AC 2012-3021: DESIGN, DEVELOPMENT, AND IMPLEMENTATION OF EDUCATIONAL ROBOTICS ACTIVITIES FOR K-12 STUDENTS

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Design, Development, and Implementation of Educational Robotics Activities for K-12 Students

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Abstract
Educational robotics provides many opportunities to enhance science, technology, engineering, and mathematics (STEM) education for students and teachers by using engineering and computer programming techniques integrated into the curriculum. In addition to in-class activities, there are many programs targeting use of educational robotics in after-school activities. In this paper, we present our experience at the Interactive Technology Experience Center (iTEC) in design, development, and implementation of robotics activities for K-12 students and teachers. iTEC is a K-12 STEM center at the University of Texas at San Antonio, which was established in 2007 with a mission to motivate young people to pursue careers in engineering by demonstrating advanced technologies and engaging them in interactive activities that build technical skills and foster critical thinking, self-confidence, communication, and leadership. Educational robotics activities discussed in this paper includes 1-day and 5-day camps for students, and a 2-day workshop for STEM teachers. Each activity is designed following a 5-step Active Learning Cycle (ALC) model. The 5-step ALC model is based upon active learning and engagement strategies developed by the iTEC team.

1. Introduction
Increasing the number of undergraduate students obtaining degrees in science, technology, engineering, and mathematics (STEM) fields will provide a workforce that is prepared to ensure a healthy economy, respond to demands for national security, and maintain and elevate the quality of life and standard of living in the United States through technological and scientific advancements. From this perspective, exposing K-12 student to STEM is very important.

Several resources highlight the need to effectively use modern technology to gain more productive and rewarding STEM exposure at K-12 level in terms of its long-lasting results, effectiveness and excitement [1, 2]. The importance of active learning through hands-on applications has been highlighted in the literature [3-8]. In the report of the Advisory Committee [9], under the auspices of the Education of Human Resources (EHR) Directorate of NSF, the importance of active learning is illustrated through the words of Prof. Eugene Galanter (Director, Psycho-physics Laboratory, Columbia University): “In so far as every science depends on data for both theory and application; laboratory or field data collection experience is an absolute
necessity. Adding up numbers from a textbook example is not the same as recording those numbers or qualitative observations based on one’s effort. When students “own” their data, the experience becomes a personal event, rather than a contrived exercise.”

In 2006, the National Academy of Engineering and National Research Council Center for Education established a committee to begin to address K–12 engineering education issues with emphasis on curricula, learning, development of engineering skills, and the impact of K–12 engineering education initiatives [10]. The report highlights the fact that there is broad agreement among educators, policy makers, and industry leaders that the teaching of STEM subjects in American K–12 schools must be improved. A review of the report is also available [11].

Educational robotics provides an opportunity to capture the interests of students in grades K-12 and to introduce them to engineering and science [12-14]. It can facilitate active learning, promote active reasoning and critical thinking, and also enhance students' interest and motivation to address often complex or abstract subjects. It is a growing field with the potential to significantly impact the nature of engineering and science education at all levels, from K-12 to graduate school [15-17].

Currently, K-12 students are exposed to a growing number of robot competitions, such as the FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition (http://www.usfirst.org) and GEAR (Getting Excited About Robots) Robotics Competition (http://www.gearrobotics.org/). Strong ties between robotics competitions, student enthusiasm, research, and education have been observed [17,18] and there is common belief that robotics activities have tremendous potential to improve classroom teaching. However, several researchers also argue that the impact of robotics on the K-12 curriculum is yet to be scientifically proven [19-21].

In the US, there are several programs and research opportunities at federal level, such as the Department of Defense, Department of Education, Department of Energy, Navy, and NASA have robotics-focused STEM programs. The National Science Foundation’s Innovative Technology Experiences for Students and Teachers (ITEST) program supports research and development projects that address STEM workforce issues. One of the focus areas in this program is the impact of robotics competitions are of special interest and their effectiveness as a means of engaging students in learning STEM content and 21st Century skills (For current and past funded projects, please visit http://itestlrc.edc.org/).

