AC 2009-492: ANALYSIS OF MIDDLE- AND HIGH-SCHOOL STUDENTS' LEARNING OF SCIENCE, MATHEMATICS, AND ENGINEERING CONCEPTS THROUGH A LEGO UNDERWATER ROBOTICS DESIGN CHALLENGE

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Analysis of Middle and High School Student Learning of Science, Mathematics and Engineering Concepts Through a LEGO Underwater Robotics Design Challenge

Abstract

The Build IT project is a university-school collaboration to increase precollege student 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 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. During the first year of classroom implementation, 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. This paper will explore the impact of the project on the students, specifically, changes in understanding of the key science concepts embedded in the curriculum and changes in knowledge about, and attitudes toward, engineering. It will also explore gender differences in attitudes toward the engineering aspects of the curriculum and in the pedagogical strategies embedded in the curriculum, including hands-on learning and group work.

Theoretical Framework

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 described cognitive tools or "mindtools"[1] that can enhance the learning process. Others have posited that robotics enables students to creatively explore computer programming, mechanical design and construction, problem solving, and collaboration,[2, 3] as well as the ability to present open-ended problems that require integrative thinking.[4] Robotics enables students to own their learning as they make choices and explore many paths in order to solve design challenges. Through the use of LEGO robotics technology, students learn various facets of problem solving while simultaneously mastering numerous mathematical and scientific concepts.

Riskowski et al. identified three components that engineering design brings to the study of science (in middle school settings), which support our theoretical framework: (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.[5] More specifically, designing robots encompasses elements of the engineering design process, and particularly, iterative design.

Posing open-ended design challenges in the context of designing and testing robotic devices is 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 [6, 7] and science skills,[8] as well as decreasing the achievement gap between some demographic groups.[9, 10, 11] Studies conducted in high school science classrooms using design-based curriculum provide evidence that these activities result in significant gains in student understanding of science concepts [12, 13] and may decrease the achievement gap between some demographic groups.[14, 15] Several studies[16, 17, 18] have documented the impact of educational robotics on student learning of STEM concepts in informal learning environments.

Project Overview

The Build IT project is a collaboration between the Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology and 36 diverse schools in New Jersey and New York to increase precollege student and teacher interest and achievement in engineering, science, mathematics, and information technology. The project utilizes a novel underwater robotics project employing LEGO Mindstorms kits, the NXT programmable brick, and related equipment. The project is being implemented Grade 7-12 in a variety of classroom settings, from science courses, mathematics, to technology education courses, to pre-engineering, to computer courses.

Build IT exposes students to science, mathematics, and engineering concepts, including buoyancy, Newton's Laws, momentum, density, gear ratios, torque, forces, energy, volume, mass-weight distribution, and simple machines. During the first year of classroom implementation, 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 to complete a series of five increasingly complex challenges: (1) a straight-line challenge, in which the remotely-operated vehicle (ROV) must travel the diameter of the pool's surface as quickly as possible 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 in a timed competition; (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 culminating challenge, in which teams compete against each other in an underwater robotics competition to collect and deposit varying-sized and weighted objects into underwater goals. In the second year of classroom implementation, currently underway, students are learning icon-based programming using the NXT-G in order to maneuver their ROVs to complete a similar set of challenges. (See www.stevens.edu/ciese/buildit for more information about the project and www.stevens.edu/ciese/buildit/curriculum.html for lessons, curricular resources and assessments.) The culminating event of the school year was a statewide competition, held at Stevens Institute of Technology, 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. In addition to the ROV curriculum, teachers, students, and guidance counselors were exposed to engineering research, role models, and careers through summer institutes, engineering career awareness days, and presentations by faculty and practicing engineers featuring women and minorities.

Previous papers have reported on the professional development model for teachers; the model's efficacy[19]; and on classroom implementation models and effects.[20] 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 the curriculum to teach concepts covered in the standard curriculum and on the state tests, and 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.

