AC 2010-457: USING ROBOBOOKS TO TEACH MIDDLE SCHOOL ENGINEERING AND ROBOTICS

Morgan Hynes, Tufts University

David Crismond, The City College of New York

Ethan Danahy, Tufts University

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Abstract

This paper reports on the initial testing and use of an innovative curriculum delivery tool called RoboBooks. RoboBooks is an interactive, digital workbook environment that integrates robotics-programming environments with reporting and analysis tools. The team developed an innovative middle school curriculum designed to introduce students to the engineering design process by asking them to create a LEGO robotic shopping cart of the future. The curriculum built upon the principal investigators' prior work in this area, and addressed the need for scaffolding students through the robotics programming to reduce the technical/troubleshooting load on the teacher. The team hosted a weeklong teacher professional development program to introduce teachers to teaching engineering design with the RoboBooks tool. The paper reports on the teachers' engineering design self-efficacy using a validated survey tool in a pre-test/ post-test design.

The Need

Involving students in solving problems, both well- and ill-defined ones, is one way to build deep understandings of STEM concepts and process skills. Such work helps avoid the creation of "inert knowledge" that has little chance of being used when real needs arise[1]. An engineering design task can serve in this mission as a "goal-directed problem-solving activity"[2], and involves optimizing parameters[3] and balancing trade-offs[4] to meet targeted users' needs [5]. Design activities are aligned with a wide range of educational reform efforts in science, math, and technology education in that they involve (a) doing practical work, (b) making connections among disciplines, and (c) pursuing ways of knowing the world and how it works.

Many instructional materials have been developed over the last 20 years that introduce engineering and the engineering design process (EDP) to K-12 students and that have aimed to contextualize and motivate STEM subject learning through design tasks (e.g., the Infinity Project, Project Lead The Way, Learning By Design, LEGOengineering.com). State standards in Massachusetts and New York include engineering design among the basic process skills students must learn. New materials are needed that scaffold students with as-needed content-based tutorials, support team-based design work, and help student avoid common pitfalls when designing. Common pitfalls include students: doing "idea fixation"[6], where design ideasremain unchanged over multiple iterations; not doing meaningful research, which could lead to better design plans[7]; creating "design diaries" that fail to capture the evolution of their design thinking from concept to final product, and missing the benefits of rich feedback from product testing.

The educational infrastructure available to support this "renaissance in design" is inadequate. Very few science teachers have training in engineering design, do not see themselves as designers, and are unaware of the unique pedagogical content knowledge [8]that teachers need to know to support using these tasks with students. School systems need special supports and programs that can help teachers guide their students with even less experience or knowledge of design's procedures, concepts, and skills than they have, and connect their own discipline knowledge with the engineering science ideas needed to solve design problems. As defined in an NSF-sponsored 2007 national symposium on the topic, there is a "need to develop, pilot test, refine, and deploy professional development models" that can help STEM teachers develop the capability to infuse engineering into K-12 classrooms[9]. Developing such models can enhance the "pipeline" by getting students excited about STEM careers, in particular those related to engineering.

Partnerships between K-12 and engineering schools may help in improving students' preparation for careers in engineering. Creating materials and contexts that support a *scalable* model for such partnerships would serve to improve this pipeline and the STEM community even more. Such collaborations involve players whose worlds of work both involve education, but engage quite different cultures of learning and clienteles. Finding ways to enhance communication between the engineering and K-12 spheres may make such partnerships more enduring and better able to help students achieve greater success in engineering education.RoboBooks might be such a tool that enables K-12 teachers, curriculum developers, and professional development specialists to communicate with college engineering faculty or industry engineers in developing curriculum that considers both pedagogical and technical perspectives. The RoboBooks platform, described in more detail in the next section, provides teachers a curriculum tool that reduces the load of student questions by scaffolding students through basic technical issues that arise within a LEGO-robotics learning environment. Thus, they are freed up to address more questions that address student learning.