There is tremendous amount of literature on educational robotics, K-12, and STEM education. In the book entitled “Robots in K-12 Education: A New Technology for Learning” [17], a variety of topics in educational robotics ranging from designing evaluations to student learning to robotics competitions are discussed. An extensive review is presented by Benitti [21]. The paper reviews recently published scientific literature on the use of robotics in schools, in order to identify the potential contribution of the incorporation of robotics as educational tool in schools, present a synthesis of the available empirical evidence on the educational effectiveness of robotics as an educational tool in schools, and define future research perspectives concerning educational robotics.
In this paper, we present design, development, and implementation of educational robotics activities, including student and teacher workshops, and 1-day and 5-day engineering camps for students. Each activity is designed following a 5-step Active Learning Cycle (ALC) model. The activities are developed as a sequence with varying depth and technical content using the Lego® Mindstorms NXT™ platform.

In order to develop an effective educational robotics program, the sequence of activities must be built on creative, accessible, and affordable materials in order to truly engage a child’s interest in STEM and to build a comfort zone for STEM teachers. Several factors must be taken into account during program development. The factors include teacher time constraints, teacher training, age-suitable academic materials, ready-to-use lesson plans, and affordable educational robotics platforms [15]. In addition, the activities must be delivered at a time convenient to children, their parents, and teachers.

2. Active Learning Model
A typical challenge in a STEM field is that students do not often see the relevancy of the topics they are learning. The concepts must be presented in a way that shows value and relevancy by providing real-world examples in order to keep “learners” engaged, active, and motivated. In ITEC, we are using a 5-Step Active Learning Cycle (ALC) model to develop educational activities and expose K-12 students to STEM in a progressive way. As show in Figure 1, the first four steps of ALC include concepts, models, applications, and problems. The last step of the learning model is on design. Due to the progression of five steps leading to open-ended design problems, the ALC model facilitates project-based learning, which makes it exciting and
relevant to real-life. This approach has been implemented in several programs offered by the ITEC Center through the University of Texas at San Antonio.

The ALC model engages students to be active learners; presents engineering concepts in concrete, relevant, and real-world contexts; and immerses students in authentic engineering-based activities [22-24]. It includes 5 steps: Content, Model, Application, Problem Solving, and Design. The objective is to keep individuals engaged, active, and motivated. First step is the content, presented to describe a concept. This is then followed by the second step, which is a model that demonstrates the concept. Next, an application step is introduced in which students tweak parameters to change the outcome of the application that is founded on the concept. Fourth step is problem solving that stimulates analysis skills. In the fifth step, an open-ended design problem, constructed on the initial concept, is presented. Students can work on the design problem in teams. The design problem can be introduced as a competition. This model is based upon active learning and engagement strategies that are widely researched topics and implemented strategies [25-28].

**Content** - At the center of every lesson, unit, or curriculum are core concepts that we want the students to learn. We identify a concept or a narrow set of related concepts that will be covered in a lesson. The main objective at this step is for students to have an operational understanding of the concept. A student may only have a preliminary definition and conceptual understanding may be very superficial and disconnected to other concepts. Such knowledge may be gained through direct teaching, such as a lecture, or from reading a book.

**Model** - The engineering concepts we expect students to know may be abstract or require a high level of understanding that may even include other high level domains such as chemistry, physics, and mathematics. The concepts may not be viewable or have an actual physical representation. For example in computer science, algorithms and data structures have no physical or tangible representations. Visualization tools give students an illustration, animation, or other visual metaphors to work with in scaffolding their understanding of the concepts. Such models are used to illustrate the concept in action and engage the learners in discussions.

**Application** - Applications are simulated concepts, which are differentiated from models in that models are more illustrative than interactive whereas simulations rely on user interaction and involvement. This is the hands-on component part of the lesson. Such interactive applications allow students to explore and interact with the concepts. It is also a “safe place” for students to test out their ideas successfully and unsuccessfully. As indicated in the literature [29-30], such interactive applications serve useful in motivating students to pursue in a given domain and recruitment. Given that students are able to control the different variables within a simulation environment and testing out their conceptual understandings, students will be able to make predictions on the outcomes of the simulation.