This paper presents findings from our study of student impact, specifically in terms of enjoyment of science, their learning of the specific concepts embedded in the curriculum, and the practice of engineering and problem-based learning practices.

Research Design and Data Sources

A total of 36 schools enrolled in the project, 50 percent of which were the lowest socioeconomic districts in New Jersey (i.e., the A and B District Factor Groups). Forty-one teachers (from all 36 schools) signed up to teach the curriculum in Year 1 and 36 of these (from 31 schools) taught the curriculum to at least one class; one-third taught it twice or more. Because the teachers had the choice of whether to teach the curriculum to some or all of their classes, we used the classroom as the unit of analysis. We collected data from 40 classes, 22 middle school classes and 18 high school classes, although not all classes provided all the requested data. The main goal of the evaluation was to determine if the Build IT curriculum was successful, with success being defined in a number of ways. First, a wide range of teachers—middle and high school teachers with widely differing science and engineering backgrounds and large disparities in the level of prior experience with LEGO robotics—had to be able to teach the curriculum. Second, a wide range of students—males and females, from middle and high schools, from high to low SES schools, with and without a prior interest in science, and with and without prior experience with robotics—had to enjoy the curriculum and learn from it. In terms of learning, success was defined as increased scores on pre/post tests for two key concept areas in the curriculum (gears and buoyancy); increased interest in science; increased exposure to engineering design practices (keeping design logs, understanding the iterative design process, working in teams, and making presentations); and expanded conceptions of the work of an engineer.

The data included here come from the pre- and post-concept tests and from two student surveys--a baseline survey administered before the students engaged in Build-IT activities and a final survey administered at the end of the year. The pre- and post-concept tests were developed by senior project faculty and were tested with both teachers and students in the first summer institute; the responses were analyzed for internal consistency and then revised. These are short tests that include three or four questions designed to elicit fundamental conceptual understandings (or misunderstandings), and including pictures or diagrams rather than just words (See www.stevens.edu/ciese/buildit/curriclum.html for the revised instruments being used in the current year implementation.) The baseline survey was designed to determine students' past experience with the various components of the project, while the year-end survey and pre- and post-concept tests were designed to determine progress. The baseline and year-end survey included many open-ended questions that were coded for analysis.

The totals for each type of data are as follows:

Table 1A: Middle School Data Sources

	Pre	Post	Matched pairs	# of schools	# of classes
Surveys	500	297	264	13	17
Gears tests	512	422	381	13	22
Buoyancy tests	398	359	309	10	14

Table 1B: High School Data Sources

	Pre	Post	Matched pairs	# of schools	# of classes
Surveys	360	305	248	8	10
Gears tests	419	346	334	12	18
Buoyancy tests	418	336	328	11	12

Student Background and Previous Experience

The background survey, administered before the students engaged in the Build IT project, contained a series of questions about the students' attitudes toward school in general and their prior experience with the material covered in the Build IT curriculum in particular.

Attitudes Toward School and Enjoyment of Science

The students were asked how hard they found school, with 1 being "Very hard" and 5 being "Very easy." Only 5 percent of middle school students, but 26 percent of high school students reported that they found school hard (1 or 2 on the scale), but a higher percentage of females than males at both levels found school moderately hard (3 on the scale). Females at both levels also take school more seriously: in their answers to an open-ended question that asked whether they saw gender differences in their math or science classes, both females and males described females as more serious and more intent on working to get good grades.

