

Curriculum Exchange: Middle School Students Go Beyond Blackboards to Solve the Grand Challenges

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Abstract

Our program offers an integrated approach to engaging middle school students in activities that improve awareness and understanding of a range of STEM college and career pathways. The program is framed within the *Grand Challenges of the 21st Century* identified by the National Academy of Engineering (NAE). The focus of this paper is the curriculum used for our afterschool Innovation Clubs. The Innovation Clubs use the LEGO[®] MINDSTORMS[®] NXT robotics kits, augmented with other technical resources, to investigate solar and wind energy. We integrate additional hardware, such as solar panels, third-party sensors, and common construction materials, and teach ways to apply new software techniques as students evolve their programming skills. Overall, students are identifying and designing innovative engineering solutions to some of our world's most pressing problems. The curriculum includes the details of structured LEGO[®] builds and specialized programming, curriculum design prompts, design challenge mats, and professional development documentation. This paper describes examples of the curriculum to give the reader a better understanding of the content, including detailed descriptions of the format of the structured builds. The goal of this paper is to disseminate to others the curriculum resources that were developed for this program.

Introduction

Now more than ever, there is a world-wide need for collaboration to solve major engineering challenges that must be addressed in order to maintain quality of life, national security, and a sustainable future¹. To address these issues, the National Academies of Science and Engineering along with many others agree that the USA needs to produce more engineers and scientists². Therefore, improvements to pre-engineering education are needed to attract more students to Science, Technology, Engineering, and Mathematics (STEM) pathways. This is the purpose of the Design Technology and Engineering for All Children (DTEACh) program that is offered by the Cockrell School of Engineering at The University of Texas at Austin. This program uses active learning with open-ended design projects to improve students' understanding of STEM concepts. This paper gives an overview of the curriculum of our afterschool program, *Beyond Blackboards*. We particularly focus on seven structured solar energy design and build activities. The layout of the components of the structured builds is discussed, as are examples of the general curriculum.

Program Background

For over 20 years, our DTEACh Professional Development Institutes (PDIs) for K-12 teachers have sought to enhance STEM concepts with active learning techniques³,⁴. The program provides guidance to K-12 teachers on using design problems in their classrooms to teach applied mathematics and science. The PDIs teach engineering concepts through the use of everyday technology, directed laboratory activities, and design briefs. Since 1998 our program has used LEGO[®] MINDSTORMS[®] robotics as the focus for hands-on experiences. The program has its roots in engineering design theory and learning science research. To clearly demonstrate the effectiveness of this teaching approach, the entire program is taught using the methods the participants are expected to use in their classrooms. This curriculum exchange paper is presented as a part of dissemination of the program's research and resources; information about the program and past research can be found at our website and in past publications^{4,5,6,7,8}.

Robotics

Robotics technology has been shown to be an effective means of engaging students in meaningful design activities. In a study of a summer program using LEGO[®] MINDSTORMS[®] robotics, 10- to 13-year old students built submersible boats over 3.5 hours at a summer camp⁹. Many students let the materials drive their progress and engaged in trial and error designs, becoming frustrated during the process. Some students stayed within the problem but spent time planning and were able to generate designs. Some students spent time planning and worked towards extravagant designs, and were driven to creating designs that somehow outperformed others' designs. One student spent too much time in planning and was not able to engage in the evaluation aspects of design. Many students completed only two aspects of the design process and then proceeded to play with their designs⁹. This is construed as a negative, but has been used to promote redesign with younger children, whose play may be leveraged as an evaluation phase; students would interrupt their play when their design had a structural failure or to accommodate changes in the storyline of their play¹⁰. In other words, robotics "play" offers multiple teaching and learning opportunities.

The evaluation of our program shows substantial agreement with this example. The *Beyond Blackboards* curriculum discussed uses the LEGO[®] MINDSTORMS[®] Education NXT Base Set, and LEGO[®] MINDSTORMS[®] Education Resource Set, and the LEGO[®] Renewable Energy Add-On Set¹¹. The program has been deployed extensively in a rural Central Texas school district in three middle schools and eight elementary schools. The curriculum discussed herein has been used in afterschool programs during the spring semester. We have evaluated the program using surveys, observations, and focus groups. The results indicate that the percentage of participants with a positive attitude toward having a career as an engineer increased from 45% to 71% from the fall to the spring. Additionally, the participants expressed increased aspiration to go beyond high school and complete a bachelor's degree (from 19% in the fall to 40% in the spring), while showing decreased uncertainty regarding their ultimate educational attainment (from 19% in the fall to 5% in the spring). Teachers who participated in the program perceived positive changes in themselves that were transferred to their approaches to and content in regular classroom instruction.

Grand Challenges

The curriculum is motivated by elements of the *Engineering Grand Challenges of the 21st Century* identified by the National Academy of Engineering. Throughout human history, imagination has come to fruition through engineering, which has driven immense advances in civilization. These advances can be seen with significant engineering feats that drastically changed societies. Among the most notable are ships that created innovative channels for trade and travel; sanitation systems for improved health and quality of life; widespread development and distribution of electricity and water; automobiles and airplanes; telephones; computers; space exploration; and the Internet.

Reflecting on the 20th century and looking forward in our first decade of the new millennium, the National Academy of Engineers (NAE) sought innovative ways to identify formidable challenges as the population grows and its needs and desires expand¹². The NAE gathered a team of leading thinkers with a wide range of experiences who are dedicated to improving the quality of life around the globe. This team explored broad realms of human concern – sustainability, health, vulnerability, and joy of living – and generated 14 specific Grand Challenges that await engineering solutions, as shown in Figure 1.

