Soft Robotics: An Introduction to Design Methodology and Engineering

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Abstract

Soft robotics is an emerging field that uses stretchy, soft, flexible materials to perform robotic functions. Though high school students may be exposed to robots, they may not be familiar with how robots fully work and operate too. This unit introduces students to design methodology and engineering through the field of soft robotics. It aims to center students in the learning process, by incorporating inquiry-based engineering design. Due to its hands-on nature and use of inexpensive materials, soft robotics is well suited to classroom use. In this unit, students will discover what makes something a robot, apply design methodology to come up with engineering solutions, create a soft robot finger and manually actuated gripper, and explain rationale for their design through evidence. Ultimately, the unit aims to increase student engagement and investment to foster motivation to engage with challenging concepts and pursue engineering.

Keywords: robotics, robot, engineering, design, methodology, process

Unit Content

Soft robotics is an emerging field that utilizes stretchy and compliant materials such as rubber, cloth, and paper to perform a variety of functions. Inspired by nature, like the tentacles of an octopus and the grip/grasp release of animals, the field of soft robotics is continually expanding in scope (Rus and Tolley). In contrast, hard robots are rigid-linked with actuators for every joint, made of metal, and require large motors. Due to its compliant nature, soft robots have actuators integrated and distributed throughout, allowing them to interact more safely with humans. Compliant mechanisms also offer increased performance, reduced cost, and the ability to be miniaturized (Howell 14).

Beyond Baymax, the soft robot from Big Hero 6, learners may not be exposed to nor know much about the field of soft robotics. On top of that, students may not know how a hard robot works and operates too. And yet, learners may be increasingly exposed to robotics with the influx of novel inventions and applications.

Problem Statement

The main challenge I hope to address with this unit is creating a more student-centered learning environment. More specifically, I would like students to have greater engagement and take ownership of their learning. If students are more interested in the topic, they may be more willing to do the critical and creative thinking that goes along with accessing that topic, i.e. using higher order math and reading skills. While I would still need to scaffold classwork, I think greater student investment would foster their motivation to engage with challenging concepts.

An inquiry-based unit on soft robotics can help address this challenge. Soft robotics is an ideal topic to focus on because it is applied and tangible; students have probably been exposed to robotics in some form, but probably do not know fully how a robot works and operates. Soft robotics is well suited to classroom use too because of its hands-on nature and use of inexpensive fabrication methods. In particular, I hope to introduce design methodology (how to think about design, how to create something that produces a particular motion) as well as the practical hands-on doing of creating a robot. So far, my lessons with the highest student engagement tend to be those involving a lab experiment or a kinesthetic component. My unit endeavors to incorporate the hands-on components of the soft robotics seminar in straightforward, accessible ways such that all students are engaged and can achieve success.

Classroom Context

I teach 9th Grade Physical Science at Northeast High School, the largest neighborhood high school in Philadelphia. My students come from a number of different feeder middle schools. I also teach two push-in classes where there are a large number of students with IEPs. Many of my students struggle with math and reading. I have found that some students have misconceptions with negative numbers and have difficulty with performing multiple operations on a set of numbers. In terms of reading, my students may not always read directions and have difficulty with following procedures due to wordiness, impatience, and/or low comprehension. Given these learning needs, I often scaffold and modify classroom instruction to support the students that test below grade math and reading levels.

At Northeast, we are at least fortunate to have one fully equipped chemistry/biology laboratory. Given that there are many science classes too, however, I have not taken my students to the lab that often. My students frequently ask me “When are we going to the lab?”, probably because they enjoyed their past experiences and want to do more hands-on work. Indeed, my lessons with the highest student engagement tend to be those involving an experiment or a kinesthetic component. Evidently, my students crave to build and tinker with materials. Therefore, creating something can be used as an incentive for students to be engaged with the course content.

Unit Objectives

This unit focuses on soft robotics in order to introduce design methodology and engineering. It will begin with an introduction that answers “What is a robot?” and the applications of soft robotics. This will be accomplished through a guided reading and class discussion. Next, design methodology will be introduced to expose students to the design process of engineers (Cooper Hewitt). Content from the Soft Robotics Toolkit (SRT), an open-access website containing information about the design, fabrication, and characterization of soft-robotic systems, will be adapted for students to create a soft robot (Holland et al.). Students will create Shape Deposition Manufacturing (SDM) Finger out of silicone elastomer (Berndt et al.). Moreover, this activity incorporates design methodology by having students make hypotheses for the device’s performance. Students will then evaluate the performance of the finger by building a manually actuated gripper and testing and customizing the gripper to an object. Students will connect the SDM Finger to course content relating to chemical reactions (curing the elastomer) and energy (calculating how much energy is needed to operate the gripper). The final performance assessment will incorporate both focuses of design methodology and engineering: students will apply design methodology to a new use case and explain reasoning for their SDM finger gripper design based on evidence. Overall, the unit will be guided by the following set of essential questions and content objectives.

Essential Questions

- What is a robot? What makes something a robot?
- What is soft robotics? How are soft robots used?
- What is design methodology?
- How can design methodology be used to solve problems?
- How can we create a finger soft robot?
- How can we customize a robot?

Content Objectives

Students will be able to:

- Describe what makes something a robot and the application of soft robots
- Apply design methodology to come up with engineering solutions
- Create a soft robot finger and manually actuated gripper
- Explore the connection between chemical reactions and energy with the soft robot finger
- Explain rationale for their robot design based on evidence

Teaching Strategies

In order to accomplish the content objectives for this unit, the following learning strategies will be utilized:

Notice and Wonder

Notice and Wonder is a strategy where students look at an image or graph and make observations and ask questions based on what they see. This is a great strategy for priming the learner about the content, and allowing them to steer the learning based on the things they notice and wonder about. All students will be able to access this strategy too because it is open-ended and there is not a set "right" answer.