We wanted to know what impact the project might have on students' enjoyment of science, and therefore asked students in the pre-implementation survey to list their favorite subject. We see that more middle school males than females liked science best, while slightly more high school females than males liked science best:[1]

Table 2A: What subject do you like best?
Middle school

	% of all females	% of all males	% of total
Liked science best	29%	38%	34%

Table 2B: What subject do you like best?
High school

	% of all females	% of all males	% of total
Liked science best	31%	28%	29%

Previous Exposure to Robotics and Science Concepts in the Build IT Curriculum

Aside from forces and motion, which is covered in most middle school curricula, few of the students reported that they had had experience with the other subjects covered by the Build IT curriculum—gears and gear ratios, electrical switches, or buoyancy—with those who had studied these topics heavily weighted toward males. Less than half of middle school students and only about one-third of high school students reported that they had prior experience with robotics, and this was as likely to be at home as at school and was much more likely to have been males than females: 60 percent of middle school males and 40 percent of high school males reported that they had experience with robotics, compared to only 27 percent of middle school and high school girls. Finally, very few of the students had had experience with any type of competition except school-level science fairs.

Because the goals of the Build IT project include integrating both project-based learning (PBL) and engineering practices into the classroom, we asked the students how often they did activities associated with these practices and in which classes. Both middle and high school students reported that they were likely to work in groups or teams, keep notebooks, and make presentations in science and (somewhat surprisingly) in math classes, but few reported that they kept design logs or used PowerPoint to make presentations in any of their classes. While about half of middle school students said they competed in groups in their classes, only about one-third of high school students reported that they did so.

Teamwork

[1] Science included: science, physics (AP, BC, CP), naval science, biology, marine biology.

Since teamwork is another essential component of the Build IT project, the students were asked if they liked working in groups. Middle school students reported enjoying group work "very much" more than high school students (42 percent compared to 34 percent), while there were more students at both levels who reported that they enjoy working in groups only somewhat (47 percent at the middle school level compared to 57 percent of high school students). In this case, there were no gender differences between males and females.

The survey also asked the students, in an open-ended question, what problems they had with group work. The problems they listed suggested the difficulties they had turning groups into functioning teams. For the middle school students, the issues were most often related to emotions (too many arguments, too much socializing, dislike of individual team members), while for the high school students the issues focused more on problems getting the task done, with the dislike of "free-riders"--students who do not pull their own weight—accounting for almost half (43 percent) of the complaints, compared to only 17 percent of the complaints for middle school students.

Conceptions of Engineering

When students were asked, in an open-ended question on the pre-survey, to define what an engineer is, they showed a very narrow conception of the kinds of work engineers do. While about two-thirds of the middle school students wrote that engineers design and build, almost one-quarter thought they "fixed things" and most thought that the things they designed, built, or fixed were cars, machines, electronics, or other mechanical objects. Very few mentioned the thinking part of engineering, including solving problems, testing designs, or improving life for people. There were no major differences between males and females.

Based on results of the pre-test, we found that high school students had a somewhat more sophisticated understanding of what engineers do. Building and designing were also included in most of their lists, but designing was mentioned much more frequently than building (64 percent compared to 18 percent), and "improving life" and "solving problems" were on their lists as well (38 percent). Females tended to emphasize designing over building and males to do the reverse, but more important in terms of understanding the profession, males were twice as likely as females to mention the problem-solving aspect of engineering. These results may in part have been because the high school student data include a large number of students at schools that focus on science and engineering.

Finally, the survey asked the students about their ambitions. In the pre-survey, seventy-five percent of middle school females and 81 percent of middle school males reported that they planned to attend a four-year college, while almost all of the high school students said so (we suspect this was attributable to the types of high schools in the program). When asked to list two occupations that they would like for themselves, even the middle school students had ambitions that would need advanced degrees. By far the most popular professions for middle school students were medical—doctors of all types, including surgeons, pediatricians, and dentists—as well as many veterinarians. Scientists and engineers were further down the list. For the high school students, in contrast, engineering topped the list, followed by various kinds of scientific research and various kinds of medicine.

Post-Implementation Findings

Based on the post-implementation survey administered to students, we found that, overall, the students rated the curriculum highly in terms of both learning and of enjoyment. Eighty percent of middle school students gave the project an A or B in terms of how much they felt they learned and 72 percent gave it an A or B in terms of how much they enjoyed it. Students in the lowest SES schools gave higher ratings than students in other schools in terms of learning and still higher ratings in terms of enjoyment. This finding may illustrate that the lower SES schools in the study do less hands-on PBL activities than higher SES schools. Overall, females assigned higher grades than males to the Build IT curriculum's impact on their learning than males, while males gave higher grades in terms of enjoyment. This is consistent with attitudinal data reported in a previous section describing females as being more serious than males about their school work.

