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A Robotics-Based 3D Modeling Curriculum for K-12 Education

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A Robotics-Based 3D Modeling Curriculum for K-12 Education (Evaluation)

Abstract

This paper presents a new curriculum designed for teaching 3D modeling and engineering design practices to K-12 students. In particular, the curriculum uses robotics to contextualize the teaching of mechanical engineering design concepts. As widely studied and suggested by new standards, such as the Next Generation Science Standards (NGSS), in order to be able to succeed in STEM related degrees and jobs, students need to be exposed as early as possible to concepts and practices typical to the world in which they are going to live and work. The standards particularly emphasize engineering design and its integration into the structure of K-12 science education. To fulfill this integration objective, the curriculum presented in this paper focuses on designing and 3D printing components for the Linkbot modular robots. Linkbots are educational robots developed at Barobo, Inc. in collaboration with the UC Davis C-STEM Center. Several other curricula have already been developed by the C-STEM Center to use these robots as a teaching tool in math classes and as an introduction to computer programming. This 3D modeling curriculum can be easily integrated with the robotics and computing ones, providing a deeper insight into the complexity of how different engineering disciplines interlace in the process of designing and programming a robot. Especially, it reinforces the concepts of 2D and 3D geometrical shapes, dimensioning of objects and combining elementary geometrical shapes to build more complex ones. The curriculum described in this paper is composed of six modules in which students can learn the basics and good practices of 3D modeling using Autodesk Inventor or SolidWorks, the modeling software commonly used in Mechanical Engineering design. A series of exercises then allows students to experiment on what they just learned. The curriculum was tested during two one-week-long summer camps held by the UC Davis C-STEM Center and is currently tested by two high schools associated with the Center. Results from surveys conducted after the summer camps are presented. They mainly show that students felt challenged by tasks typically performed by "real engineers" and proud of being able to design and 3D print their own idea. All the students felt that they were given the means to complete the assigned tasks.

INTRODUCTION

From an engineering point of view, 3D printing is classified as an additive manufacturing technique. This means a manufacturing process that allows the building of a component directly from a 3D model developed on a computer. This production process can be completely performed by a machine and uses plastic as a structural material. These two characteristics, complete automation, and use of plastic instead of metal, make 3D printing the perfect manufacturing process for prototyping because less safety and procedural training are required when operating a 3D printer and the production time is much shorter than that required to produce a part in a machine shop. In the last decade, this simplicity of operation and reduced production time have contributed to increasing the diffusion of 3D printing[1,2] and made 3D printers more widespread and affordable machines. In the meantime, 3D modeling software has become more widespread especially in educational environments for which CAD software companies have developed specific versions of the software.[3,4] The increased availability of 3D modeling software and 3D printing machines has opened the way to a number of new applications in STEM education, where, as reports show,[5,6] 3D printing can be used as a powerful tool in engaging students in learning and experimenting design methods. When using this manufacturing technique, parts are readily available, all the risks related to machining are removed and students can develop their projects and study their results within a limited amount of time. 3D design and printing are also commonly used prototyping techniques in engineering colleges and in the industry. Therefore, introducing K-12 students to engineering design practices and its applications in the STEM field as early as possible can prepare them better for future education and careers.

Following this idea of integrating engineering design in K-12 STEM education, the Next Generation Science Standards (NGSS)[7,8] were developed to help educators formulate curricula[9,10] that integrate engineering design core ideas and practice in a multidisciplinary learning environment. This approach promotes the linking of concepts and hands-on experience during the learning process which helps students better remember[11,12] what they learn. Moreover, if the experience utilizes the same tools used by engineers, it can be useful for students when entering the job market or pursuing higher education. A number of curricula have been proposed to integrate these aspects,[13] for example those from Project Lead The Way (PLTW).[15]

NGSS defines the three core ideas of engineering design[14] as: (1) Definition of the problem, (2) design of solutions to the problem and (3) optimization of the solution. The curriculum described in this paper was developed at the UC Davis C-STEM Center[16] as a tool to introduce engineering design concepts to high school and middle school students. To introduce the three core ideas identified by the NGSS in a more effective and engaging way, the curriculum approaches the concept of introducing engineering design to K-12 education in a different way than other curricula. In fact, it uses robotics to contextualize the design process and to provide a real-world framework for defining the problem and conceiving a solution.

