%	97%
Figure 8 (Slalom) challenge	17	12	29	100%	86%	94%
Vertical motion challenge	16	12	28	94%	86%	90%
The final “grabber” challenge	16	11	27	94%	79%	87%
Other	5	2	7	29%	14%	23%

Several of the teachers who did not complete the entire curriculum—which meant that they did not complete all the challenges—ran into logistical and time problems: a few ran out of time at the end of the year or had other time conflicts (some of these had already taught it once), while one had problems with the pool. Only one teacher simply quit, reporting that the students lost interest. Several others reported that in some (but not all) iterations they stopped because the students had trouble working in groups.

Challenges in teaching the curriculum

The teachers reported a number of challenges in teaching the curriculum. The most common were logistical problems with the pool, getting access to materials, and time issues. In addition, some teachers had problems getting the teams to function well.

Curriculum components

The curriculum was designed to develop a number of discrete skills, including teamwork, iterative design, and presentation skills. Because of limitations in the amount of equipment available (equipment was provided to accommodate up to four groups of five students working together, however some classes exceeded this number of students and other teachers created smaller groups, thereby requiring more equipment than provided in the equipment grant), all the teachers had their students work in groups—mostly groups of three or four, although there were also groups of five and some teachers started with pairs and then combined them into larger groups. Although the curriculum was structured as a competition, not all the teachers reported that they had the groups compete. In addition, although design logs were considered an important part of the curriculum, not all teachers had their student keep logs, and even fewer had them make final presentations--the latter presumably because of time constraints. This question was only asked on the immediate post-implementation survey, which had 31 respondents:

Curriculum components

	High	Middle	Total	High %	Middle %	Total %
Worked in pairs	7	4	11	41%	29%	35%
Worked in groups or teams	**17**	**14**	**31**	**100%**	**100%**	**100%**
Had groups of teams compete against other groups or teams	14	12	26	82%	86%	84%
Kept design logs	13	12	25	76%	86%	81%
Made presentations	11	8	19	65%	57%	61%

One of the original goals for BUILD-IT, which combined the teaching of science concepts with an engineering challenge, was that students would learn the iterative design process. They were asked to keep logs, to draw pictures of their designs, to write explanations for changes, etc. As noted above, not all the teachers had their students keep design logs. In addition, when asked how they explained the difference between the scientific method and the iterative design process to their students, only some of the teachers reported that they had done this, with many expecting that the students would simply see the difference:

These high school teachers said they did:

- I told my students that scientific method and the iterative design process are built upon the same principles. I was able to show the correlation between the two.
- I had students work with experimentation to gain knowledge and then apply the knowledge by using the design process, and explained to them that the scientific method is to gain knowledge where as the design process is to apply that knowledge you have gained.

Only two middle school teachers reported that they explicitly taught iterative design.

One teacher noted how difficult it was for students to actually design iteratively:

- The process of making SINGLE CHANGES to the vehicles is often a hard spot for most students to accept at first. After several days of making multiple changes between testing the vehicles, it is good to hear one or two members of each group repeat the advice .... "Test each change, one at a time" Eventually, they see the advantages to this process and it strongly supports the scientific method in the long run.

Group work

Group work was built into the curriculum, not only because of the limited amount of material but because group work is an important 21st-century skill that the project was designed to help develop. There are many ways to organize group work, and considerable time was spent during the summer workshop and subsequent professional development days discussing the best ways to do this. As noted above, many teachers had difficulty getting the groups to function well as teams.

The final survey asked the teachers to list the problems that they had faced in working with groups. One of the key problems was the dominance of one or more group members, or the reverse—the lack of participation by one or more students. Some of this had to do with gender issues in which boys dominated the building activities and girls engaging in the presentation activities.

During the summer institute and also during the professional development days, some of the participants had described how they managed groups by assigning roles to the students. The survey therefore asked the teachers if they assigned the students roles and if so, what those roles were. Twelve of the 17 high school teachers and 11 of the 14 middle school teachers reported that they assigned roles. There was great variation in the roles they assigned, however, although parts manager and presentation manager were on many of the lists.

Curriculum integration

It was clear from planning discussions held during the summer institute that some teachers were going to find it easier than others to integrate BUILD-IT into their curriculum. Those who taught technology found it easiest because they had a flexible curriculum and did not have to focus on preparing students for a high-stakes test. High school science teachers reported that they used the curriculum to teach, or reinforce, the following concepts, all of which are required by the New Jersey state tests:

- Buoyancy
- Newton's Laws
- Momentum
- Density
- Gear ratios
- Torque

Middle school science teachers who taught physical science, and high school teachers who taught Physics, also found it easy to integrate BUILD-IT, and reported that they used it to teach these concepts:

- Forces
- Energy
- Motion
- Density
- Buoyancy
- Volume
- Mass-weight distribution
- Ratio and proportion
- Electricity

High school teachers also reported that they used it to teach critical thinking, problem solving, synthesis and analysis of problems, and evaluating the design process.

Those who could not make a good fit with their regular courses used the curriculum with special groups of students or with elective courses. For example, one high school teacher used it as part of a science research curriculum, which he described as "discovery-based, problem-solving, teamwork approach to find solution to everyday problems." Another used it as a replacement for a normally scheduled initial design project. Both of these were teaching electives.

Changes made on second implementation

Teachers who taught the curriculum more than once were asked to describe the changes they had made in the second or third iterations. Most tightened up the organization and logistics, while others focused on some of the learning issues (such as gears for the middle-school students). Those teachers who had trouble with groups in the first implementation also made some changes in the second. For instance, some tightened up their procedures, adding clearly defined roles.

Awareness of engineering careers

One goal of the project was to make teachers—and eventually their students—more interested in science and engineering as future occupations. The teachers were not given any specific information on engineering careers, other than hand-outs, but they did spend time at Stevens during the summer and did accompany their students on their visits to various labs. The final survey asked if the project had made them more aware of engineering careers. More than half of the 38 teachers who responded to the final survey, including almost all of the middle school teachers, said that their awareness had grown as a result of the project:

Has your awareness of engineering careers changed as a result of this project?

	High	**Middle**	**Total**	**High %**	**Middle %**	**Total %**
Yes	7	13	20	30%	**87%**	53%
No	11	1	12	48%	7%	32%
Not sure	5	1	6	22%	7%	16%
Total	23	15	38	100%	100%	100%

In response to an open-ended question about what exactly had changed, they wrote about how their understanding of engineering careers had broadened:

- Through the days spent at Stevens with the robotic teams I became aware of how versatile and growing the fields off engineering are becoming. The days spent at Stevens (especially for the students) were excellent.
- The introduction to new fields that prior to the program I was not aware of.
- Simple activities can influence students to major in engineering.
- How much broader engineering is now than when I worked as one.
- Engineering is amazing. I never understood my father's passion for engineering until I started with this program. Personally I can talk to him more frequently about issues that in the past were abstract or just word problems. As a teacher I will encourage my students more to become engineers.

- The concept of introducing engineering to my students has changed (I am an architect!). I have also become more aware of the breadth of career choices in engineering.
- I have a much better understanding of what engineers do, the different types of engineers, and how broad the scope of engineering has become. I understand the problem solving process better and am more comfortable with implementing it.

Teachers' Assessment of Student Learning and Engagement

The survey asked the teachers to rate the project in terms of how much their students learned and how engaged they were in its activities. (Note that a separate analysis will be developed to elucidate student learning based on pre-/post test data and will be presented in a future paper.) In the survey, almost all the teachers gave the project an A or B, although a larger percentage of high school teachers gave it a B:

What grade would you give the Underwater Robotics project in terms of how much the students learned?

	High	Middle	Total	High %	Middle %	Total %
A	6	7	13	**26%**	**47%**	34%
B	14	7	21	**61%**	**47%**	55%
C	1	0	1	4%	0%	3%
D	1	1	2	4%	7%	5%
F	1	0	1	4%	0%	3%
Total	23	15	38	100%	100%	100%

In their response to the second question, about engagement, 91 percent of the high school teachers and 80 percent of the middle school teachers gave the project an A or B in terms of how engaged their students were. In contrast to the distribution of A and B grades on learning, a much higher percentage of high school than middle school teachers gave the project an A in terms of engagement:

What grade would you give the Underwater Robotics project in terms of how engaged the students were?