As for high school students, 78 percent of those who responded to the survey gave the project an A or B in terms of how much they learned and 82 percent gave it an A or B in terms of how much they enjoyed it. Females again gave higher grades than males in terms of learning and males again gave higher grades in terms of enjoyment. And, as with the middle schools, students in the lowest SES group high schools gave the curriculum higher grades than students in higher SES schools in terms of both learning and enjoyment.

In the pre-survey, when students were asked which subjects they liked best, science had not scored well and the percent did not increase on the post-survey. However, if we look only at those students in middle school science classes where Build IT was taught,[2] the percent that reported that they liked science best increased (even though they were more likely to have reported that they liked science best in the pre-survey). This change was due to a dramatic increase among girls:

Table 3: Change in Percent of Middle School Students in All Classes and in Science Classes that did Build IT Who Liked Science Best, By Gender

	% of all students	% of students in science classes	% of females in science classes	% of males in science classes
Pre-survey	34%	44%	40%	47%
Post-survey	35%	**50%**	**58%**	42%

When the students were asked, in an opened-ended question, what they had liked best about the project, the middle school students tended to focus on the building aspect. For the middle school males, the attraction of designing and building was in large part due to the hands-on and open-ended aspect, a key element of problem-based learning:

- It was hands on and it is a lot more effective than lab books.
- How different it is compared to other classes and it is fun.

[2] We cannot do this at the high school level, where Build-IT was mostly taught in pre-engineering and computer/technology classes.

- How we got to explore robotics and see how it worked - it inspired me.

For the females, it was this but also the fact that they were able to be creative:

- That I got to design robots and think technically and physically. I liked that we were able to have freedom with it. There was no specific design we had to follow.
- I loved creating something and having it perform tasks right in front of me.
- The feeling of creativity--inventing allows you to see how it works.
- Working without a teacher, having to just figure out things on our own.

While many of the high school students also focused on building, they were less likely to focus on building alone and more likely to also use the terms "designing" and "creating":

- How one can design something, then create it and then make it.
- The fact that we were able to create a workable robot (design, construct, etc).
- We had to be creative, while building a vessel that actually worked.
- The design and actual building aspect of the project.

The high school students, both males and females, also liked the fact that they had to solve problems on their own, without having to follow books or rely on teachers:

- I liked that we really didn't have to follow a specific design. We did what we wanted.
- I liked that it was more hands-on rather than a lot of written work like my other classes.

Many middle and high school students specifically mentioned that they liked the testing aspect. Their responses show that they understood the essential elements of iterative design, even if (as we shall see below), they did not necessarily know the term or could not quite put it into words:

- I enjoyed trying the robot out each time I made a change to see if it worked.
- Making mistakes and learning from them.
- Testing to see how we could make our robot better!
- I liked the fact that we had to solve problems and better the ROV after each test.
- I liked trying to create the working structure and improve from design to design.

Although many students had reported problems with turning groups into functioning teams, it is noteworthy that many students specifically noted that they enjoyed working in teams in this project. It is also important that by high school, students were welcoming other people's ideas, rather than seeing them as a cause for argument:

- What I liked most about robotic project was that it taught us how important teamwork is.
- I liked working in a group and helping create a robot with my team.
- The part that I like about it the most [was] working together to build it.
- I liked working and building with my team.
- I mostly liked the challenges I faced in this program and the teamwork we had to do.
- Problem solving with a group.

Student Learning of Concepts

The students' learning of the three key concepts involved in the Build IT curriculum—gears, buoyancy, and electricity—were assessed through pre- and post-tests for each concept. Since only a few teachers used the electricity tests, they will not be analyzed here.