Robotics is one of the most eclectic fields in engineering because it involves many different disciplines from mechanical engineering to electrical engineering and computer science. It is therefore an ideal platform for introducing students to the concepts of engineering design. Getting a robot to achieve a task is a complicated process that involves both a good programming strategy and having the proper hardware accessories, which often need to be custom made. The curriculum presented in this paper was developed as a module of the other Robotics and Computing curricula developed at the UC Davis C-STEM Center with the objective of giving students the means to design custom parts for the robots.

The curriculum is composed of six modules where students learn how to use Autodesk Inventor[25] or SolidWorks[26] for 3D modeling. All the tutorials and examples are related to the design of components for Linkbot modular robots, made by Barobo, Inc.[27] These easy to assemble robots were specifically designed to be used as teaching supports in programming and mathematics classes. They have a limited number of parts to help students focus on accomplishing the programming task rather than dealing with overly complex hardware issues. As can be seen from Figure 1, these robots are cube shaped, with one face rounded and on the other three presenting moving joints and standard connectors. This last feature allows users to design virtually any type of accessory to enhance the functionality of the robots. Many of the currently available Linkbot accessories are also shown in Figure 1.

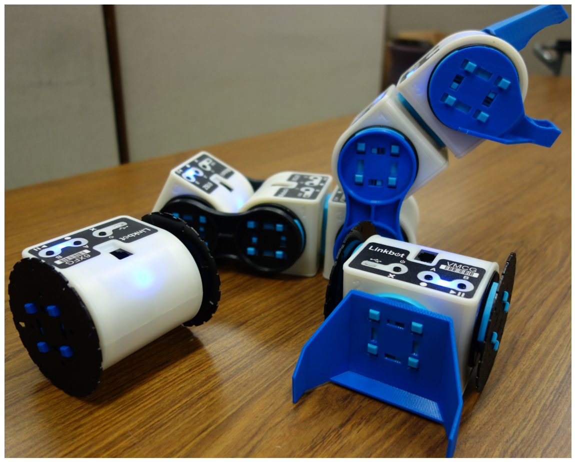


Figure 1: Linkbots with different accessories

When using the curriculum, students first learn the basics of 3D modeling and reinforce some geometric concepts such as 2D and 3D shapes, dimensions and combination of elementary geometric shapes to build more complex designs. After learning these concepts while following a tutorial, students are encouraged to use their creativity in designing new components to solve specific problems. The designs created are then ready to be 3D printed. These features of exploiting creativity, easy manufacturing and immediate testing of the design, can make the developed curriculum interesting also to underrepresented groups in the mechanical engineering and robotics fields.[28,29] In the curriculum, concepts are taught starting from the very basics of mechanical design. Therefore, teachers who want to implement this curriculum, need no prior knowledge of 3D modeling software apart from that required to complete the tasks in the curriculum.

The next sections presents some implementation aspects and feedback from testing some of the modules of the curriculum during two one-week-long summer camps. It is important to stress again that this curriculum can not only be used standalone to teach the basics of 3D modeling in engineering design but can also be used as an extension to the robotics curriculum already developed by the UC Davis C-STEM Center.

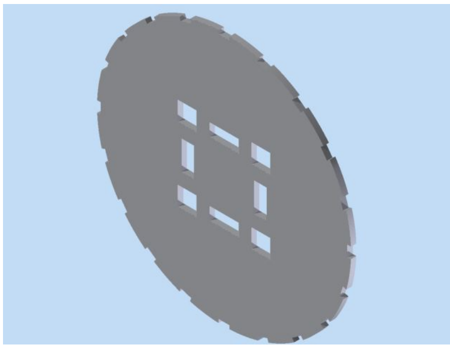
3D MODELING CURRICULUM

To progressively teach the tools and good practices of mechanical design, the curriculum was divided into six modules, each of them corresponding to a three hour long activity. In each module, students are first introduced to the new concepts through a step by step tutorial and then asked to use what they just learned to solve a specific problem. To reinforce their understanding, once introduced in a section, topics are carried on and reused in the following module. As already said, all the tutorials involve designing a part for the Linkbot modular robot and this common thread is developed throughout all the curriculum. Two versions of the curriculum were developed. One uses Autodesk Inventor, the other SolidWorks thus allowing more flexibility in the choice of the 3D modeling software.