Writing-to-Learn

Another open-ended strategy that will be utilized is Writing-to-Learn. WTL activities are short, impromptu, informal, low-stakes writing tasks that help students think through content. These prompts can be accomplished as Do Now or Exit Ticket questions, or even during the period. WTL activities can be categorized as exploratory writing, writing that allows the learner to discover what they want to say (Zinsser). Specific strategies that will be utilized include Questions, having students write as many questions as they can about a topic, and Misunderstanding, having students write about their old versus new understandings (Worsley and Mayer).

Modeling

'Developing and Using Models' is a Science and Engineering Practice from the Next Generation Science Standards (NGSS Lead States). Modeling includes creating diagrams, physical replicas, and mathematical representations to represent a system or parts of a system. This practice will be used to help students visualize a phenomenon and then refine and adjust their models once they gain new evidence. This strategy allows students to visually depict their learning and understanding.

Guided Reading - PAR Method

Reading is an important skill for students to develop in general. Moreover, 'Obtaining, Evaluating, and Communicating Information' is a Science and Engineering Practice from the NGSS (NGSS Lead States). In order to aid students in their reading comprehension of scientific articles, the PAR Method of Preview, Assistance, Reflection will be utilized. Preview involves the teacher setting a purpose, connecting to prior learning, and pointing out text features in the article. The last part, in particular, is especially important to model to students as it can show them how to make inferences about the reading before actually even reading. Next, Assistance may involve completing a graphic organizer or guided questions while reading the material. Finally, Reflection may involve summarizing what students learned, relating it to prior learning, and getting final questions answered.

Claim, Evidence, Reasoning

This strategy has students respond to a question with a Claim or answer to the question, Evidence, and Reasoning or explanation based on scientific principles. It coincides with the 'Constructing Explanations and Designing Solutions' Science and Engineering Practice from the NGSS (NGSS Lead States). The goal of science is to construct explanations for the causes of phenomena and the goal of engineering is to solve problems. The CER practice will be used as an evaluative tool; students will write a CER to justify their design choice for their gripper.

Classroom Activities

Lesson 1: Introduction to Robotics (2 Days)

Objective: Students will describe what makes something a robot and discover the application of soft robots.

Materials:

- Whiteboards (DIY Tutorial Guide), whiteboard markers
- STEM Career Interest Questionnaire
- Article - "Soft robot hand, first fully 3D-printed in single step, plays "Super Mario""

Lesson Plan - Day 1:

- Pre-Unit Survey (5 min): Students complete the STEM Career Interest Questionnaire to gain pre-unit understanding of students' interest in STEM.
- Whiteboards Modeling - Robots (25 min): Students will work in groups to brainstorm responses to the following prompts.
  - What is a robot? Write/Draw what a robot is AND what it isn't
  - Explain whether this is a robot: a mixer, a washing machine, a self-parking car, a telepresence base
- Lesson - Introduction to Robotics (10 min): Slides: Robotics Overview will be presented to teach students how robots work.
- Exit Ticket - Writing to Learn (5 min): Students will individually describe what they think makes something a robot.

Lesson Plan - Day 2:

- Do Now - Notice and Wonder (5 min): Students respond to the following Robot GIF by noting at least 3 things they observe and 3 things they have questions about.
- Guided Reading (35 min): Students read the article "Soft robot hand, first fully 3D-printed in single step, plays "Super Mario"" in groups based on reading level. Newsela allows the article to be downloaded by reading level. The article will be introduced with PAR by Previewing the information, Assistance through guided questions, and Reflection to summarize what they learned from the article.
- Video (5 min): Students watch soft robotics videos (Veritasium or Nature). Short class discussion to share thoughts.

Lesson 2: Introduction to Design Methodology (1 Day)

Objective: Students will apply design methodology to come up with engineering solutions.

Materials:

- Engineering Design Process Handout
- Cooper Hewitt - *Design in the Classroom* Challenge Cards
- Whiteboards (DIY Tutorial Guide), whiteboard markers

Lesson Plan:

- Do Now - Notice and Wonder (5 min): Students respond to the Engineering Design Process by noting at least 3 things they observe and 3 things they have questions about.
- Lesson - Design Methodology (10 min): Slides: Cooper Hewitt - What is Design? will be presented to teach students about Design Methodology.
- Video (5 min): Students watch Crash Course Engineering Process Video.
- Whiteboard Modeling - Design Problem (25 min): Students will work in groups to brainstorm ideas for each of the Cooper Hewitt - *Design in the Classroom* Challenge Cards. Teacher will model the Design Methodology/Engineering Process as students come up with solutions.
- Exit Ticket - Writing to Learn (5 min): Students will individually explain how their group came up with a design solution and how it followed the steps of the Engineering Design Process.

Lesson 3: Creating a Soft Robot Finger (4 Days)

Objective: Students will create a soft robot finger. Students will explore the connection between chemical reactions and energy with the soft robot finger. Following this lesson, students will have experience making a mold, dividing the mold into subsections, and creating a cast.

Materials:

- SDM Finger Bill of Materials
- SDM Finger Worksheet
- SDM Finger Educator's Guide
- CER Graphic Organizer Template

Lesson Plan - Day 1:

- SDM Finger Worksheet (10 min): Students complete 'Before you Build' questions to review prior knowledge about robotics. Short class discussion to share answers.
- Fabrication Part 1 (35 min): Complete fabrication steps #1-16 in SDM Finger Educator's Guide.

Lesson Plan - Day 2:

- Fabrication Part 2 (15 min): Complete fabrication steps #17-18 in SDM Finger Educator's Guide.
- SDM Finger Worksheet (10 min): Students complete 'While Curing - