# A One-hour Curriculum to Engage Middle School Students in Robotics and Computer Science using Cubelets

Nikolaus Correll, Chris Wailes and Scott Slaby

**Abstract**
Robotics has become a standard tool in outreaching to grades K-12 and attracting students to the STEM disciplines. Performing these activities in the class room usually requires substantial time commitment by the teacher and integration into the curriculum requires major effort, which makes spontaneous and short-term engagements difficult. This paper studies using "Cubelets", a modular robotic construction kit, which requires virtually no setup time and allows substantial engagement and change of perception of STEM in as little as a 1-hour session. This paper describes the constructivist curriculum and provides qualitative and quantitative results on perception changes with respect to STEM and computer science in particular as a field of study.

## 1 Introduction

Robots are computers that are extended by sensing, actuation, and communication capabilities. As such, they provide students access to a variety of engineering concepts [10]. Robots also stimulate people's imagination, a development heavily supported by arts, media and toys. Robotics is therefore considered as an ideal tool to provide young children with first exposure to science, technology engineering and math at K–12 level [2, 3, 6, 9].

Prominent examples that have found their place in middle- and high school curricula are LEGO Mindstorms [4, 5, 14], Vex robotic kits [1], the FIRST robotics competition [15], or platforms specifically developed for robotics education [7]. An

C. Wailes and N. Correll
Department of Computer Science, University of Colorado at Boulder, 80309 USA e-mail: firstname.lastname@colorado.edu

S. Slaby
Angevine Middleschool in Lafayette, CO. scott.slaby@gmail.com

often cited drawback of these systems and tools is that they tend to attract student populations that are already interested in STEM. Consequently, others have proposed to design robotic activities specifically targeted at girls by adopting robotic building kits that are thematically more associated with girls' interest such as puppetry and arts and crafts [8].

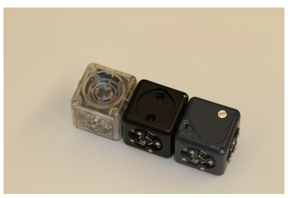
An additional drawback of "standard" robotic tool kits is that they require a certain level of engagement for the students to become productive. For example, LEGO Mindstorms requires assembling a large number of parts, attaching the robot to a computer, and learning a graphical programming system before students can obtain results. In other words, curricula designed around these tools put certain minimum time requirements on the participants that make spontaneous activities such as substituting a lecture in middle or high school impossible.


**Fig. 1** "Cubelets" manufactured by Modrobotics are a modular robotic construction kit consisting of various cubes with specific actuation (drive, rotation), communication (light, sound), sensing (distance, temperature, knob, brightness), and computation (min, max, inverse) capabilities, as well as structural parts (blocker, passive, battery). Cubelets exchange sensor information and allow the construction of simple autonomous robots.

This paper studies the use of "Cubelets" (Figure 1) to convey basic concepts of computer science using a constructivist educational model. Cubelets are a modular robotic construction kit that allows students to quickly assemble autonomous robotic systems by programming with their hands [11–13]. For example, students can construct a line following robot by combining cubelets with wheels, cubelets that can sense light, a power cubelet, and a structural blocking cubelet. Cubelets do not require an external computer to work and allow creative discovery with little to no instruction.

This paper describes our experiences with two half-hour sessions with $8^{\text{th}}$ graders at a middle school. Students were surveyed both on their perceptions on the role of robotics in their daily lives, computer science as a field of study, and on their prior interest to engage in computer science activities in their professional or personal lives. Data shows that an hour engagement with Cubelets spread over two days has significantly altered their perceptions and could therefore be delivered in a single, 1-hour session as an outreaching activity, or form the basis for a multi-session teacher-led curriculum.

This paper is organized as follows. Section 2 describes the curriculum as well as the information given to the students before and during the activity. Section 3 describes the background of the student population and the survey questions. Section 4 provides results from pre- and post tests. Section 5 discusses these results and Section 6 concludes the paper.