**Problem** - Thus far, we have provided the information about the concept and several tools (models and applications) for students to work on. They have demonstrated some form of conceptual understanding, retention of information, and generalized knowledge to transfer between different situations. At this point, students must continue demonstration of that understanding through solving an open-ended problem involving the concepts to contend with
the complexities and ambiguities of real-world situations [31]. In order to accomplish these objectives, we use project-based learning (PBL) activities. PBL is a model for inquiry-based instruction in which students work together on an open-ended project to explore a topic, issues, or problem [32]. Teachers become facilitators and guides as students develop and explore their questions. Although the problem is open-ended, teachers can still give goals and set expectations. Since these challenges are open-ended and multi-faceted, students will have the ability to contribute their individual expertise to the same project. It takes into consideration the different learning styles that students may have. For example, students who have an exceptionally strong interest or ability in calculus may focus on the mathematical part of the project. Another example, students who are visual learners may be in charge of creating charts, illustrations, and graphs.

**Design** - This is the engineering design phase, which involves a set of steps that an engineer would typically follow. As teachers or facilitators, we present the students a desired state or outcome. Students in teams go through the engineering design process. First, they define the problem based on the concepts they have learned in the previous steps of the ALC model. If needed, they do additional research to be able to refine their problem statement. Next, they specify requirements based on the facilitator’s (or teacher’s) definition of desired state/outcome. They develop alternative solutions to meet the problem requirements and benchmark them. They chose the “best” alternative, build a physical model and continue with testing and redesign. During the engineering design process, teams frequently jump back and forth between these steps. Through these iterations, they aim to improve the performance of their designs.

In ITEC, we use the Lego® MindStorms NXT™ kits since this platform allows students to easily modify their design, test and make changes in a timely manner, and limit the number of components that teams can use so that the design experience of the teams can be shared and compared easily.

A sumo-bot competition is an example for the design phase of the ALC model. The engineering design challenges for a robot include detecting the presence of its opponent and pushing it out of the playing field while trying to avoid leaving the playing field. In summer camp of 2011, this design problem led to many alternative robot designs with varying levels of performance. The general outcome of the design step in the ALC model is to have students engage in dialogues and interactions with others. The teams of campers at the end of the camp period were able to collaboratively develop a set of design guidelines and lessons learned based on the presentations of each team’s design.

Another example from the summer camp of 2011 is a catapult design using Lego® MindStorms NXT™ platform. The “Concept” step of the ALC model included principles of work and energy concepts, as well as conservation of potential energy to kinetic energy. The “Model” step used a simple catapult computer animation to demonstrate conservation of energy. The “Application” step involved the computer animated catapult with adjustable launching angle, spring constant, and a ball. The energy equation allowed student to relate the parameters and results. The “Problem” step involved solving the energy equation to determine the launching angle to hit a target at a known distance. The “Design” step was a Mini Catapult Competition. Students were required to design and build a mini catapult to hit a set of targets in classroom with different
distances, heights, and angle of attack. Knowledge of energy method, kinematics, and mechanical design was utilized. The performance was assessed in both theoretical analysis and actual practice.

3. Educational Robotics Activities Based on the ALC Model
In ITEC, we developed a train-the-trainer workshop for teachers, and a 1-day spring break camp and 5-day summer camp for middle school students. The activities were built on the Lego® Mindstorms NXT™ platform.

3.1 Train-the-Trainer Teacher Workshop
This is a 2-day workshop for middle/high school teachers. Educational robotics is an effective tool to introduce integrated science, technology, engineering, and mathematics concepts to the students. In this workshop, Engineering Design concepts are introduced along with hands-on applications using Lego® Mindstorms NXT™. This workshop provides the teachers with a solid foundation to build upon for their classes. The workshop includes presentations and discussion on learning styles, effective team building strategies, and managing robotics competitions. The workshop objectives include:
- To demonstrate the engineering design principles through a robotics application using Lego® Mindstorms NXT™.
- To guide you through hands-on practices for effective learning.
- To engage you in a simulated robotics competition to implement the engineering design principles.
- To facilitate a “teach me” session for you to develop a demonstration based on your area of expertise.

By the end of this workshop, the participants will be able to (i.e., workshop outcomes):
1. Define main components of Lego® MindStorms NXT™ platform.
2. Demonstrate how NXT™ components can be assembled into “robots” and programmed to exhibit certain functions and behaviors.
3. Apply the engineering design principles to robotics.
4. Compare design alternatives in terms of performance, select the best alternative, and explain the reason.
5. Design a robot given a “need statement”
6. Judge different designs in terms of overall performance

The workshop schedule is given below. Each step of the ALC model is also given next to the activities.