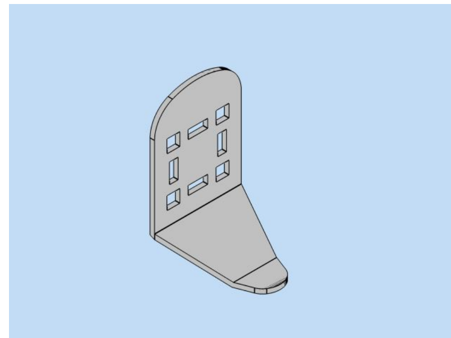
- **MODULE 1: Design of a wheel. Learn the basics.** In this first module, students learn how to design a single part. They are presented with the basic drawing tools available in the Autodesk Inventor or SolidWorks software together with some basic mechanical design good practices. In particular, the basic steps of CAD design are taught: build a 2D "sketch" and then "extrude" it into a 3-dimensional shape. At the end of the tutorial, students are also taught how to create patterns of the same feature on an already existing part and how to properly format the part for 3D printing. Figure 2a shows the output of the first tutorial, ready to be 3D printed into a real wheel usable by the robot. When working on this first module, students learn the difference between 3D and 2D geometry. Also, while discovering the "sketch" tool, students reinforce their understanding of how to define an elementary geometrical shape, such as the length of the sides for a rectangle or the diameter for a circle.
- **MODULE 2: Design of a caster. Learn to work on multiple planes.** In this second section, students learn how to design a caster, a tool to support the rear part of the Linkbot when it is moving as a two wheel vehicle. A 3D model of a caster is shown in Figure 2b. While following the tutorial, students are initially presented with the same design tools as the previous module: sketching and extruding. However, more complicated shapes are built in this tutorial. The concept of building on already existing parts to add features on them is also introduced. While still working on the definition of geometric shapes, students learn how to correctly set the dimensions and how to combine elementary parts to build more complicated shapes.
- **MODULE 3: Design of a bridge connector. Learn circles and arches.** In this module, students are still challenged to create a sketch for a more complicated shape. In particular they work on merging elementary geometric shapes like arcs and circles and on their relative positioning. The result, shown in Figure 2c is a component designed to connect the joints of two Linkbots when they are on the same direction but separated by an offset. Once completed, some more advanced extrusion features are introduced to teach how to create hollows in an already existing solid part.
- **MODULE 4: Design of a square snap connector. Learn how to build on existing parts.** In this section students are taught how to design a square snap connector, a component that allows the robot to stand up. To begin with, students are given the 3D model of a standard snap connector and then learn how to design more advanced features and add them to the

existing part to personalize it. The result is shown in Figure 2d. While working on this section, students reinforce their understanding of 3D figures, made up by a collection of faces separated by an offset and oriented in different directions of space.