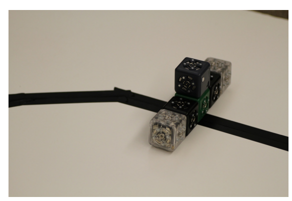
(a) Alarm consisting of sound (transparent), distance sensor (black) and battery block (gray).

(b) Runner consisting of distance sensor, battery, and two wheel blocks (transparent).

(c) Chaser consisting of "Runner" with inverted (red block) distance sensor.

(d) Light-tower consisting of a flash-light block, rotator, knob (to adjust the speed), and power block.

(e) Max-speed Runner made of a runner with a knob and "min" block (pink).



(f) Line Follower made of two light sensors (black blocks), two wheels (transparent blocks) and a passive connector block (green).

**Fig. 2** Robots built by the students during the first session.

## 2 Curriculum

The course curriculum was divided into two half-hour activities that were presented to the students during two 40-minute class periods with 10 minutes reserved for assessment, and was designed to teach students about several concepts at the core of computer science: decomposing problems into sub-problems and composing solutions to partial problems to solve a larger problem. The Cubelets robotics kit facilitated this lesson by allowing the students to break down the logical problems (what are the robot's inputs and how does it respond to them) the same way that they decomposed the task of building a complex physical robot.

### *2.1 Cubelets*

Cublets are a set of cubic building blocks that connect via magnets and a proprietary unisex-connector. They are about an inch wide. Connectors not only withstand torque and orthogonal forces (magnets are strong enough to withstand the gravitational pull of up to three other Cubelets), but also allow information and energy to flow between Cubelets. Cubelets each implement a specific sensing, actuation, or logic function. Sensing Cubelets emit sensory information to their neighbors, actuator Cubelets consume information, and logic Cubelets manipulate information flow. There exist also passive Cubelets, which exclusively block or forward information, as well as a Power Cubelet, which includes rechargable batteries. These batteries can power the Cubelets for multiple hours of activity, depending on the actual use. Actuation Cubelets include Cubelets with a single wheel (Drive), a rotating face (Rotate), a lamp (Flashlight), and a bargraph (Bar). Sense Cubelets include brightness, infrared distance sensor, a potentiometer (Knob), and temperature sensors. Think Cubelets include Inverter, which performs a mathematical operation equivalent to 1-value, a Maximum Cubelet, which forwards only the maximum value that it receives on any of its faces, as well as the Blocker, which only forwards energy, and the passive Cubelet, which forwards both energy and power it receives. Cubelets used in this curriculum are shown in Figures 1 and 2.

### *2.2 First Part*

The first part focusses on using the Cubelets to accomplish simple tasks and begins with an explanation of the basic functions of the individual cubes. This explanation includes how they are powered, how the cubes fit together, their categorization as Think, Sense, and Actuation blocks, what values could be produced by sensor blocks, how these values propagate across the blocks, and how Actuator blocks are controlled by the values they receive. The students are then shown how the blocks could be assembled to produce simple behavior using the Power, Knob, Bar Graph, and Inverse cubes.

Next, the class is divided into groups of 4-7 students and each group is given a set of Cubelets. In the study presented in this paper, the class with 17 students was divided into three groups and each group was given the following cubes: 2 Power, 3 Passive, 2 Brightness, 3 Distance, 2 Drive, 2 Flashlight, 1 Bar, 1 Knob, 1 Temperature, 1 Blocker, 1 Rotate, 1 Inverse, and 1 Maximum. The class with 26 students was divided into four groups and each group was given the following cubes: 1 Power, 2 Passive, 1 Brightness, 2 Distance, 2 Drive, 1 Flashlight, 1 Blocker, and 1 Inverse. In each case the remaining cubes were available for the students to use, and each group was encouraged to lend cubes to other groups when they were not using them.