Robobooks

The RoboBook platform developedat the Tufts Center for Engineering Education and Outreach (CEEO),is a digital portfolio that supports the development and modification of curriculum that takes the form of a digital, interactive LEGO-based workbook product. The RoboBook supports users in programming a LEGO robot they construct and that is connect to and can be controlled via computer. The RoboBook provides information, tutorials and videos on background STEM concepts and skills needed to solve robotics-related engineering design challenges. The main idea is to extend the power of a wiki (which builds and shares portfolios of text, graphics, and multimedia) to include live data feeds, plotting and analysis, robot programming, and direct robot control. The RoboBook supports students in understanding the relevant science and engineering concepts associated with the curriculum.

As a learning system, a RoboBook is a customizable digital workbook that supports students in learning and using the LEGO robotics toolset, learning and applying key STEM concepts, conducting "fair-test" experiments on the prototypes they develop, and building capability in doing and reflecting upon engineering design. Linking the robotics hardware to the computer provides students with critical, immediate feedback regarding their programming ideas and the devices and structures they create. The RoboBooks software tools enable students to store digital notes, photos and videos as they proceed with their designing. Such records can support students in doing meaningful assessment of their designs, do reflective writing about their decisions, and communicate with others about their design work and final process in ways that go far beyond a "veneer of accomplishment" [10] often seen in design portfolios [11].

Robocart(Robobooks curriculum)

The Tufts/City College of New York teamadapteda piece of paper-based, middle-school engineering curriculum previously developed by Hynes (NSF Award#DRL-0423059; see www.LEGOengineering.com)resulting in the new Robocart curriculum. The previous curriculum hadbeenshown effective in addressing middle-school engineering standards[12], where teachers were successfully implemented it with studentsin after-school programs.

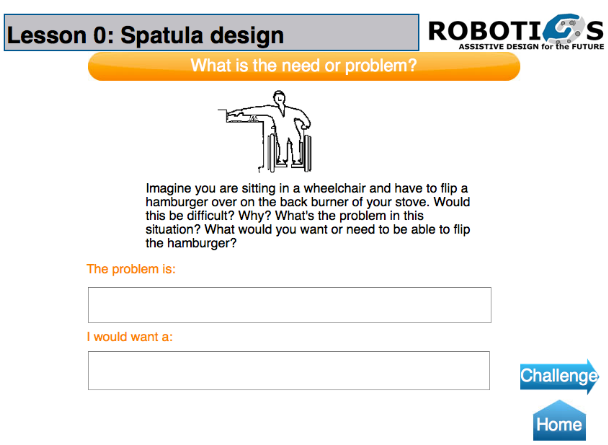
The pedagogical model (see table 1 below) was used in developing the instruction and activities for the Robocart curriculum, which sharesmany features of Bybee's 5E pedagogical model[6]. By building upon and improving thepreviouscurriculum, the development of the Robocart curriculum focused on making strong connections with STEM concepts, integrating the RoboBook's data collection and display capabilities, and building formative assessment strategies seamlessly into the RoboBooks.

Table 1. Robocart curriculum pedagogical model

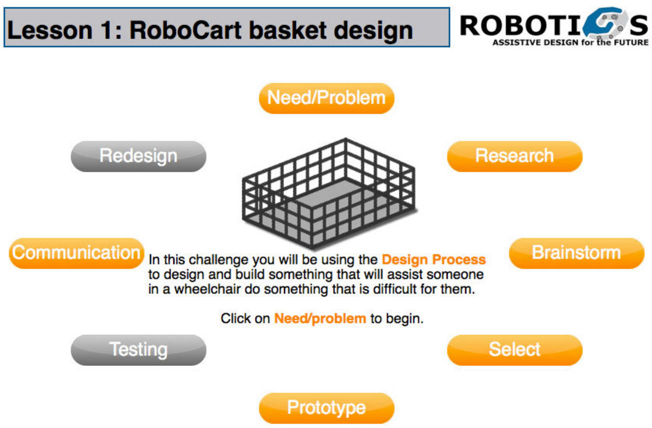
Bybee's 5E Model	**Instructional Model for StudentRoboBooks**
Engage	Review design brief, understand problem context
Explore	"Mess about" with LEGO structures, programs, and sensors.
Explain	Learn how the device work; Plan "fair tests" to explore key design variables, variations on programs
Elaborate	Plan solutions and describe product's preferred behavior
	Diagnose and iteratively improve prototype
Evaluate	Conduct final tests and give presentations

