Robotics: Enhancing Pre-College Mathematics Learning with Real-world Examples

Abstract:

Seventeen ninth grade students worked in teams to build low cost robots, program them, and use them to draw various geometric shapes on a canvas of 6’ x 6’, all during a regular semester long course. The course was designed to enhance their interest in engineering and math, while providing a social context of empowerment, competition and cooperation. This paper will document our past and planned efforts to integrate robotics into high school math curriculum. We are driven by two fundamental objectives: (1) Build low cost robots that can be purchased or built incrementally to manage budgetary restrictions. These robots should be reliable, robust, and most important of all, be customizable for the specific needs of the teacher and the student teams; and (2) adapt the approach of “Understanding by Design” by Wiggins and McTighe in integrating robots into math lessons. They recommend a three-stage process: define objectives; determine assessments, and develop tasks (in our case, robotics based exercises).

For the first objective, we will provide details our on-going work on building low cost robots that every K-12 school can afford. It is based on open source principles, making it easy to learn from the community, and to innovate and contribute back to the community. New ideas and lessons will evolve that can provide a small remuneration to the inventors, while as a larger community we will all make progress in educating our next generation in math and engineering principles. There is potential for many exciting extensions.

For the second objective, we have used “Algebra 2: Common Core” by Charles et al., as the starting point to seek this mapping. This book fully aligns with the Common Core State Standards. Further, Dr. Wiggins is a co-author of this book, thus ensuring that this book is faithful to the Understanding by Design (UbD) philosophy. This paper in its final version will present our approaches fully. We seek the feedback of the reader to improve them.

We have made available all our course assets (robot design, Apps, code, and presentation videos) at a university website. We visualize this as a community resource that other researchers and educators can leverage to improve and adopt; we hope they will share their lessons and tools with the larger community.

Background:

The journey towards this project started when we came to know that a local school had a robotics club, but no robots. The students, both boys and girls, met once a week to discuss, but could make no headway on how to finance their club; purchase, operation, and maintenance of commercially available robots was beyond their means & capability. We wanted a simple low cost solution that they could easily comprehend and build upon. To this end, we offered a course to engineering undergraduate students in fall 2011. The result was a blueprint (for both hardware and software) for building a low cost robot. We have published the details elsewhere.
We also wanted the robot to fit into the K-12 science, technology, engineering, and mathematics (STEM) curriculum, specifically in math and Science, so more students would benefit from it, rather than a small group who is motivated to participate in a robotics club. Studies in the mathematics education research indicate that students may be able to recall certain facts, but fail to use those facts in solving novel problems. Some students do not even recognize that solving such problems is important. Students often “give clear evidence of knowing certain mathematics but then proceed to act as if they are completely ignorant of it” \(^8\). Bringing engineering technology into the mathematics classroom can help students understand the subject matter more deeply than in traditional mathematics instruction. We need to help expand our students’ mathematical toolbox: they need to learn the rules, concepts and formulas to solve mathematical problems. Students who only encounter the abstract nature of mathematics often describe it as a boring and dry subject and state that they never learn anything that they could use in real life. When practicum and pure thought are inextricably intertwined, that is real math instruction. Teaching math with robots combines these two sides of mathematics. This is elaborated in another paper by us\(^9\).

As we will elaborate further in the discussion section, there is a rich literature on the use of robots, computers and simulation tools to further the K-12 education. As a girl in 11\(^{th}\) grade at another local school commented recently, “We had a robotics class where we assembled and pushed buttons; but we really did not learn anything.” We provide here a different approach, of having students as partners, rather than mere users, in designing and developing their lessons. Hands-on team based activities and consequent social networking will also help them channel their energies better, reinforce each other’s learning, and collaboratively achieve more elegant solutions. We wanted our course to provide transparency on the software and hardware building blocks, to achieve three things: (1) the students could appreciate better the physics and engineering principles underlying the components; (2) the students could manipulate these components at a high level of abstraction, so they were not burdened with technological and software details; and (3) they feel empowered to manipulate the robotic platform to achieve their specific goals. To this end, we offered in spring 2012 a mechatronics course to 9\(^{th}\) grade pre-engineering students at a high school affiliated with our university. They worked in teams of 3 or 4 and built robots and programmed them to autonomously plot intermediate complexity mathematical shapes. Preliminary results were presented earlier\(^{10}\).

To achieve those semester end goals, these students first learned, as a class, to draw lines, circles and simple polygons, in various shapes and sizes, and with nesting. These components were then used as building blocks to create simple robotic art that they presented at semester end. Such art, after a few course offerings, may mature enough to be construed as creating something that is visual and inherently interesting to viewers, in the sense that the robots can be used to create a visual representation of geometric patterns; this can be highly motivating to students. Throughout history and in particular during the renaissance, artists such Leonardo daVinci and Piero della Francesca studied the correlation between geometry and aesthetic composition. The renaissance masters provide relevant examples. Students can extract geometric forms from printed reproductions as well as program the robots to create line forms such as the Golden rectangle\(^{11}\). This can be appealing to arts-oriented students to bring them into the fold to get better grounding in math. See Figure 1 for an example of a potential future robotic art project for this course\(^{12}\).
We also want to develop ways to sustain a larger community while facilitating individual schools to achieve sustenance, with their own innovation and creativity. For this to happen, one needs to note that this robotic infrastructure also furthers the goals of STEM, since a robotic platform would require seamless integration of all the STEM disciplines. For this reason, we have focused mainly on open source and component technologies for both hardware and software, so one could mix and match components that achieve the same end goal, perhaps with variation in one of the many system metrics, such as cost, speed, battery life, ease of use, etc. Challenges, however, abounded. Sophisticated robotics as practiced elsewhere require advanced knowledge, skill-set, and access to expensive hardware and software. The developers of Arduino have already addressed these issues by providing an user-friendly (higher level) interface and an open source tool suite, to primarily aid artists in developing physical computing applications. The open source platform uses a state-of-the-art microcontroller from ATMEL. Further, we wanted a central resource (to start with) that provided the most current information on our robotics platform, as Arduino has done for their embedded system platform. We have made progress in that direction with our current university website on robotics. We hope others around the world will access the information and benefit from it and to contribute to it, to further reduce the cost and the barrier to learning and innovation. We also have followed a similar path in developing our capabilities in building smart phone Apps. The associated website has had over 200K visits from developers around the world in the past 30 months.

In developing this flow, we have benefitted enormously from a six year industry grant on significantly improving a system company’s engineering design productivity. We were immensely helped by the open source software and hardware from Arduino, as mentioned above; it allows one to use low cost off-the-shelf components to assemble and program rapidly a microcontroller-based system. We extended this to build robots. The robot software and hardware were prototyped a priori by engineering college students, so we knew that the flow for high school students would be predictable and repeatable, and that robots built would be robust.
We were able to develop this infrastructure during multiple semesters, thanks to supportive administrators at our engineering college and the high school who saw value in supporting such explorations. They are once again behind our efforts as we attempt to put this platform in the right context to find ways to use it to benefit math education. We will elaborate our plans in the final paper and invite the reader to critique the same.

**Technical details of our existing courses:**

As indicated above, the impetus for this came from a local school that had a robotic club, but no robots. To address the issues of affordability and self-repairing ability, the authors offered a course in fall ’10 in which engineering students explored ways to build low cost robotic systems that were designed to be robust and reliable. The goal was that any hardware or software module that either did not function properly or was not meeting their goals, could be easily substituted with another one that was compatible at the level of interfacing (this is not difficult to do today, but still needs to be planned in; it cannot be an afterthought). The focus was on the design of hardware and software components to reach that goal. Most of the projects are fully documented along with videos.