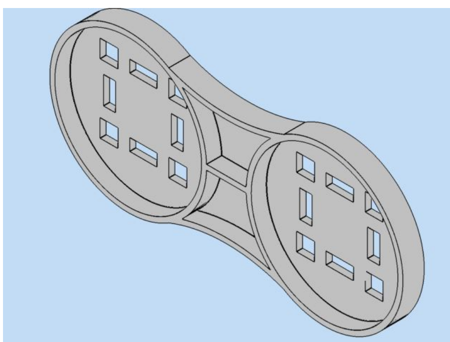
- **MODULE 5: Design of a Lego Mindstorms wheel connector. Learn how to use advanced features and build on existing parts.** The scope of this section is similar to the previous one. Starting from the 3D model of the basic snap connector, students learn how to add features to it and obtain a component to connect Lego Mindstorms wheels to the Linkbot. More advanced 3D modeling features are introduced. The result is shown in Figure 2e. When working on this section, students learn the importance of dimensions to make sure the part they are designing interacts properly with already existing ones.
- **MODULE 6: Design of a gear. Learn about gears.** In this last section, students are introduced to the concepts of gear design, one of the most common components in mechanical engineering design. Before starting the design process, some basic information on gears is provided, such as nomenclature and relevant dimensions. Students learn how motion is transmitted between gears and where the contact points of the two wheels are in relative motion. The most common gears used in industrial applications are described as well as the importance of standardizing dimensions. Once the basic concepts of gears are learned, students are guided into the design of a gear to be connected to the Linkbot. The software used for the curriculum provides specific tools to design gears, where the user needs to enter the relevant dimensions and the software generates a gear of standard size. The resulting gear is shown in Figure 2f. This last module was designed to give a deeper insight into the complexity of the mechanical engineering design process, as a combination of modeling, mathematics and geometry concepts.



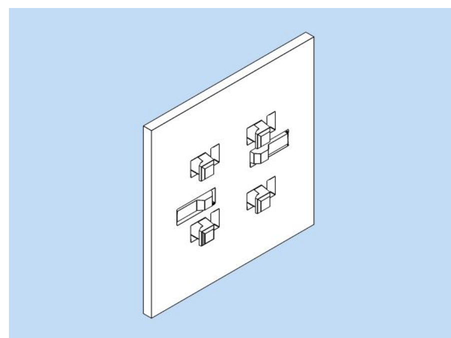
(a) Wheel



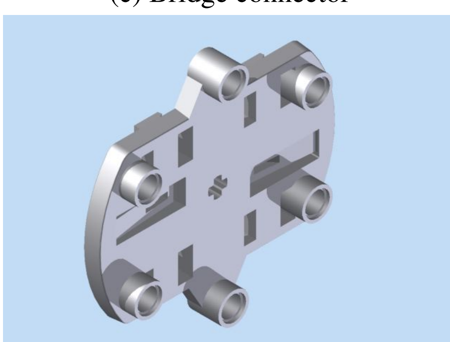
(b) Caster



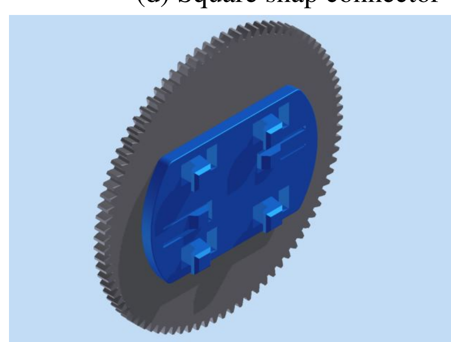
(c) Bridge connector



(d) Square snap connector



(e) Lego Mindstorm wheel connector



(f) Gear

Figure 2: [a-f] Parts designed in each section of the curriculum.

APPLICATIONS OF THE 3D PRINTING CURRICULUM

The developed curriculum[17, 18] can be used together with the robotics[19] ,programming[20–22] and mathematics[23, 24] curricula developed at the UC Davis C-STEM Center for integrated learning of all the different aspects of engineering design, from programming, computing and software development to design of mechanical parts. However, the curriculum can also be used independently as an introduction to mechanical engineering design and to reinforce geometry concepts through a series of practical examples. When taught using this curriculum, once the basic concepts and practices are introduced, students are able to use the 3D modeling software independently to exploit their creativity to solve specific tasks that require the design of a customized part.

The application becomes even more appealing when a 3D printer is available so that students can immediately see the result of their design. An important feature of the curriculum is that when designing a part, students are always reminded that what they are designing will be used for real world applications such as robotics.Therefore it is important, for example, to properly dimension the parts to perform the desired task and to make them interact with other existing components.