The students were then given *only* the following descriptions of several robots and asked to build them (see Figure 2 for corresponding pictures):

1. Alarm - Makes noise when something approaches it.
2. Runner - Drives away from objects that try to approach it.
3. Chaser - Moves forward at maximum speed until it gets close to another object.
4. Lighttower - Rotating flashlight whose speed can be adjust with a dial.
5. Max-speed Runner - Same as the Runner with the added ability to set a maximum speed.
6. Line Follower - Follows a black line on a white surface.

During the class period all groups were able to complete the first five tasks, most were able to build a runner robot with the ability to set a maximum speed, and at least one group in each class was able to build the line following robot. While all groups had sufficient blocks to complete almost all tasks (in some cases they had to use some blocks from those available to the entire class) additional blocks would facilitate group participation. With the limited supply of blocks most groups would have one or two students who did most of the hands on interaction while the rest of the students commented or observed.

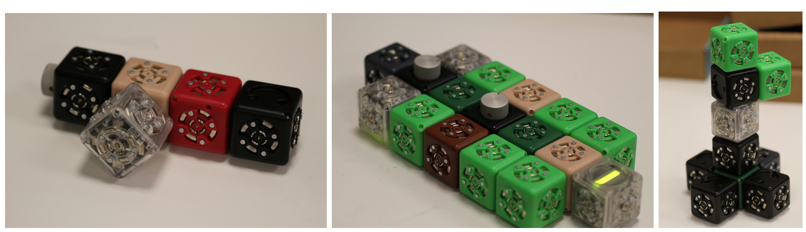
### *2.3 Second Part*

The second part includes both a mini-lecture and discussion. While the first 30 minutes are spent using the blocks to build the simple reactive robots described above, the main focus of the second part is on composing groups of blocks to build more complicated behavior. Specifically, the instructor motivates a scenario such as “tracking down a source of nuclear radiation using a Geiger counter” and discusses with the students what the basic functions are that such a robot must have. These include a pivoting sensor to track down the source of radiation and logic that controls the robot in this direction.

During the lecture several collections of blocks that are relevant to this task were passed around the classroom (Figure 3) and students were asked to postulate as to the functions the partial robots. These included a simple robotic arm, a logical AND gate (here the students were introduced to the concept of binary input), a distance-, and direction-sensing ‘head‘, and a large driving mechanism. While there were not enough blocks to assemble all of these components at the same time, they could be combined to form a robot capable of looking around, finding the nearest object, and moving to it.

The subjects of problem decomposition and solution composition were discussed in the context of the partial robots the students were studying. Once the students were aware of the function of these robotic fragments, they were able to identify how they might be able to re-use the same design when building robots in the future. The idea that each functional unit’s behavior could be reasoned about independently, based on their inputs, was then presented.

Up to this point, the physical structures that were being built in class or presented to them determined the behavior of the system. This is not the case for most computing systems, including robots, and so the idea of separating the physical and logical behaviors of a system was introduced. Students learned about *for* loops, *if-then-else* statements, and *functions* and how they were the logical ’blocks’ that computer programs were constructed from. A concrete example of a chat application that would allow students to communicate with each other using their phones was then used to show how logical problems could be sub-divided in the same way that a robot could be divided into its functional units. The different components identified for this application were authentication (logging in), communication (sending data over the network), input handling, and displaying output. Lastly, the students were asked to identify several sub-problems in building robots and how they might be solved and re-used. These sub-problems included movement and balance, vision and sensing, and interacting with the physical world. Here, the robots were used to introduce the students to the idea of functional units and *functions* (in the programming language sense), and how the behavior of components of larger systems could be reasoned about based on their inputs and outputs.



(a) (b) (c)

**Fig. 3** Robot parts examined during the second part of the activity. *a)* Simple arm mechanism capable of approaching a block and stopping when it connects. *b)* An AND gate that receives binary input from the knob blocks and produces a binary output from the *min* block at the lower-right. *c)* A robotic ’head’ capable of detecting the distance and direction of objects around it.

# 3 Student background and Survey Content

## *3.1 Student Background*

Angevine Middle School (AMS) in Lafayette, CO, serves grades 6-8. AMS has a high population of students of Latin origin (42.3%), and 72% of the 8th graders score “unsatisfactorily” or “partially” in math, 48% in reading, 59% in writing, and 61% in science in the Colorado Student Assessment Program (CSAP) [1]

The curriculum described here was taught to four cohorts of 8th graders within their social studies course. This setting was chosen to prevent any bias from a STEM-based setting such as science and math classes, both in terms of preconceptions to the field and to the activity itself. All four classes met consecutively on Tuesday and Friday. A pre- and post assessment was administered to two of the cohorts (“Group 1” and “Group 2”) before their first exposure to the Cubelets and after the second session on Friday, respectively.

Group 1 consisted of 17 students, 8 male, 9 female. Group 2 consisted of 26 students, 6 male, 20 female. Each group included one special needs student who was accompanied by a paraprofessional. The paraprofessionals were present in the class room, but did not interfere with their student’s engagement in the curriculum.

## *3.2 Questionnaire*

The questionnaire consisted of a pre-test and a post-test administered before the first (Tuesday) and after the last (Friday) activity, respectively. Both pre- and post-test consist of identical questions, with the post-test including one additional quantitative question.

The questions are geared to explore conceptions on robotics, the role of computer science in robotics, and the level of interest to engage in computer science as a field of study and/or as a hobby. The questions were designed by the teacher to be age and student appropriate. Questions were projected to a white-board one-by-one and narrated by the teacher and responses collected immediately. This approach required the students to write down answers spontaneously without time for discussion or deliberation. Questions asked were:

1. What is the purpose of a robot?
2. How can Computer Science “build” robots?
3. How can a robot help humans solve problems?
4. How interested are you to pursue Computer Science in High School and beyond? (1=not at all interested, 5=very interested)
5. How interested are you to purse Computer Science in your spare time, for example reading magazines? (1=not at all interested, 5=very interested)

[1] 2010 data, available from http://www.schoolview.org, last retrieved April 25, 2012

6. *Have you done any research on robotics since last time?*

Questions 1-5 were administered for both pre- and post-test. Question 6 was administered only at the post-test.

# 4 Results

## 4.1 Pre-test

Response rate in group 1 were 17/18 and 26/26 in group 2. Two ESL (English as a second language) female students required additional help by their teacher to answer the questionnaire (group 1). All results are aggregated over both groups, whereas students that did not participate in the post test (3) were removed, leading to 40 samples.

The dominating pattern (25/40) in answering *Question 1* was that robots make the life of humans easier by being assistive companions in everyday live ("robots ease human life", "robots help humans with things","to help or entertain"), followed (5/40) by robots being tools for performing dull or dangerous jobs ("robots do things that humans don't want to do"), and (4/40) robots are more efficient than humans ("robots are more efficient","robots are meant to eliminate human error"). Other comments (6/40) were tongue-in-cheek (indicated by drawn emoticons) of the kind "robots creep people out" and "to take over the world". *Question 3* lead to similar patterns and outcomes, with students mentioning specific applications such as surgery, manufacturing, repairing, or outperforming the human mind such as in Chess or Jeopardy.

Answers to *Question 2* fell into three groups: students (11/40) able to identify a computer as significant component of a robotic system, which allows the robots to execute plans and reason ("Computer Science helps by telling the robot what to do", "It helps to make the robot 'think'", "To make the robot smart", "Because a robot is basically a computer that can move and talk"); students (13/40) that understand Computer Science as a discipline involving programming, but do not clearly articulate the role of programming in robotics ("because they program the robot", "It helps with programming"); and students (16/40) who seem to have little to no understanding of Computer Science ("It uses a robot to make a robot", "because they understand everything", "By showing and telling us how to build one", "because it takes a lot of science to build one", "to visualize how a robot will function", "to design a robot").

Quantitative results to Questions 4 and 5 are provided in Section 4.3. Answers provided by male and female students are significantly different with a p-value of 0.019 for Question 4, and p-value of 0.06 for Question 6.

## 4.2 Post-test

Of the 17 students in the first group, only 14 were present during the post-test. These 14 students consisted of 7 male and 7 female students. All students in the second group were present for both the pre- and post-test.

Answers to *Question 1* on the post-test followed many of the same patterns as during the pre-test. The most common answers (24/40) stated that robots make life on humans easier by assisting in everyday tasks. The two next most common answers were that robots do tasks that are too difficult, dull, or dangerous for humans (6/40), and that robots do whatever they are programmed to (6/40). Several students (3/40) stated that robots are machines that receive input and act upon it. One student (1/40) answered that robots do tasks that they are more efficient at than humans. No students gave tongue-in-cheek answers to this question on the post-test.

The same three groups of answers to *Question 2* identified in the pre-test are also present in answers to the post-test. However, the majority of students (24/40) were now able to identify the role of a computer in a robot, and the role of computer scientists in programming it. The remaining students either correctly identified programming as something that computer scientists do (9/40) or demonstrated a continued lack of understanding of how Computer Science relates to robotics (7/40).

Quantitative results on Questions 4 and 5 for pre- and post test are compared in Section 4.3. Answers provided by males and females were significantly different with a p-value of 0.014 for Question 4, and a p-value of 0.11 for Question 5.

When asked if the students had researched robotics between the first and second session, six students answered in the affirmative.

## 4.3 Qualitative and Quantitative Improvements

In answering *Question 2* approximately half of the students (19/40) showed an increased understanding of the role of computers and computer scientists in the creation and operating of robots. The other half of the students (21/40) showed no improvement in their understanding, although 9 of these students had previously identified the role of computers in robotics.

Of those students who showed an increased level of understanding 6 students who had not previously been able to identify the role of programming in robotics were able to indicate in their answers during the post-test that it was involved in their operation. An additional 2 students who answered similarly, and 8 students who identified Computer Science and programming as involved in the creation of robots, were able to state that a program controlled the actions of a robot. None of the students showed a decreased understanding of the role of Computer Science and programming in the field of robotics.

In answering *Question 4* (“How interested are you to pursue Computer Science in High School and beyond?”), all means show increasing trends, from $2.67 \pm 1.22$ to $2.91 \pm 1.3$ overall, from $2.36 \pm 1.05$ to $2.58 \pm 1.24$ for females, and from $3.25 \pm 1.34$

to $3.53 \pm 1.18$ for males. Although the increases are consistent among all groups, the means are only weakly significant (p value $\approx 0.16$ for all three paired distributions, all, male and females). This analysis, however, forgoes the polarizing effect the exercise had and which is reflected in the increasing variance: 16 students ranked Question 4 higher than at the pre-test, whereas 12 ranked it lower and 12 remain unchanged. (10 females ranked higher, 8 worse, 6 males ranked better, 4 worse.)

For *Question 5* ("How interested are you to pursue Computer Science in your spare time, for example reading magazines?"), all means show a slight decrease, from $2.36 \pm 1.38$ to $2.3 \pm 1.23$ overall, from $2.10 \pm 1.31$ to $2.10 \pm 1.11$ for females, and from $2.86 \pm 1.40$ to $2.68 \pm 1.38$ for males. These distributions are not significantly different, paired t-test return p-values of 0.74 overall, 0.30 for males and 0.48 for females. Also here, the activity has been polarizing: 11 students increase their ranking, while 11 decrease it, and 22 remain unchanged. (7 females ranked higher and 7 worse, 4 males ranked higher and 4 worse.)

## 5 Discussion

The response to the questions "What is the purpose of a robot?" and "How can robots help humans to solve problems?" show that robotics is overwhelmingly received as a positive by the $8^{th}$ graders and is perceived to improve the life of humans one way or the other. This is important as it shows that robotics can indeed serve as a strong motivator to engage in STEM. Whereas the observation that tongue-in-cheek answers to this question vanished in the post-test can be attributed little statistical significance due to the low number of samples, it could be attributed to students being more confident on the subject than before, which is supported by data.

In response to "How can Computer Science help to build robots", a little more than half show a more or less solid understanding how Computer Science can contribute to robotics and therefore to the societal benefits identified by most. Around 40% of the students show little to no understanding of Computer Science as a field. The fact that around half of the students do (subjectively) improve their understanding of the role of computation in robotics is encouraging, however.

As expected given the low enrollment by females in Computer Science, interest of girls in studying computer science (both in school and at home) is significantly lower than that of boys. Although an increase in chosing Computer Science as a field of study due to the activity is only marginal (from 2.36 to 2.58 on a scale from 1 to 5) for this group, the data shows a polarizing effect (also for boys) of the activity. By actively engaging into a Computer Science-related activity, students can make up their mind: 10 girls that are more interested than before (more than a third), are 10 potential future CS students, whereas 8 that are even less interested, are 8 more students that might have avoided a potential mistake and engage in a disappointing activity.

Interest in "Computer Science" or "Robotics" expressed by the students, as well as an increase of their interest level after a playful activity such as the one described here, should not be overestimated, however. Computers and robotics are clearly exciting, especially when offered as extra-curricular activity in a class-room setting, but science and learning how to make them might not. As anecdotal evidence we note the response of one student who expressed that he wants to pursue Computer Science “very much” (Question 6), but cannot imagine studying Computer Science (”not at all on Question 5). He annotated “Because I don’t like working with Computers about Science”. Conversely, drawing students into a field of study without presenting them with the technical rigor it requires might even be detrimental for their success.

As much as interest in Computer Science as a field of study increases, results on interest in Computer Science as an afterschool activity show little change. A possible explanation might be that the proposed activity is not very well suited on enabling this transitions. Cubelets are relatively new and little available (the 3 kits used in this activity were part of the first 3000 Cubelets shipped to Beta customers) and are expensive at $299 per kit. In order to serve as a vehicle to bring the classroom activity home, both its availability and affordability need to increase. Alternatively, lessons could be extended with “action items” that students could pursue at home and/or in follow-up after-school activities.

Although the test group have been middle schoolers, the proposed activity might equally well extend to 4th or 10th graders. While the complexity of possible construction is open-ended (the platform is Turing universal), younger children can potentially be reached by increased scaffolding of the activities. Exploring these opportunities is subject to future work.

## 6 Conclusion

This paper presents a 1-hour curriculum that allows outreach activities that increase awareness and understanding for computer science and robotics in a middle school setting. The activity is centered around Cubelets, a modular robotics construction kit that allows students to program with their hands, and which can be deployed with little to no preparation. The impact of the proposed activity has been examined by testing it on two classes of 8th graders within two 30 minute sessions plus a pre-test and post-test. Interest and understanding of computer science increases both qualitatively and quantitatively. Students are able to more precisely articulate the role of computing in robots after building a series of primitive, reactive vehicles, a mini-lecture and examining a set of more complex robotic building blocks including an AND gate. Students also show a significant increase in interest to pursue computer science as a field of study, whereas interest to pursue Computer Science as an after school activity remains unchanged. The proposed curriculum has therefore the potential to allow quick interventions by computer science graduate students or professors in local schools as well as rural areas as little to no setup time is required and the time of engagement is low. Here, it can provide encouragement to pursue

STEM-related topics in the future for some, while leading to a more informed choice for others.

## Acknowledgment

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