The planned RoboBookcurriculum starts off by presentingstudents with a design brief that outlines the main design challenge to create a shopping cart for the future. The shopping cart would be a remotely controlled robotic cart designed to travel from the user's home to the store hauling an empty wagon, navigate through the store to select desired items and deliver them to the stationary wagon, and then return to the user's home hauling the heavily-loaded wagon. Before jumping into solving the main design challenge, students solve mini more constrained design challenges scaffolding them up to the main design challenge. For example, one challenge tasks the students with designing and building a spatula out of LEGO materials, which provides students an opportunity to become familiar with the LEGO pieces and connections. In the lesson, students also learn the physics of torque and bending while attempting to optimize the trade-off between length and strength since their score is based on both length and strength (length – constant x # of discrete weights). Students then learn about constructing a basket for their Robocart, testing and selecting a controller for their Robocart, and then synthesizing all that they have learned into creating their final Robocart, which they test competition-style in the culminating lesson.

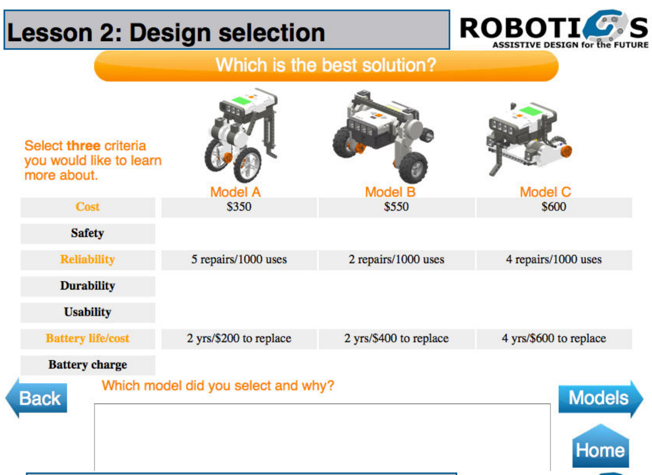
The following narrative highlights specific RoboBooks capabilities that were integrated into the curriuculum.



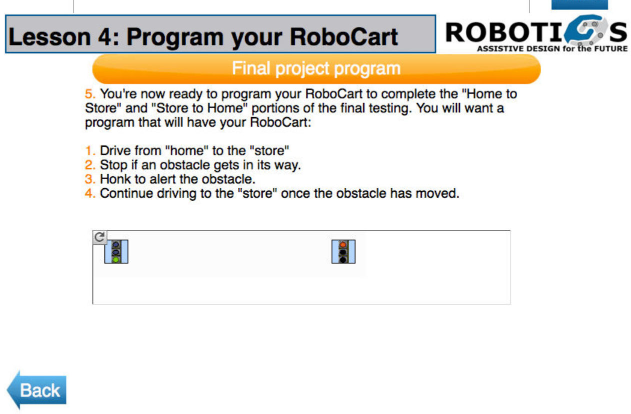
A. The RoboBook's introductory pages engage students with a design brief for the lesson's design challenge. Movies, pictures, and a relevant story help create a context for the students where they will act as engineers and solve real problems with sophisticated technologies.



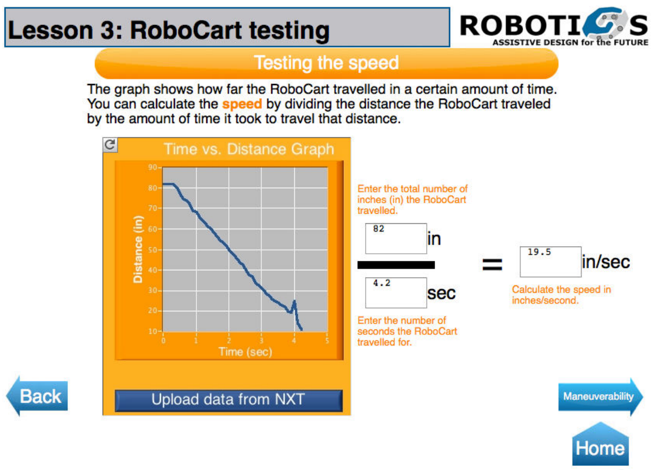
B. One of the RoboBook's main navigational pages uses an interactive "Engineering Design Process" map, which students can click on to get support doing different design processes. For instance, selecting the Research link will provide them with tutorial pages on the needs of users, digital movies on the stability of structures, and webpages on the strength of structures (needed to build the Robocart basket). This particular process map can be replaced so that the RoboBook displays the design model found in the state or local standards.