Some preliminary testing of the curriculum was carried out during two one-week-long summer camps at UC Davis. The main focus of these camps was on 3D modeling and mechanical engineering design but students were also introduced to programming the Linkbot robots. This was done to give a glimpse of how mechanical design and programming can be related. Implementation details and results from surveys carried out at the end of each camp are analyzed and summarized in the next two sections.

CURRICULUM IMPLEMENTATION

To get a preliminary idea on the consistency of the 3D modeling curriculum developed, some modules of it were tested during two one-week-long summer camps for middle school students. The classroom instruction and independent work all took place in a computer lab at the University of California, Davis, in the summer of 2014. The number of students attending the camps was 18 for the first week and 23 for the second. Camps were jointly taught by UC Davis students from the Mechanical Engineering and Education Department. Daily lesson plans were developed in conjunction with the C-STEM Center staff to ensure teaching effectiveness. During the camps, campers were engaged in different activities aiming at introducing the basic concepts of engineering design such as brainstorming, prototyping and testing. Computer aided design activities were held for three hours every day and the 3D modeling curriculum was used during that time.

During the computer design activities, particular attention was given to how the mechanical design software SolidWorks and 3D printing are introduced to students who have no prior experience using these tools. In both camps, after going through the first three modules of the curriculum, students were encouraged to use their creativity and the skills just learned to create their own custom designs starting from a basic, common model. The design they had to create was a personalized plaque to attach to the robot. Once the design was done, students had the opportunity to use a 3D printer to print their work.

The same curriculum is currently being tested in two high schools associated with the UC Davis C-STEM Center. These schools use it mainly in conjunction with the other curricula provided by the Center as well as other engineering curricula.

CURRICULUM EVALUATION RESULTS

At the end of each camp, anonymous evaluation surveys were administered to the campers. In particular, students were asked to evaluate what was their most and least favorite part of the camp and if what they learned had somewhat changed their perception of technology and the engineering field. Data about gender and ethnicity was also gathered. For the open-ended questions in the surveys, common themes have been identified while for the quantitative questions, percentages have been calculated. In general, the feedback obtained from the two camps was very similar. Following are the results obtained analyzing the surveys from both weeks.

1. **What was your favorite part about learning 3D modeling and why?**

   Theme 1: Designing and creating the plaques was a favorite activity.

   - Learning how to design a model...
   - Designing the plaques because it was fun...
   - I liked making my name plaque...
   - ...seeing my plaque all finished and knowing I made all of it.
   - ...we could design our own stuff because we got to do whatever we wanted.

   Theme 2: Learning about technology was a favorite activity.

   - ...learning about 3D printing.
   - ...we were able to actually do it on a computer.
   - SolidWorks.

   Theme 3: Mimicking engineers was a favorite activity.

   - ...feeling like I was actually doing what an engineer would do.
   - ...it was like something that the engineers did, so I thought it was very exciting.

	5	4.5	4	3	2	1
How easy was it to learn SolidWorks (5 being easiest)	5.9%	0%	47.1%	47.1%	0%	0%
How easy was it to to follow the steps of the tutorial (5 being easiest)	23.5%	0%	41.2%	35.3%	0%	0%
Was learning Solidworks interesting? (5 being definitely, 1 being not)	64.7%	5.9%	23.5%	5.9%	0%	0%

2. **What was your least favorite part about learning 3D modeling and why?**

   Theme 1: The physical environment was a least favorite part.

   - It had uncomfortable chairs.
   - The computers are nasty to touch (please de-germify).
   - The computer lab is crowded.
   - It was really cold in the computer lab.

   Theme 2: Feeling confused or left behind was a least favorite part.

   - There was a lot of steps and instructions in order to understand the process of this thing, it was a bit confusing.
   - sometimes the teacher taught too fast so it was hard to follow along on the computer.
   - When I was first trying out SolidWorks because it was confusing...

   Theme 3: The first day was a least favorite part.

   - Watching the video on SolidWorks. That was the first day. Kind of boring.
   - The first day we didn't have speakers so we couldn't hear.
   - The first day was boring.

3. **What did you like most about the 3D printer? Least?**

   Theme 1: Seeing a 3D printer and watching it in action was a most-liked aspect.