DAY-1 – Introduction to Lego® NXT
8:30-9:00 am Introduction
9:00-9:25 Engineering Design: Systems Thinking (ALC Content step)
9:25-9:45 Learning and Teaching
9:45-10:00 Break
10:00-10:15 Your Expectations
10:15-12:15 Introduction to Lego® NXT (ALC Model step)
The workshop evaluation includes a questionnaire with five sections. In section 1, the participants are asked to evaluate the content of the workshop in terms of its value, details presented, cohesiveness of the program, and if the stated objectives are met. In section 2, they are asked to evaluate each presenter in terms of his/her knowledge, presentation skills, communication with the participants, and preparedness. In section 3, the questions are related to the effectiveness of the training materials, which is followed by the questions in section 4 on the pace of the workshop and whether it exceeded their expectations. In section 5, the questions are focused on the workshop outcomes. Each question is answered on a scale from 1 to 5, with 1 indicating “strongly disagree” and 5 indicating “strongly agree”.

After the first two workshops, the evaluations indicated that the following workshop outcomes (see full list on previous page) needed our attention:

3. **Apply** the engineering design principles to robotics.
5. **Design** a robot given a “need statement”

In the next three workshops, we have added more examples and sample Lego® robots to the ALC Application and Problem steps. In addition, we have added videos of different Lego® robots and discussed each one from the standpoint of engineering design. The evaluations indicated an improvement on the aforementioned workshop outcomes.

### 3.2 Robotics Spring Break Camp: Solar Hot Rods

In the spring break of 2011, we did a 1-day camp for middle school students about solar energy. Students used Lego® robotics kits to build a car of their design. They then used solar panels to make a solar powered car, as shown in Figure 2. The 1-day camp activities were developed around the ALC model:

1. **Content**: Energy and work principles; Forms of energy; Conversion of energy
2. **Model**: Computer simulation of various forms of energy; Videos of wind and solar powered vehicles; Lego® robots: catapult (rubber band-based), wind turbine, and use of solar panel in various applications.
3. Application: Introduction to Lego® solar panels and NXT™ kits.
4. Problem: Build your solar vehicle.
5. Design: Solar Hot Rod competition – who can go the farthest?

Figure 2. A Solar Powered Car

3.3 Robotics Summer Camp
In the summer of 2011, we did a 5-day camp based on the ALC model. Similar to the spring break camp, the summer camp activities were built on the Lego® MindStorms NXT™ platform. Each day of camp was centered on a challenge (e.g., follow a line using a light sensor). As shown in Table 1, each day’s topics and challenges were designed to guide students toward the participating in the competition at the end of the week, which encompasses all the topics learned throughout the week.

**Content**
Content was delivered using a variety of approaches. Most instructors relied on direct instruction using lectures and handouts. There were some more active teaching approaches. Some instructors used role-play to illustrate the relationship between programming and robotics (one student was the robot and another student was the programmer telling the robot what to do). In this same role-play scenario, instructors taught the concept of sensors, gathering data from the sensors, and acting upon that feedback. Direct instruction lasted a short time during each lesson as most time was spent on building and testing robots. The purpose was to give students the basic foundational information they needed before they could start building or programming. It was through the actual process of building the robot, writing the programs, and testing the robots that students gained a deeper understanding of the concepts.

**Model**
Models were used to illustrate the robotics concepts and design challenges throughout the curriculum, especially during the building and testing phases. It was important for instructors to demonstrate what the robots were supposed to do because the challenges typically involved the robot interacting with an environment, such as following a line, avoiding obstacles, or picking up an object. It may also involve pushing other robots around. Since these environments are dynamic in nature, it makes the challenge more complicated. So, students observe the
instructors’ robots to see what the objectives are and to see what possible difficulties or issues may occur when testing their robots and may account for them in their design.