	High	Middle	Total	High %	Middle %	Total %
A	12	5	17	52%	33%	45%
B	9	7	16	39%	47%	42%
C	1	2	3	4%	13%	8%
D	1	1	2	4%	7%	5%
F	0	0	0	0%	0%	0%
Total	23	15	38	100%	100%	100%

The difference between high school and middle school in terms of engagement seems to have been related to the time frame and possibly to the large size of some groups, with middle school students more likely to become disengaged the longer the project lasted. Thus in their responses to a comment section at the end of this question, the teachers praised the curriculum itself, and the high school teachers in particular noted that it had built confidence among their students, but there were a few middle school teachers who seemed to have trouble getting their students to focus and persevere in the face of design failures.

High school (positive)

- Students became confident as the project progressed. Students took leadership and ownership of the robots they built.
- Both of the groups that were exposed to the Underwater Robotics program were initially not that confident about their own abilities to complete the vehicle described in the final challenge. As each of the groups involved made progress through each challenge, the lack of confidence faded away and gave way to a high degree of accomplishment in its place.
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Middle school (positive)

- The robotics program was my main motivation tool this year!
- With limited class time and long intervals between, it severely limited learning. But the curriculum was excellent

High school (difficulties)

- The project was great, but I had a poor group of students, and feel that they could have easily been more engaged, and learned more, but it was the quality of my students, and not the project that was the dilemma.
- The students that I had lost interest way too quick. No motivation, no success is what I saw. I think students should be selected to participate.

Middle school (difficulties)

- I have to add more supplemental information to make it more meaningful. The kids were very engaged at the beginning and then became frustrated and enthusiasm faded in many students.
- Most students learned the concepts involved with the project. Due to the size of some groups it was difficult to keep everyone engaged all of the time. Some students wanted to take over and others were more passive and didn't want to participate.
- Engaged the students for about 4 weeks, beyond that they got frustrated and wanted to move on to something else.

Other benefits of the curriculum

In their responses to a question that asked about the other benefits of the curriculum, the teachers went beyond the science concepts to write about such 21st-century skills as teamwork, problem solving, and innovation, as well as such "thinking" engineering skills as the design process.

For science concepts, they focused less on the concepts themselves than on how hands-on activities had not only helped the students learn but gotten them excited about science:

- The vast majority of our students have had no contact with LEGOS nor with the concepts of buoyancy, center of mass etc. They enjoyed the various stages involved in the building. We even had repeat customers!
- Hands-on activity explains the concepts very easily.
- Learned about the design process. They gained the knowledge about gears, buoyancy, electrical boxes along with building the prototype for retrieving materials from underwater habitat.
- The hands-on portion that allowed them to see gears and ratios in action.
- They were able to apply book knowledge kinesthetically.
- a) Understood abstract concepts on buoyancy. b) Fostered student participation both individually and by groups. c) Enriched the curriculum.

They also wrote about 21st-century skills, particularly teamwork, the ability to deal with failure, and the ability to deal with real-world problems:

- Teamwork, trying new ideas, getting along with time constraints and completing the tasks.
- Learning to work as a team. Integrating skills and knowledge to solve a problem. Learning to tolerate the frustration of failure.
-

Some teachers focused on the engineering aspects of the project, including robotics:
- Got interested in engineering.
- Getting hands-on training and exploration in engineering.
- Being able to see on a small scale a practical application of engineering principles.

Year 2 Goals and Activities

A Revised Curriculum

In the first version of the Build IT curriculum, students were challenged with building a control box for their robot (*Figure 1*), which involved tasks such as making a circuit, wiring, soldering, and using heat-shrink insulation. It was hoped that this would help students learn some aspects of basic circuitry. However, in practice many students found this activity confusing and/or uninteresting. It seemed to slow the momentum of the project. Many teachers simply skipped this part by making the controllers for their students beforehand. Furthermore, controlling the robot using switches proved to be cumbersome.