   - I got to see a 3D printer.
   - ...watching the 3D printer work.
   - We saw an actual 3D printer.
   - I loved getting to see the printer...
   - I liked watching our plaques being printed.

- I liked seeing the 3D printer when it was printing!
- Being able to watch a 3D printer in action...
- I got to see a real 3D printer actually working in person.

Theme 2: Students' sensory experiences were a least-liked aspect.

- The protective glasses were uncomfortable
- I did not like it because it was hot and stuffy.
- I didn't like the smell.
- ...the thing I liked least was how it was so crowded.

4. **How confident were you with computers and robot technology before this camp? (5 being the most and 1 the least)**

5	4.5	4	3	2	1	Mean	SD
0%	5.9%	47.17%	23.5%	11.8%	5.9%	3.3438	.9784

5. **How confident are you with computers and robot technology now that you've completed the camp? (5 being the most and 1 the least)**

5	4.5	4	3.5	3	2	1	Mean	SD
35.3%	5.9%	29.4%	5.9%	17.6%	0%	0%	4.1875	.7719

6. **Demographic information**

Gender

- 41.2% of the respondents marked "male"
- 41.2% of the respondents marked "female"
- 5.9% of the respondents did not mark either gender.
- 11.8% of the respondents marked both "male" and "female."

Which of these best describes your race/ethnicity?

- 0% of the respondents marked "African American/Black."
- 17.6% of the respondents marked "Asian/Pacific Islander."
- 5.9% of the respondents marked "Hispanic/Latina."
- 0% of the respondents marked "Native American/American Indian."
- 17.6% of the respondents marked "White/Caucasian."
- 41.2% of the respondents marked "Mixed."

- 11.8% of the respondents did not mark anything and instead wrote “do not feel comfortable revealing race.”

The survey results show that students greatly enjoyed creating their own, custom 3D models. The freedom to experiment within the confines of a given problem allowed students to learn the basics of SolidWorks without feeling smothered by the lesson plan. The ability to design custom parts was a major positive theme in the survey. The curriculum also emphasizes the fact that the models created during the students’ exercises are exact replicas of the actual 3D parts used on the Linkbot modular robots. This emphasis also proved to be a theme in the students’ responses and shows that students respond well to such stimulus.

It should also be noted that the students were far more sensitive than expected to the environment they were working in. The majority of negative feedback received is related to this theme. Even when students were asked to reflect specifically on the teacher, or the lesson, they often provided critiques regarding the physical environment. This shows that more care should be taken in creating a pleasing environment. Students can be very easily distracted when using computers and the survey shows reducing the environmental distractions should be a higher priority to help students focus on their tasks.

There were a wide variety of ethnicities represented in the camp: 17.6% Asian/Pacific Islander; 5.9% Hispanic/Latina; 17.6% White/Caucasian; and 41.2% mixed.

The percentage of male and female students attending the camp was perfectly split, 41.2%. This last data is of great importance since it demonstrates interest and participation of female students in a field generally dominated by males.

CONCLUSION

The presented 3D modeling curriculum follows the stream of educational standards and guidelines which point towards a stronger integration of engineering design practices in science and engineering education for K-12 students. It is a modular curriculum contextualized in the design of parts for Linkbot modular robots. Through the tutorials and exercises in the curriculum, students learn the basics of the mechanical engineering design process and how to combine these skills with their own creativity to solve real-world engineering problems. The curriculum can be used in conjunction with the robotics, programming and mathematics curricula developed by the UC Davis C-STEM Center and become a powerful means to teach students how to approach the solution of a real world problem using mathematics, physical and engineering concepts.

This curriculum has been tested in two one-week long summer camps for middle school students at UC Davis and is currently tested by two high schools associated with the UC Davis C-STEM Center. Results from data collected during the summer camps are promising. Students were engaged by having the possibility to successfully use a software tool commonly used in the mechanical engineering field. Also, being able to 3D print and use their designs, boosted students’ confidence.

ACKNOWLEDGMENT

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