Table 1. 5-Day Robotics Camp in Summer 2011

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<tr>
<th>Time</th>
<th>Day 1</th>
<th>Day 2</th>
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<tr>
<td>8:30 AM</td>
<td>Introduction to camp rules and policies and the camp objective</td>
<td>Intro to sensors and sensor application</td>
<td>Discuss what was learned from the engineering design approach</td>
<td>Implement any final changes and answer questions about designs and the course this will transition into rules</td>
<td>Intro to competition and getting competition field set up</td>
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<td>9:30 AM</td>
<td>Introduction to proper laptop handling</td>
<td>Implementing line sensor and design process</td>
<td>Look at introducing the sound sensor and how it will be used in application</td>
<td>Rules of competition and guide based on what is seen in the designs</td>
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<tr>
<td>10:00 AM</td>
<td>Introduction to Programming</td>
<td>Test line sensor design with single sensor</td>
<td>Allowing them to apply the engineering design approach again</td>
<td>Allow to do test runs and see how the robots perform</td>
<td>Discus strategy, give final demo with final course changes and let them start</td>
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<td>11:00 AM</td>
<td>Challenge 1: Introduction - Critical Thinking and Your First Program</td>
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<td>12:00 PM</td>
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<tr>
<td>12:45 PM</td>
<td>Challenge 2: Hands on - design, build and program</td>
<td>Design final line sensor with two line sensors</td>
<td>Showing them how it will be used and help them to implement the sensor if needed.</td>
<td>Testing and modifying the robots and allowing them to apply design changes to meet competition goals and to improve robot’s performance</td>
<td>Final competition and give out awards</td>
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<td>2:30 PM</td>
<td>Challenge 2: Conclusions</td>
<td>Analyzing final design</td>
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<td>3:30-4:00 PM</td>
<td>Discussion about important ideas from the day</td>
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Additionally, instructors built more complex robots using the same parts that were available to the students. For example, one instructor built a turtle robot that used the ultrasonic and sound sensors to detect any movement or sound. When the turtle robot detected something nearby, it would retract its head and legs similar to a real turtle. This is far more complicated than what students in the robotics camps would create. Most students based their robot designs on the default Mindstorms robot. We wanted to show how the same sensors, motors, and bricks could be used to build elaborate robots. This was done in part to engage students and let them see
examples of some interesting robotics projects. We also wanted to model how those same sensors and motors could be used in other contexts.

**Application**
With a basic understanding of the concepts and having seen models of what they are supposed to do, students apply their knowledge through building or programming their robots. This portion of the activity is the most hands-on as students are working with the robotics kits and the programming software. They are also working in teams with each student given a particular task: builder, programmer, and tester. At this time, students are only working within their groups and there is no competition element yet.

**Problem Solving**
Up until this step, instructors gave students the technical requirements (e.g., what sensors to use) of the robots and described the overall challenge (e.g., follow a line).

At this time, instructors would present the final parameters of the challenge based upon the original demonstration. In the case of the follow-the-line challenge with a light sensor, the instructor would change the line from the original demonstration model to include a curve or more paths to add more complexity to the challenge. Or for obstacle detection, the instructor would add another wall, move existing walls, or add walls that protruded from the top but not the bottom. Again, this was to change the original problem from the demonstration model so that students would have to re-think the design of the original robot that was built during the application process.

Instructors were now facilitators, answering student questions and only assisting those that required a lot of help. Students worked among themselves—primarily within their own groups—to solve their problems. Students were able to contribute their own expertise and knowledge to completing the problems. Some students reported having experience with the Mindstorms robotics kits before and were able to build fairly quickly.

**Design Problems**
Each day different instructional objectives were presented and included a challenge for the students, which involved extending (or entirely redesigning) the robots they were taught to create by the instructors. The last day and a half of camp was devoted to the final challenge. The challenge is a culmination of all topics that were learned throughout the week and was presented as a competition between groups. The typical challenge was an obstacle course where students had to navigate through a course, avoiding obstacles using an ultrasonic sensor, following a line using a light sensor, and grabbing items and delivering it. Completion of each task results in points. The competition is to score more points than other teams’ robots. The implementation of the ALC model is shown with pictures in Figure 2.

We observed that the design step was the most engaging and interactive. Students were observed to stay on-task and kept working with their groups to create a robot, which resulted in very autonomous groups. There was also a sense of camaraderie within and between groups. Often struggling groups relied on help from other group’s to complete their projects. The competition aspect seemed to motivate students to design better robots. When a team was ready to test their
robot, many students would go to the competition course to observe the run through. When another group’s robot was successfully going through the test course, other students would go look at it to see how the robot was built and programmed to make it successful.