In general, although the high school students did somewhat better on the gears pre-test than the middle school students, neither group did well (mean score for all middle school classes of 1.72 out of 4 compared to mean score for all high school classes of 2.11). However, there was no correlation between the pre-test scores and the SES of the students' schools, for either middle school ($r = .169$) or high school ($r = .148$).

The mean class scores increased by almost 40 percent from pre-test to post-test. A paired t-test shows that the increase was highly significant:

Table 4A: Impact on Concept Understanding: Gears

Assessment	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	1.8833	30	.47856	.08737
Post-test	2.6267	30	.66898	.12214

Table 4B: Paired Samples Test

	Mean	Std. Deviation	Std. Error Mean	T	Df	Sig. (2-tailed)
Gears pre/post	-.7433	.55316	.10099	-7.360	29	.000

Few middle or high school students had previously learned about buoyancy, and this was reflected in the mean class scores on the pre-tests (0.57 for all middle school classes and 1.06 for high school). Buoyancy scores increased by 33 percent from pre- to post-test. A paired t-test again shows that the increase was highly significant:

Table 5A: Impact on Concept Understanding: Buoyancy

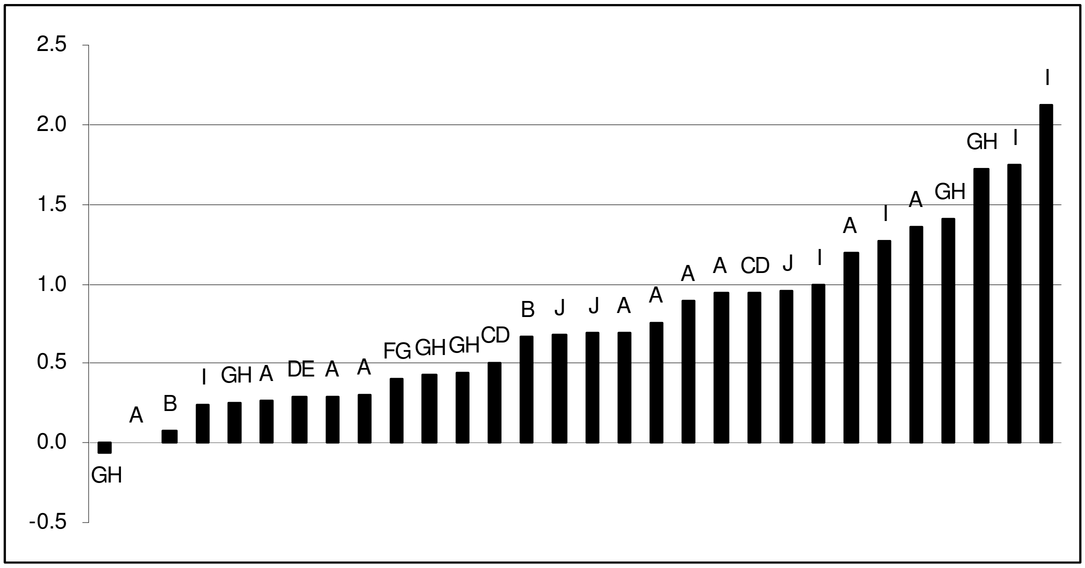
Assessment	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	.9280	25	.45873	.09175
Post-test	1.8880	25	.69541	.13908

Table 5B: Paired Samples Test

	Mean	Std. Deviation	Std. Error Mean	T	Df	Sig. (2-tailed)
Buoyancy pre/post	-.96000	.70059	.14012	-6.854	24	.000

As with pre-test scores, there was no correlation between a class's mean post-test scores and the school's SES (for middle schools, r = .193, for high schools, r = .557). In other words, students from lower SES schools were as likely to do well on the post-tests as students in high SES schools, particularly at the middle school level. There was instead great variability from class to class, both across schools and even within one school. For example, when we look at gain scores on the gears test, we see large gains in classes in all District Factor Groups, from A (the lowest) to J (the highest):[3]

Figure 1: Gear test, mean gain scores for all classes



The same pattern (or lack of pattern) holds true for the buoyancy tests, and for both middle and high school.