Our robot comprises of a DF Robot 2WD mobile platform, 2 DF Robot wheel encoders, Parallax Ping Ultrasonic (US) range sensor, Robotics DMS infrared (IR) short distance sensor, Arduino Uno microcontroller board, Arduino Protoshield, 2 H-bridge motor drivers, and a few other miscellaneous items, all secured from two suppliers [www.robotshop.com, www.sparkfun.com]. Arduino is an open source initiative that provides significant hardware and software support for embedded system designers. Arduino’s Sketch language and APIs provide programming support for the underlying microcontroller without exposing the user to the extremely complex and confusing register level details of the ATMega 328 microcontroller from Atmel. The Arduino platform was developed primarily to aid artists (to control the stage props, applause, music, etc., for example) without overwhelming them with the underlying electronics. Extrapolating, it seemed like a good fit for both our engineering undergraduate students (from computer science, electrical engineering, and computer engineering), so they could focus on systems issues, and for high school students who have limited or no programming and electronics skills. See Figure 2 for the two robots that were built. There were differences, as described later; experiences with high school students’ class has allowed us to specify a $100 robot (without IR and US sensors) that is adequate for use in math classes at the 9th grade level. The robot can be made more sophisticated and useful for other applications, such as interactive gaming, with the aid of add-on components (such as IR and US sensors, as well as building blocks for wireless communication such as Bluetooth and Xbee).

Engineering pertinent experiences from our undergraduate level course: This class, offered in fall 2011, had an equal number of students from computer science, computer engineering, and electrical engineering. Each team was typically comprised of one student member from each of these three disciplines. Such teaming helped them harness different strengths and also appreciate and accommodate different perspectives. Seven teams were formed. The students used a 1 m x 1m floor space with reflector walls encircling the space. The student blog sites and videos of their robotic art are available at our website. Two teams focused on creating simple polygon patterns (a rectangle and a triangle); See videos of groups 1 and 6; this required effective use of the IR receivers and the ultrasound sensor for distance measurements, corrections for
interference and potential avoidance of ‘drunken sailor’ behavior of the robot because of the IR receiver characteristic in near field (more on this later). A third team (group 3) created intricate polygon pattern that was repeated a large number of times$^6$. See Figure 3. This required effective use of optical encoders and interrupts. The former did not yield clean ten pulses per turn, as would be expected. The electromechanical bouncing was evident even here and led to thousands of pulses. The students used back-to-back Nand gates and software delays to overcome the problem. Prioritization of interrupts had to be carefully thought through. Finally, while some teams complained of loss of precision in robotic movement when the batteries were somewhat drained, this group managed to create intricate patterns without losing control. Group 7 specialized in building a pen holder and the reflector walls that were used by other teams. In terms of lessons learned, the pen we chose was too bulky and the pen holder with pen ended up being a drag on the performance of the robot. Further, the use of four wheels caused large circles when the robot turned. It appears that other teams suffered because of lack of communication and coordination. However, we also recognized the need to help them plan and strategize; and also address issues in a piece-meal fashion. Experiences, both positive and negative, helped us identify a better kit and a focused syllabus when this material was used to teach a mechatronics course to high school students the following semester (spring 2012).

This section discusses the transition from the first robot to the second robot (See Figure 2); the four wheel version was used by the undergraduate students; the three wheel version, shown on the right side, was used by the high school teams. The high school students worked in teams of three and used a large canvas (80 cm by 80 cm sheet with greeting card thickness) to draw (or plot) their art on. They used a color pen that could be mounted in the center of the robotic platform when needed (in the previous version, we used a larger pen at the back, which was too heavy and impacted the drawing; see above). The robots now had three wheels (this facilitated the drawing of smaller circles and reduced power consumption), with two motors that are driven (through an H bridge and a power amplifier) from the PWM outputs of the Arduino Uno microcontroller. The robot also had one US ping sensor mounted in the front and two IR sensors mounted on the two sides. The sensors were used to ensure that the robot traveled on a straight line; this is achieved with reflector walls placed to make a 1 m x 1 m square fence. The wheel encoders provided 10 positive going pulses per turn. Student teams used Sketch language to program their robots$^9$. Undergraduate engineering students used interrupts and achieved intricate geometric patterns$^6$. We intentionally restricted our 9th grade high school students to draw simpler patterns that repeated in some simple way, so we could show how an algorithm can be reused with changes in parameters. The goal then is to make sure the algorithm is rugged and that it leads to repeatable results and then use this algorithm in different contexts to create their desired pattern. For example, a triangle involves two algorithms repeatedly used, viz., to draw a line, and to turn an angle. The first one will need two parameters: distance and angle (the angle parameter is used to ensure that the robot does not drift from its intended path), while the latter one will need one parameter: angle, with the angles referring to a standard coordinate system.