![Implemention of the ALC Model in Summer 2011](image)

*Figure 2. Implementation of the ALC Model in Summer 2011*

Although it is not a formal assessment or an evaluation with statistical significance, we conducted exit interviews on the last day of camp with 18 students and emailed them a survey to see what they enjoyed about the robotics camps. Overall, students seemed to be interested in
robotics, particularly the building and programming aspects of robotics. As shown in Table 2, overall, 12 respondents indicated that they enjoyed the camp. Seventy-one percent of respondents stated that the instructors motivated the students to become interested in robotics. The instructors appear to have been mostly successful in motivating students in robotics. As mentioned before, instructors would often show examples of more sophisticated robots that can be built with the Lego® Mindstorms set. Often, instructors would show videos of more advanced robots as a way to inspire students’ imaginations. Having a sense of pride and ownership of the artifacts they create is another indicator of engagement: 13 respondents said they were proud of their final project.

### Table 2. Survey Summary: Questions and Responses

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Responses (out of 18 students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did you enjoy the camp?</td>
<td>Yes – 12</td>
</tr>
<tr>
<td></td>
<td>Most of the time – 2</td>
</tr>
<tr>
<td></td>
<td>Sometimes – 1</td>
</tr>
<tr>
<td></td>
<td>No – 2</td>
</tr>
<tr>
<td></td>
<td>Don’t Know – 1</td>
</tr>
<tr>
<td>Did the instructors motivate you to become interested in robotics?</td>
<td>Yes – 12</td>
</tr>
<tr>
<td></td>
<td>Most of the time – 3</td>
</tr>
<tr>
<td></td>
<td>Sometimes – 1</td>
</tr>
<tr>
<td></td>
<td>No – 2</td>
</tr>
<tr>
<td>Are you proud of your final projects?</td>
<td>Yes – 13</td>
</tr>
<tr>
<td></td>
<td>Most of the time – 1</td>
</tr>
<tr>
<td></td>
<td>Sometimes – 2</td>
</tr>
<tr>
<td></td>
<td>No – 2</td>
</tr>
<tr>
<td>Do you plan to join a robotics club?</td>
<td>Yes – 7</td>
</tr>
<tr>
<td></td>
<td>Maybe – 3</td>
</tr>
<tr>
<td></td>
<td>No – 4</td>
</tr>
<tr>
<td></td>
<td>Don’t Know – 4</td>
</tr>
</tbody>
</table>

From our exit interviews, students also talked about how they enjoyed the programming and building aspects of robotics. The robots themselves seemed to be a huge motivator for students. A student said camp was fun because of “all of the robots” while another said “...it’s a lot of fun and you get to play around with the robots.” Though programming was regarded as one of the more difficult tasks, one student liked the programming aspect of robotics: “I like the programming the stuff” while another student highlighted its versatility: “...we got to do different programs everyday with the robots.” In this case, the student was thinking of different ways to use the devices provided with the standard kit. This may indicate that the hands-on component found in the Application, Problem Solving, and Design Problem was very effective in getting students engaged in robotics. One student had fun because he said he was “able to work with technology and all that.” We even saw one student who started thinking of new problems to solve: “I want like three or so [robotics kits] so I can take two and Bluetooth two of them together, and make two of them control a robot.” Again, the students seemed to be interested in the hands-on nature of robotics. One student wanted to come back again to “…to learn more and get more interactive with [the robots].”

We tried to show the many possibilities of robotics with the elaborate models that instructors built. One student found robotics fun “because I didn’t know I could build these robots and have different choices to build,” which implies that students were able to see how much flexibility
there is in the robotics kits. Legos are a popular toy for children, but the Mindstorms kit adds a new level of play. One student who was familiar with Legos said, “I didn’t know how to make robots out of Legos, I thought it would be the other Legos.” So, hopefully, the camp was able to stimulate students’ interests and imagination in STEM, especially since students said, “Because I like to learn new stuff and I like to learn” and “I just like it, I like science.” If our goal is to get children interested in STEM, we also have to sustain those interests particularly if they have that existing interest.

Informal interviews with parents, instructors, and camp administrators also validate the fact that the summer camp of 2011 was much more effective than that of 2010, which was not based on the 5-Step ALC model. Since the sample size (only eighteen students) was small, the data presented in this section provide limited evidence but only demonstrate how the assessment process was carried out. Our goal for the summer camp of 2012 is to expand the assessment and reach out to as many campers as possible in order to obtain significant amount of data in terms of the effectiveness of the 5-Step ALC model.