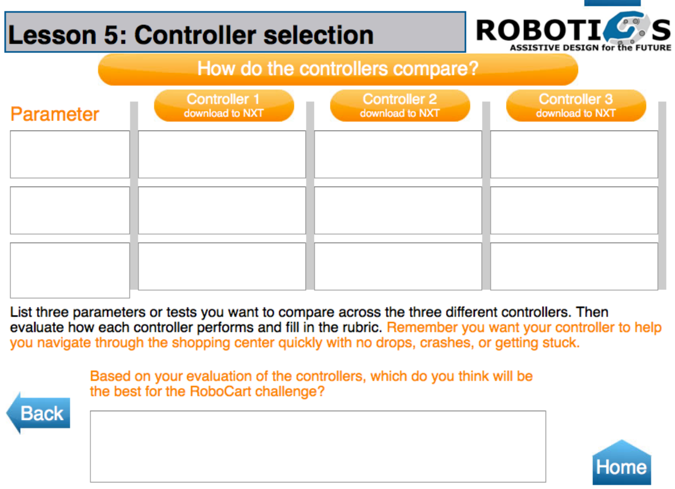
C. AnotherRoboBook section guides students in selecting the best solution. In the case of selecting the best sample cart drive-train, the RoboBookpresents students with a number of property variables which they can base their decision on. However, the RoboBook restricts the students to selecting three of the seven variables to view and then base their decision (akin to the real world where cost limits the number of tests a prototype undergoes.



D. The embedded programming environment assists students with programming basics and then testing and quickly modifying simple programs via the linked physical prototype that gives students instantaneous feedback and control. Students can program their Robocart to follow achieve the various missions of the challenge. For teachers that wish to spend less time on programming with their students, they can choose to embed previously created programs.



E. Using their working prototypes, students can enact the Test and Evaluate step in the design model right from the keyboard. Sensors provide data on their robot's performance. RoboBook can portray this data as a spreadsheet or dynamic graph with plots of points. Student groups can compare results of different iterations of their own prototype, or the designs of other groups, and save these results for their final presentations and reports.



F. Data collected by students working individually or in teams is stored both in the RoboBook, allowing students to ask questions and interpret their data, while building an understanding of how the device works. Students can correlate these views of test data with videos shot of product tests, all of which can support students' diagnostic reasoning about their current design. The RoboBooks compiles all student-made images, movies, data for review by teachers, parents, or other students in the classroom.

Teacher engineering design self-efficacy

The one-week teacher professional development (PD) workshop held at Tufts was developed as a partnership between Tufts, City College of New York, and Boston Public Schools. Teachers were recruited from BPS to participate in the workshop and all consented to participate in research surrounding the use of Robobooks and the EDP. The primary focus of the workshop was to show teachers how to use the RoboBooks software to teach the Robocart curriculum to their students. To do this, the PD team modeled the teaching of the Robocart curriculum engaging the teachers as students in the curriculum. Beyond the lessons included in the Robocart curriculum, the PD team led sessions that delved deeper into specific portions of the EDP (i.e., evaluating constraints, optimizing trade-offs, and the science of gears).

The primary goal of increasing the teachers knowledge of the EDP was based upon the notion that a teacher's knowledge of the content they are teaching influences their ability to teach [13-15] and can directly relate to student achievement [16]. Furthermore, a teacher's content knowledge impacts their teacher self-efficacy, "a teacher's belief in her or his ability to organize and execute the courses of action required to successfully accomplish a specific teaching task in a particular context" [17]. Hoy and Davis [18] describe teacher's self-efficacy as a cyclical process where high teacher self-efficacy leads to more diligent preparation leading to better students outcomes, and back to higher teacher self-efficacy. The opposite is also true where low teacher self-efficacy leads to poorer student outcomes. Furthermore, a teacher's beliefs about content, when incongruent with the intended curriculum design, can hamper the implementation of the curriculum [19]. Similarly, poor teacher self-efficacy within a subject can lead to less effective curriculum implementation, and, even worse, lower student efficacy in that content area [20].