Engineering pertinent experiences from our high school level course: This course attracted 17 ninth graders at the Henderson School, FAU’s University School on our Boca Raton campus. These students are in their pre-engineering program. This was the second engineering course that they had taken. The students comprised of 11 boys and 6 girls, with strong aptitude for mathematics and engineering. Five teams of 3 or 4 students were formed and were asked to
choose a geometric pattern of medium complexity to draw with their robots. Each team built their own robot and developed algorithms for drawing lines and rotating by given angles. This required calibration of their robot’s wheels for the distance traveled (at different duty ratios of pulse width modulation, or PWM) in a given time period, and the length of the PWM train to make a complete circle (again, at different PWM duty ratios). To make such a tight circle, the outer wheel was subject to this PWM train, while the inner wheel was held stationary. One could make fairly precise angular turns by controlling the duration of the PWM train. Different groups needed angles of 45, 60, 72, or 90 degrees depending upon the mathematical shape they were creating. Our initial goal here was to have the student teams use the reflector walls along the fence as guideposts; but the IR receiver characteristic has a negative slope in the near field. So, any simple algorithm that checks for a large reading from the near side IR sensor to keep the robot away from that wall ended up making the robot end up at the wall. It was difficult to convey the concept of a more sophisticated algorithm to the student teams because of the time pressure to get a working prototype completed. Another way would have been to use ultrasound sensor to measure the distance from the front wall and use that to correct the robot’s path. Time pressure precluded us from incorporating either. Thus the final student implementations ended up being ‘deaf’ to the surroundings that executed their motions purely based on control of the motors with PWM trains and different duty ratios. The five teams implemented four different patterns (Trinity force of courage, Butterfly, our university logo, and Star). Links to their blogs and demos are provided at two sites 6, 21.

Other activities: We interviewed five of the high school students who had signed the institutional review board’s consent form for research protocols on human subjects. We interviewed them at the end of the semester in groups of 2 or 3 with the intent to see whether the course made any significant difference in the student’s understanding of the underlying Mathematics and Engineering principles. Results from this study, generally encouraging, were published last year 9.

Other Implementation Issues:

Errors involved in line-drawing with robots: Our goal is to use low cost robots in our work. Low cost robots will need to use mass manufactured parts in their kits. That brings in the issue of manufacturing variability. A wheel may not be precisely 2.5 cm in radius, as an example, and might have a tolerance of \( \pm 5\% \) in the radius. If one were to determine the distance traveled as being equivalent to a number of full and fractional turns, this tolerance will carry over to the distance traversed as well. A fractional or full turn can be estimated with the help of optical encoders. Such encoders will generate a pulse for a certain degrees of rotation of the wheel. However, there is finite resolution associated with this. As a consequence, there might be errors involved in quantifying fractional turns, which will add further ambiguity to the distance traversed. Also, in our elucidation of the Pythagorean Theorem, there will be need for physical turns of the robot by 90 degrees and 45 degrees. Such turns can also benefit from optical sensors, since it is a differential drive to the two sides of wheels that will bring about the physical turn. There could be errors in creating physical turns by these angles, furthering the ambiguity. These three types of errors may be considered to be systematic errors, but random with respect to each other. Thus, the total error from these errors is not an arithmetic sum, but will be based on the rms (root mean square) sum, and will be less. Our estimate is that for our
given robotic kit, the error in estimation of the distance traversed will be slightly higher than ±10%. This, however, is strictly based on the error compensation one can achieve with hardware alone. However, this can be improved in two distinct ways: (1) positional adjustment once the destination is reached, with the aid of an ultrasound range sensor; and (2) use of predictive algorithms in software to estimate fractional turns to a better accuracy than is feasible with feedback pulses from the optical encoder itself.