Changes in Engineering Practices and PBL

The Build IT curriculum was taught in science classes and in technology-related courses (i.e., Computers, Industrial Arts, Technology) at the middle school level and in Physics, Pre-engineering, and Technology-related courses at the high school level. Although the project cannot take total credit for changing the degree to which students reported that they engaged in project-based learning or engineering-related practices in their classrooms, it can at least take partial credit for the change in those classrooms where Build IT was taught.

As noted earlier, on the pre-survey, middle school students in Science courses that integrated the Build IT curriculum did not differ materially from students who did not do Build IT in terms of such project- and engineering-related activities as working in groups or teams, competing with other teams, keeping notebooks and design logs, making presentations, and using PowerPoint in presentations. By the end of the year, however, middle school students in science classes that integrated Build IT were much more likely to report that they competed in teams and kept design logs than students in science classes that were not participating in Build-IT activities. Similarly, although middle school students in Computer/Technology classes were somewhat more likely to participate in these types of activities than the entire set of students at the beginning of the year, more students kept design logs, made presentations, and used PowerPoint

[3] In New Jersey, District Factor Groups run from A (the lowest) to J (the highest) and include some combinations (CD and GH).

in these presentations in Build IT classes at the end of the year than at the beginning, outstripping the rest of the students in these activities.

For the high school students, there was a large increase in the percentage of students in Science and Computers/Technology classes in terms of competing in teams, keeping design logs, and making presentations, with the changes in the Computers/Technology classes dramatic enough to suggest a major change in teaching practice. In Pre-engineering, students in the classes that implemented Build IT already did more of these activities than students in other Pre-engineering classes; the major change was in the amount of competition.

<u>Conceptions of Engineering (Post-Implementation)</u>

The year-end survey repeated the question on the pre-survey that asked the students to define what engineers do. While middle school students were even more likely than on the first survey to refer to designing and building, they were no longer writing as much about building structures, cars, and machines and writing more about building things that would improve life for people. In addition, many fewer wrote that engineers "fix things" and many more wrote that they solve problems. There was very little difference by gender. High school students continued to list designing and building, although they were much more likely to link them. In addition, some mentioned applying math or science, which none had done on the baseline survey. As with the previous responses to this question, girls were more likely to stress design and boys to list solving problems, while more girls than boys mentioned improving life for people.

The final survey for high school students asked specifically for a definition of the iterative or engineering design process. Only 65 percent of the students attempted to answer the question. Sixty percent of these described what they thought an engineer does, with a heavy emphasis on such steps as brainstorming ideas, finding solutions to problems, modeling, and (for a few) documenting:

- Research + investigate a problem and brainstorm a solution, then design it.
- Research, brainstorm, investigate, and design/ construct.
- The process of bringing an idea from paper to reality.
- Engineers get ideas, build designs, and make their inventions.
- The keeping of logs and passing certain milestones till moving on to the next stage.
- The engineering design process is the process of thoroughly documenting designing something to be built for use.

Forty percent of the students who attempted to answer the question—and therefore only 26 percent of all students—described the iterative aspect of engineering design process, although they did not use that term:

- Find a problem, learn about it, make a solution, test it, evaluate it.
- Think, design, redesign, redesign, redesign...
- It's the process of doing things over and over to see if your idea works.
- You build something then check, modify if needed, then check again.
- Research, brainstorm, solution, rejection, final solution, build it.

As noted previously, many students had written that one of the aspects of the Build IT project that they liked best was the testing. All these responses suggest that the students were engaging in iterative design without being aware of it or being able to put a name to it.