4. Conclusions
In this paper, we share our experiences related to the development of teacher workshops and student camps focused on educational robotics based on an active learning model. Our conclusions can be summarized as follows:

- Understanding a concept entails having a mental model that reflects the structure of the concept and its relationship to other concepts. Therefore, presenting organized knowledge through concepts that are combined to form propositions that show the relationship among concepts is essential.
- Learning is an active and continual process, where knowledge is constructed, continually updated, and refined as the individual gains more experiences. During knowledge construction and refinement, individuals use all their senses: hear, see, touch, etc.
- Interacting with a physical object or an experiment enhances and expedites learning.
- Effective K-12 STEM instruction requires engaging students to be active learners; presenting engineering concepts in concrete, relevant, and real-world contexts; and immersing students in authentic engineering-based activities.

The ALC Model is based on three constructivist principles of knowing and learning: learning is an active process, learning is engagement, and learning is situated. This framework built upon constructivist perspectives of knowing and learning serves as the foundation for the ALC Model for effective engineering instruction. We believe the model affords students
1. a support structure built by a community of peers and engineers to promote learning;
2. engaging activities that allow them to apply their interests, expertise in engineering and other fields, and creativity;
3. intellectual and social growth towards becoming an engineer; and
4. active learning environments with activities and tasks that are authentic to the engineering domain.

In order to carry out an assessment of the ALC model and its implementation in various STEM areas, we need to develop formal assessment methods based on statistically significant number of
participants. In summer of 2011, we were focused more on the execution of the camp itself and not so much on assessment.

Similar to the work reported in Hussar et al. [33], we are currently developing assessment methods for summer 2012 that are focused primarily on student outcomes, based on a framework provided in a National Science Foundation report [34] for evaluating the impact of informal science education programs. More specifically, our focus is on the following factors for summer 2012 summer camps:

- **Engagement / Interest**
  - Level of participation / Interest in activity
  - Curiosity in STEM-related activities and issues
  - Excitement about / Enthusiasm for engaging in STEM activities
  - Fun / Enjoyment in STEM activities
  - Desire to become a scientist/engineer

- **Attitude / Behavior**
  - Belief that STEM is sensible, useful and worthwhile
  - Belief in one’s ability to understand and engage in STEM (“can do attitude”)
  - Pro-social / adaptive learning behaviors in relation to STEM

- **Content Knowledge**
  - Knowledge and/or re-affirmation and expansion of what one already knows
  - Development of fundamental skills
  - Ability to use basic instruments

- **Competence and Reasoning**
  - Ability to formulate strategies and to investigate STEM problems
  - Capacity to think logically, reflect, explain and justify one’s strategies and solutions
  - Ability to see connections between topics
  - Ability to apply content knowledge in novel context

- **Career Knowledge / Acquisition**
  - Knowledge about STEM career options
  - Knowledge of pathways to STEM careers (i.e. pre-requisite classes, internships etc.)

**References**


9. Advisory Committee to the National Science Foundation, "Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology (SME&T)," Directorate for Education and Human Resources, 1996.


development and research can foster student success," in *New Mexico Higher Education Assessment
27. R. D. Pea, "Beyond amplification: Using the computer to reorganize mental functioning,
29. S. Cooper, W. Dann, and R. Pausch, "Alice: A 3-D tool for introductory programming concepts,
30. C. Kelleher, R. Pausch, and S. Kiesler, "Storytelling Alice motivates middle school girls to learn
computer programming," *Proceedings of the SIGCHI conference on Human factors in computing
project-based learning: Sustaining the doing, supporting the learning," *Educational Psychologist*, vol.
26, p. 369, Summer/Fall91 1991.
32. S. Bell, "Project-Based Learning for the 21st Century: Skills for the Future," *Clearing House*, vol. 83,
pp. 39-43.
33. K. Hussar, S. Schwartz, E. Boiselle, and G.G. Noam, "Toward a Systematic Evidence-base for
Science in Out-of-School Time: The Role of Assessment," A Study Prepared for the Noyce
Foundation, August 2008. (Available at http://www.pearweb.org/pdfs/Noyce-Foundation-Report-
ATIS.pdf)
34. A. Friedman (Editor), *Framework for Evaluating Impacts of Informal Science Education Projects*.
Report from a National Science Foundation Workshop, Mar 12, 2008. (Available at:
http://insci.org/resources/Eval_Framework.pdf)