Course pedagogy issues: (1) We have taught project oriented courses for a number of years. The emphasis, before this spring semester, had been to give lectures, and institute a few quizzes, but essentially allow the teams to develop the project on their own. However, unlike the robotics course, the earlier groups (in non-robotics oriented courses) had the benefit of projects completed by earlier groups of students; that facilitated the thinking of the latest term’s students. However, this was missing for the fall 2011 students taking our robotics course, and some of their projects suffered. We changed our approach to teaching such project oriented courses in spring 2012. The first half of the semester was focused on the theory during the lecture hours, while they built the robots during the lab hours. Several quizzes and a mid-term exam evaluated the students on the lecture and lab material. This ensured that the students had an acceptable minimum level of understanding and competence when they started the project in the second half of the semester. The students also had a clearer idea of how they were faring in the class. These younger high school students may also have needed reinforcement of the ideas. Either way, it appears that we were able to help them in successful completing their projects. This was a significant improvement over the results from the fall 2011 semester with our undergraduate students from three different disciplines. (2) The high school students, under time pressure, discarded our recommended approach for use of infrared and ultrasound sensors and designed their algorithms merely based on control of distance traveled and angle turned. Successful completion of their projects is proof that high school projects can be undertaken with a simpler robotic kit. This brings down the cost from about $160 per kit (currently) to about $100, our targeted price point that should be met for schools to afford the robots. (3) The high school students seemed to have had problems with soldering, and thus had to use breadboards to connect wires from motors (and sensors) on to the Arduino Photo shield and the Arduino microcontroller board. It appears that we will use, in future course offerings, wire-wrap technology to make semi-permanent connections and avoid the potential for one of the bread-board wires to pop off and cause malfunctioning of the system. (4) Battery drainage was blamed by one student group for not drawing their star with proper angles, thus leading to a gap at the end. This group used 100% duty ratio and tried a large size star. Another team that drew a smaller sized star completed without any problems. (5) All these issues provide enough research material for an undergraduate robotics course in engineering at a later date. We expect to focus on building components or subsystems that can aid expansion of robot’s role in STEM education for high school students. Possible examples of this are: robust sensor sub-systems for tracking; optical encoder-based interrupt driven sub-system for angular turns; and graceful slowdown based on battery voltage fall—off characteristics.

Results:
Figure 2 shows the two robots we built. The second robot (to the right) built and used by the high school students had fewer wheels and used a lighter pen fixed in the center of the platform, rather than at the back as with the first robot (to the left) built and used by the undergraduate students.

Figure 3 shows an undergraduate student project for creating an intricate pattern. Figure 4 shows three geometric patterns proposed by the high school students (the middle picture is blocked out, as it is our university logo). Figure 5 shows a robot autonomously plotting the star and its completed form after the plotting was completed.

We have two sites that provide all the presentation videos and links to the student blog sites\textsuperscript{4,21}.

**Figure 2:** Our first and second robots, used in the undergraduate and high school courses, respectively.

**Figure 3:** Potential robotic art and its partial implementation in our undergraduate course.
Figure 4: Medium complexity mathematical shapes proposed and implemented in the high school class

Figure 5: Robotic Plot in progress and completed, for the Star in Figure 3

Figure 6: Some of our high school teams
(Please note, the students shown are enrolled at our developmental research school and their parents have signed Photo / Video Release forms).
Literature and Product Survey:

Although there is a clear lack of quantitative research on how robots can increase STEM achievement in students, and some of the research findings are inconclusive, most of the studies have shown positive correlation between the use of robots and students motivation towards STEM careers. Robotics is recognized by NSF to be an excellent vehicle for education and involving students in science and engineering, and, with the proper initiative, motivate promising students to pursue career tracks in mathematics and its applications.