The final survey also repeated the question about career plans. Although the medical professions remained the highest category among middle school students, they declined as a percent of all choices, while the job category of engineer doubled as a percent of all choices:

Table 6A: Change in Career Choices
Middle School

	Baseline	Final survey
Doctor, dentist, surgeon, veterinarian	38%	32%
Teacher	17%	11%
Lawyer	13%	12%
Scientist	13%	11%
Engineer	**11%**	**21%**
Sports-related	9%	11%
Computer-related	6%	8%
Architect	5%	4%

However, although the number of females who chose engineering as a possible career also almost doubled, from 6 to 11, it was still a small fraction of the whole.

Engineering had been the most popular career choice among high school students at the beginning of the year (we believe this is due to the fact that much of the data comes from students in pre-engineering courses), but this percentage nevertheless increased about 25 percent over the course of the year:

Table 6B: Change in career choices
High school

	Baseline	Final survey
Engineer	**34%**	**42%**
Scientist	26%	23%
Doctor, dentist, surgeon, veterinarian	25%	21%
Teacher	11%	10%
Computer-related	8%	9%
Architect	7%	4%
Lawyer	4%	6%
Sports-related	2%	4%

Furthermore, while at the beginning of the year only 25 percent of those high school students who chose engineering were females, the percentage had increased to 30 percent by the end of the year.

Discussion and Next Steps

Student data, including attitudinal and conceptual learning data, suggests that the Build IT curriculum has increased student awareness of engineering, their interest in engineering careers, and their understanding of the engineering design process and iterative design. In addition, understanding of key concepts embedded within the curriculum increased significantly, although there was considerably variation among participating classes.

These findings have suggested opportunities to improve the curriculum, both by making more explicit some of the underlying concepts that guide the behavior of the ROVs and by deliberately using specific terms—such as iterative design—to describe the process of designing-building-testing and redesigning the ROVs. These and other improvements have been added to the curriculum and are being used by teachers in the current implementations and will be assessed after the Year 2 classroom implementation, taking place in the 2008-2009 school year.

Further, this year's implementation has added a programming component, utilizing LEGO Mindstorms™ materials. These kits include a programmable device, called the NXT; several sensors that can measure touch, sound, rotation, light, and distance, and programming software for the NXT. Using these materials, students will be able to create a large variety of controllers that will be much easier to use than the switch boxes, and in the process they will learn programming skills. We will be measuring students' growth in programming at the conclusion of the school year as well. We will also be exploring the factors that led to such variability among classrooms.

Conclusion

In the book, *Educating Engineers*, Sheppard et al. articulate a vision of "networked engineering education," in which students learn by experiencing an interconnected web of theoretical, practical, contextual, and other knowledge, and which is designed to orient students toward a professional practice in which engineers increasingly grapple with complex, ill-defined, problems that encompass technical and non-technical aspects. The authors describe the transformation of engineering education that is needed to prepare "new-century engineers" as integrative: it supports synthesis of knowledge, requires strong analytical skills, and cultivates mental habits of practical ingenuity, problem-definition, persistence, creativity, communication, and teamwork.[21] Further, a number of studies have demonstrated that science factual knowledge and higher levels of thinking as evidenced in responses to open-ended questions increased in classrooms where the subject matter was presented in the context of an engineering design project.[22, 23] It is precisely these types of learning experiences—targeting conceptual understanding of science topics and "new engineer" workforce skills—that we are seeking to provide for students through the Build IT curriculum.

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Bibliography

[1] Jonassen, D. (2000). Computers as mindtools for schools. Engaging critical thinking (2nd ed.). Saddle River, NJ: Prentice Hall.
[2] Chambers, J. & Carbonaro, M. (2003). *Designing, Developing, and Implementing a Course on LEGO Robotics for Technology Teacher Education*. Journal of Technology and Teacher Education. 11 (2), pp. 209-241. Norfolk, VA: AACE.
[3] Portsmore, M.D. and Rogers, (2004). C., Bringing Engineering to Elementary School. Journal of STEM Education. Vol 5. 2004.
[4] Beer, R., Chiel, H. & Drushel, R. (1999). Using *automonomous robots to teach science and engineering*. Communications of the ACM. 42(6), pp. 85-92. New York, NY.
[5] Riskowski, J., Todd, C., Wee, B., Dark, M., & Harbor, J. (2009). *Exploring the Effectiveness of an Interdisciplinary Water Resources Engineering Module in an Eighth Grade Science Course.* International Journal of Engineering Education. Vol. 25, No. 1, pp. 181-195.
[6] Mehalik, M. M., & Doppelt, Y., & Schunn, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. Journal of Engineering Education, 97(1), 71-85.
[7] Hmelo, C.E., Holton, D.L., and Kolodner, J.L. (2000). Designing to Learn About Complex Systems. *The Journal of the Learning Sciences*. 9(3): 247-298.
[8] Kolodner, J.L., Camp, P.J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., and Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ Into Practice. *The Journal of the Learning Sciences*. 12(4): 495-547.
[9] Cantrell, P., Pekcan, G., Itani, A., & Velasquez-Bryant, N. (2006). The effects of engineering modules on student learning in middle school science classrooms. *Journal of Engineering Education, 95*(4), 301-310.
[10] Cantrell, et. al. (2006).
[11] Riskowski et al. (2009).
[12] McGrath, E., Sayres, J., Lowes, S., Lin, P. (2008). *Underwater LEGO Robotics as the Vehicle to Engage Students in STEM: The BUILD IT Project's First Year of Classroom Implementation***.** American Society for Engineering Education Mid-Atlantic, Hoboken, NJ, October 2008.
[13] Fortus, D., Dershimer, R. C., Krajcik, J. S., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching,41*(10), 1081-1110.
[14] Klein, S., and Geist, M. (2006). The Effect of a Bioengineering Unit Across High School Contexts: An Initial Investigation in Urban, Suburban, and Rural Domains. New Directions in Teaching and Learning. 108: 93-106.
[15] Klein, S., & Sherwood, R. D. (2005). Biomedical Engineering and Cognitive Science as the Basis for Secondary Science Curriculum Development: A Three Year Study. *School Science and Mathematics, 105*(8), 384-401.
[16] Gura, M., & King, K. P. (2007). *Classroom robotics: Case stories of 21st Century instruction for millennial students.* Charlotte, NC: Information Age Publishing.
[17] Nourbakhsh, I., Crowley, K., Bhave, A., Hamner, E., Hsium, T., Perez, Bergquist, A., Richards, S., & Wilkinson, K. (2005). The robotic autonomy mobile robots course: Robot design, curriculum design, and educational assessment. Autonomous Robots, 18(1), 103-127.
[18] Nugent, G., Barker, B. & Grandgenett, N. (2008). The Effect of 4-H Robotics and Geospatial Technologies on Science, Technology, Engineering, and Mathematics Learning and Attitudes. In *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2008* (pp. 447-452). Chesapeake, VA: AACE.
[19] McGrath, E., Lowes, S., Lin, P., Sayres, J., Hotaling, L., Stolkin, R. (2008). *Build IT: Building Middle and High School Students' Understanding of Engineering, Science and IT through Underwater Robotics.* American Society for Engineering Education Annual Conference & Exposition Proceedings, Pittsburgh, PA, June 2008; 2008-781.

[20] McGrath, E., Sayres, J., Lowes, S., Lin, P. (2008) *Underwater LEGO Robotics as the Vehicle to Engage Students in STEM: The BUILD IT Project's First Year of Classroom Implementation.* American Society for Engineering Education Mid-Atlantic, Hoboken, NJ, October 2008.
[21] Sheppard, S, Macatangay, K., Colby, A. & Sullivan, W. (2009). *Educating Engineers: Designing for the future of the field.* Jossey-Bass: San Francisco, CA. pp. xxii, pp. 6-9
[22] Riskowski et al. (2009).
[23] Cantrell et al. (2006).