ENGINEERING GRAND CHALLENGES OF THE 21st Century Develop carbon Make solar energy Provide energy from fusion sequestration economical methods Manage the Provide access to Restore and nitrogen cycle clean water improve urban infrastructure Advance health Engineer better Reverse-engineer in formatics medicines the brain Prevent nuclear Secure Enhance virtual cyberspace terror reality Advance Engineer the tools personalized of scientific learning discovery

Figure 1: 21st Century Engineering Grand Challenges¹².

The curriculum and pedagogy of our program have evolved over the years to shift with the dynamic nature of engineering education. Our curriculum evolution now incorporates the Grand Challenges as the framework for designs. The curriculum described in this paper focuses on the challenge of "Making solar energy affordable".

Curriculum Elements

The curriculum includes the detailed structured LEGO[®] builds, specialized programming, curriculum design prompts, challenge mats, and professional development documentation. These elements are described below.

Structured LEGO[®] Solar Builds

For the solar based curriculum structured builds were created to provide the students with experiences with design process and the new hardware to ensure their success when tackling open ended design challenges. Structured builds were created for seven different products and ranged from basic to advanced assemblies, as shown in Table 1. The instructions for each build start with an overview picture and description of the build. Figure 2 shows the overview picture of the completed yardstick cable car. Next, the structured build provides a detailed materials list of all LEGO[®] and non-LEGO[®] items needed to complete the build. This materials list includes a picture and a written description of each component to help students learn common terminology when discussing the LEGO[®] parts. Figure 3 shows a portion of the materials list of the yardstick cable car.

	Structured LEGO [®] Solar Builds	
1	Automated Solar Door	
2	Solar Four Wheel Vehicle	666
3	Solar Rope Walker	
4	Solar Rope Runner	Axle Main Solar
5	Solar Treaded Vehicle	
6	Solar Yardstick Cable Car	
7	"Big Belly" Solar Trash Can and Compactor	

Table 1: Structured Solar Builds



Figure 2: Yardstick cable car.



Figure 3: Example build materials list for the yardstick cable car.

The final section, the majority of the document, comprises the actual building instructions. For each step there is a written description of what needs to be done, a materials list for the step and a picture of the results of the step. An example is shown in Figure 4.

I. Pulley Assembly

To construct the Pulley Assembly of the Yardstick Cable Car, please follow the instructions as below.





Specialized Programming

For the structured labs specialized program examples are provided for the more complex builds. Basic, intermediate and advanced builds are created and documented to help the students and teacher explore the performance of the devices. Figure 5 shows an example of one of the documented basic programs.



Figure 5: Documented program example for the Big Belly build.

Challenge Mats

As part of the curriculum large-scale challenge mats were developed to provide a "playing field" on which the students can test their designs. Figure 6 shows the "(Re)New Orleans" challenge mat. The mat provides context for the design challenge and a "course" that the students use to test their devices. This mat focuses on the Grand Challenge of "Restore and improve urban infrastructure", particularly in the wake of a natural disaster (i.e., Hurricane Katrina).



Figure 6: (Re)New Orleans Challenge Map

Professional Development Documentation

As part of the curriculum professional development documentation was created to assist the teachers with the curriculum. Figure 7 shows a sample of the agenda slide for the one-day PDI associated with the Grand Challenges of alternative energy and revitalizing infrastructure. In addition to providing content and experiences with the builds and programs, the PDI allows time for the participants to discuss pedagogy and to plan the semester's afterschool activities. Figure 8 is the suggested schedule for the curriculum.



Figure 7: Agenda slide for PDI.

Scheduling the Spring			
Week	Grand Challenges Module	Scope & Sequence	
1	(Re)New Orleans & Improve Infrastructure	Build in Bins & Gondolas	
2	(Re)New Orleans & Improve Infrastructure	Single Funky Fridge Pusher	
3	(Re)New Orleans & Improve Infrastructure	Multiple Funky Fridges Herder	
4	(Re)New Orleans & Improve Infrastructure	Star Trek Door/Retractable Levee Wall (optional)	
5	Exploring Alternative Energy	Build in Bins Solar Derby Car & Solar Vehicles	
6	Exploring Alternative Energy	Solar Tracker	
7	Exploring Alternative Energy	Solar Tracker & Wind Turbine	
8	Exploring Alternative Energy	Wind Turbine (optional)	
9	Working with Water	Capture Water	
10	Working with Water	Transport Water	
11	Working with Water	Clean Water	
12	Working with Water	Store Water (optional)	
13	Open Ended Grand Challenges Designs in the Gulf Coast Region	"Respond with Repairs" or "Imagine to Improve"	
14	Open Ended Grand Challenges Designs in the Gulf Coast Region	"Respond with Repairs" or "Imagine to Improve"	

Figure 8: Suggested schedule for curriculum.

Conclusion

With our curriculum, students are identifying and seeking innovative solutions to some of our world's most pressing problems by designing engineering solutions. The curriculum includes the detailed structured LEGO[®] builds, specialized programming, curriculum design prompts, challenge mats, and professional development documentation. We continue to evolve the curriculum to address other Grand Challenges, such as "Provide access to clean water." As these curriculum materials develop, they will be made available on our website³.

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