Figure 1

Therefore, the most significant modification to the curriculum for the next version has been to change the controller. Instead of building a control box using aluminum boxes, wires, and switches, students will assemble them using the LEGO Mindstorms materials. These kits include a programmable device, called the NXT (*Figure 2*); several sensors that can measure touch, sound, rotation, light, and distance (*Figure 3*); and programming software for the NXT (*Figure 4*). Using these materials, students would be able to create a large variety of controllers that would be much easier to use than the switch boxes (*Figure 5*), and in the process they would learn programming skills.

Figure 2

Figure 3

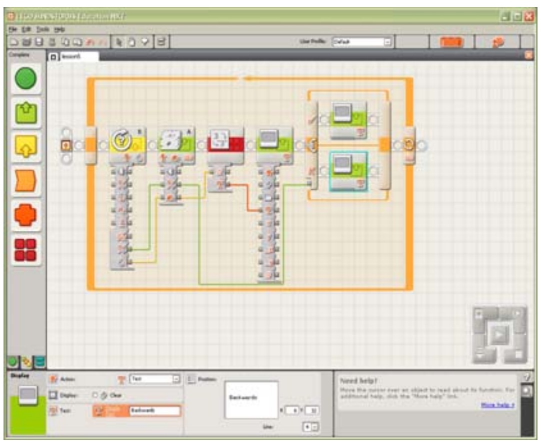

Figure 4

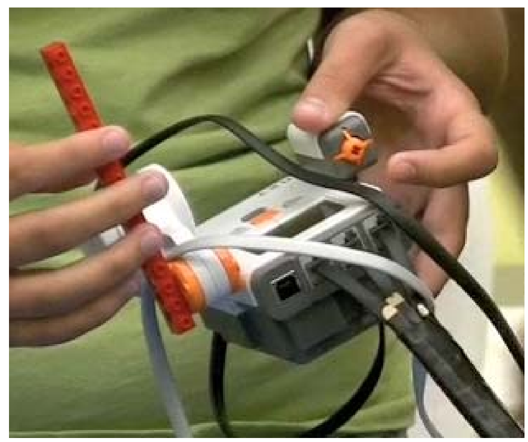

Figure 5

<u>Revised Design Challenges</u>

As in the previous version, the new Build IT curriculum is implemented as a series of challenges, which are described previously. In the NXT curriculum, each challenge now incorporates controller design and programming in addition to the design of the ROV. In order to help students with this extra component, each challenge is accompanied by programming lessons, which progress in difficulty.

In the previous version of the curriculum, there was a Grabber Challenge, in which students built a device that was able to hold on to the submerged wiffle balls. This challenge has been removed, due primarily to the fact that the NXT can only operate 3 motors independently. A grabber would require a fourth motor, so there would be no way to control it apart from the movement of the bot. However, in tests of the curriculum, there have been some teams that were able to build the grabber and control it by linking it to the vertical control. When the bot would go down, the grabber would open, and when it would go up, the grabber would close. Because this is a possible solution, we have shared this with the teachers in our training sessions, so that they may allow their students to try it if desired.

For the majority of groups that will not be building a grabber, picking up the wiffle ball will be a significant challenge. To prevent the final challenge from being too difficult, a “hoop” is attached to the ball to provide a place to hook it. For variety, the hoops are made in two different sizes, large and small, with the smaller hoop being worth more points.

Future Plans for the Curriculum

As the teachers implement the project during the school year, project staff will continue to do research into further development of the curriculum. At this time, the goal is to extend the course to culminate in the building and programming of an autononous underwater vehicle (AUV). This presents several challenges, such as water-proofing LEGO Mindstorms sensors, limiting programming complexity, and choosing realistic and achievable goals for both middle and high school students. We will also explore the possibilities for use in after-school and informal science education settings, as well as exploring impacts on girls’ motivation, engagement, and learning through specialized implementations. Findings from this research will be presented at the professional development sessions, and some teachers who express interest may choose to test out any new materials by extending their courses or running after-school programs.

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