Robots also promote learning of scientific & mathematic principles through experimentation. Bringing robots into the classrooms will have lasting benefits. When students learn with robots they will inevitably learn about many other disciplines. Students will learn to apply knowledge of math in novel ways to real world problems developing a richer knowledge base for their math education.

To teach mathematics with robots requires lessons that focus, motivate and highlight the mathematics in a meaningful way. Just because the math is present in an activity, it doesn’t indicate that students will learn math. The instruction, robots, and lessons have to be carefully designed in an integrated approach to achieve that goal. Unit activities have to be so tightly interwoven with an important math concept that the students couldn’t help but learn about the math in order to solve the design problem.

Logo and the Turtle for Robotics and Mathematics Education: The popular Logo environment has involved the Turtle, originally a robotic creature that moved around on the floor. It can be directed by typing commands at the computer. The turtle was invented by Seymour Papert and his colleagues at MIT. He wanted to make a computer language for children. He created a robot and called it the turtle. The robot could move forward or backward and it could turn right or left. With these simple commands, the turtle robot could draw amazing pictures. Logo can be a very powerful tool to help children – and college students – learn mathematics. It could help kindergarten children write simple programs to draw interesting shapes. It has also been used by college students to solve difficult problems in calculus.

Despite its many potential benefits, Logo did not become part of the school math curriculum, and it is not referenced in the Core Curriculum Standards. It is, however, possible to create something that has many of the good points of Logo, and still connect it to classroom practice. It is especially important to have a transitional object, like the turtle. But that object must make a transition to topics that are relevant to the mathematics curriculum. Logo was developed by computer scientists with a strong interest in solving difficult mathematical problems. That may have caused a barrier to its usage.

A brief comparison with other academic robotic platforms follows: (1). Lego and VEX at unit prices of $265 to $350 are expensive, and for some schools, cost is the difference between robots and no robots. Our starter robot will cost $100. (2). Lego and VEX are proprietary. We use the open source tools of Arduino and extend it to robotics. There is a need for an open source approach to help all to learn from each other and increase the number of lessons and examples. If the students at a school develop innovative ideas, they can use the open source market to
generate some revenue and help acquire more robots. (3). Lego is too sophisticated -- it sets some students' expectations too high -- and then they will not be able to solve engineering problems in an optimal manner when they move to college or a job. They will lack good STEM skills. (4) Lego’s sophistication sets the bar too high. This may discourage some other students from under-represented communities from entering the STEM fields.

**Robotics Curriculum Research:**

CMU’s Robotics Academy is working to provide research-based documentation for educators interested in teaching 21st century skill sets to children. Their belief is that when you have students “doing” as opposed to watching, that they will be able to build concrete bonds to the concepts they are learning. These bonds will enable new learners to reconstruct and synthesize the information later, which in turn will lead to deeper understanding. The links in this section provide access to papers and research that others have posted on the web. This list is by no means comprehensive and the Robotics Academy does not agree or disagree with all of the findings of the authors of these papers. These papers serve as food for thought for anyone using or considering using robotics and authentic assessment strategies in their classroom.

**Mapping to the Mathematics Curriculum:**

A famous story says that the initial flash of analytic geometry came to Descartes by watching the fly crawling about on the ceiling near a corner of his room. It struck him that the path of the fly on the ceiling could be described if only one knew the relation connecting the fly’s distances from two adjacent walls. Even though this story may be apocryphal, it has good pedagogic value.

The content of the math curricula has been fairly constant (Algebra is still Algebra), however, the way we teach math, our aim, the educational methodologies and strategies we use must be adjusted to meet the needs of our 21st century students. These students have fundamentally different goals, interest and motivation. Today’s learners recognize that going to school is not about earning a certificate but learning valuable and marketable knowledge and skills that can be utilized in their future professions. The high school diploma is far from a final destination; it is only a tool. The practice, training and professional development they gain during their school years must count as significant for the world of work. Teachers have to keep in mind that their students are affected by technology gadgets, the information and media revolution, as well as by economic and social changes. Educators need to develop and deliver instructions that are relevant to the students.

Mathematics is dualistic: it is pure science as it is the achievements of human thought; a timeless, yet ever-evolving system. On the other hand, mathematics is a tool; it offers real life applications and practical usefulness in solving real life problems. The effectiveness of the teachers’ work can be determined by finding the correct proportions in this duality.

Idit Harel Caperton, who worked with Seymour Papert while at MIT, has been the inspiration behind the Globaloria learning network in her role as President of the World Wide Workshop Foundation. The program has been incorporated in Virginia and Texas in large school counties,
and by the third year, has had about 350 students in each of the states in the program (starting from <100 students in each of the states). They used PC-based gaming (with Adobe tools) as their intervention. The focus was on 6th and 7th graders, and they had six learning outcomes of their own, and used math and science state tests as pre- and post-tests. The students did 90 minutes of the intervention (most of the days) during the regular school year. The final outcome: Mathematics and Critical Thinking skills scores were very significantly improved. She involved many university professors in conducting objective evaluations. This provides a theoretical framework/ initial feasibility study that we can reference and build on.

Our flow differs thus: We will use robotic puzzles and art (not computer games). There are advantages in terms of social interaction, team concepts (collaboration and competition), and physical realization, that PC games do not provide. We have made the robots low cost by using open source tools. Hands-on-robotics, however, may be said to present real-world limitations in terms of precise distance and angle measurements. We believe that ‘estimation’ and the consequent physical and visual realization help capture Mathematics in both its dual roles of a science and a tool. Overmars compared Logo and Lego, opted for the latter, but cites the disadvantages of cost and limited programming. Open source tools and innovations will overcome both these issues. Also, we will use robots to create geometric art. STEM with Arts (STEAM/ TEAM) has recently gained momentum.

Mapping to Common Core Standards: These standards were developed in collaboration with teachers, school administrators, and experts, to provide a clear and consistent framework to prepare our children for college and the workforce. This section will be fully developed in the final paper, in conjunction with references to a book that incorporates the common core standards.

Mapping to Future Skill Demands: Because important standards for college and career readiness are distributed across grades and courses, systems for evaluating college and career readiness should reach as far back in the standards as Grades 6-8. This body of material includes powerfully useful proficiencies such as applying ratio reasoning in real-world and mathematical problems, computing fluently with positive and negative fractions and decimals, and solving real-world and mathematical problems. The National Research Council (NRC) has identified the following as future skill demands: STEM, practical skills that complement concepts, team building and social skills, systems thinking, cognitive adaptability and flexibility, entrepreneurship, communication, and abstract thinking and problem solving. Our proposed incorporation of robotics in a math course would prepare in most of these areas. Incorporation of such hands-on team activities in other courses would further strengthen our national fabric for the future.

Conclusions:

National Science Foundation (NSF) has launched a new initiative entitled CE21 (Computing Education for the 21st Century). Researchers at other institutions have explored the use of Java, Processing, and Python to expose K-12 students to computer education. We provide here yet another programming paradigm based on robotics and the Sketch language that has the potential to provide a social context and attract non-STEM oriented students to the STEM fold. Learning
programming with robots has the advantage (compared to the above cited programming languages) of providing a social context and a hands-on experience. However, commercialization of robotics has priced the robots too far beyond the point of affordability for K-12 schools. We believe we can build low cost robots that schools can afford. We have presented our experiences in that regard here.

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