The project team did not have a validated tool to measure the teachers' EDP content knowledge, but were able to use a newly validated tool to measure the teachers EDP. The Engineering Design Self-efficacy Survey developed by Carberryet al.[21]measures one's self-efficay, motivation, expectancy, and anxiety towards carrying out the EDP. The tool was developed to discern individuals self-efficacy towards the EDP and was applied to groups ranging from little to no engineering background to experts in the field (professional engineers and engineering professors).

Results

The teachers who participated in the summer workshop each took the Engineering Design Self-Efficacy Survey (EDSES) pre-survey on the first morning of the workshop and then an identical post-survey on the last day of the workshop. Prior to administering the survey, the hypothesis among the research team was that the teachers would likely fall within what Carberry et al. [21] categorized as having*intermediate self-efficacy*, which was described as current learners of engineering (undergraduate engineering students) or non-engineers with science backgrounds. This hypothesis was based on the fact that the majority of the teachers in the workshop taught science, and thus had science backgrounds, and for those that did not teach science (two taught computer courses) fit better in this category than the *low self-efficacy* group since they have ongoing exposure to technology. We could not validate the survey for our specific group of only eight teachers; however, since Carberry et al.[21] validated the survey for a number of groups Along with this hypothesis, the research team hypothesized that the workshop, which focused on teaching the teachers about the EDP and giving them opportunities to apply the process would increase their engineering design self-efficacy. With the data in hand, the team then ran a matched-pairs t-test (one-tailed) to confirm the hypothesis.

Table 2 Results from the Engineering Design Self-Efficacy Survey

EDP Measure	Pre-test prior to workshop	Post-test after workshop	Change
Self-efficacy	70.3(23.70)	87.0(9.47)	16.7*
Motivation	84.7(11.35)	88.9(8.46)	4.2*
Expectancy	73.4(14.82)	84.5(9.04)	11.1*
Anxiety	39.8(33.14)	12.9(12.18)	-26.9*

*significant at $p<.05$

Table 2 displays the results from the pre- and post-surveys for the four different constructs measured by the survey. Positive changes for *Self-efficacy, Motivation,* and *Expectancy* and a negative change for *Anxiety* would point to an improvement among the teachers and their affect toward the EDP. The results for all four measures show a statistically significant ($p<.05$) improvement suggesting that the teachers' participation in a one-week professional development workshop using RoboBooks to learn and apply the EDP can significantly improve their personal view of implementing the EDP. Compared to Carberry's et al. results (see figure below), the teachers, as a group, jettison from being between the *Intermediate* and *High* groups before the workshop to higher (lower in the case of *Anxiety*) than the *High* group after the workshop. It is important to note that this is a measure of one's beliefs about themselves and in no way implies that the teachers would be better at engineering design than the professional engineers of the *High* group. However, it is promising to see that teachers greatly improve their self-efficacy, motivation, expectancy, and anxiety relating to engineering design in a one-week workshop, and hopefully leads to the teachers being more apt to teach engineering and the EDP in their classroom.

	Self-Efficacy		Motivation		Expectancy		Anxiety	
Group	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
High	80.14	17.04	81.64	17.80	78.77	15.09	38.77	30.23
Intermediate	54.35	25.95	63.48	29.07	53.70	26.38	49.46	25.31
Low	21.89	26.34	21.35	26.05	21.89	25.80	62.16	30.20

Table II: Mean ED scores with standard deviations for experience analysis.

Figure 1 Table from Carberry et al.[21]validation results for *high, intermediate,* and *low self-efficacy groups.*

Conclusions

The RoboBooks curriculum delivery tool successfully introduced teachers to a new engineering-focused middle-school curriculum, and provided them with a tool to assist them in delivering a curriculum employing LEGO robotics. The preliminary research results measuring the participating teachers' engineering design self-efficacy revealed that the one-week professional development workshop was effective in improving their engineering design self-efficacy, and quite possibly their willingness and effectiveness in teaching the Robocart curriculum with their students. Further data remains to be collected and analyzed in January/February 2010 regarding the teachers' implementation of the curriculum in their classrooms.

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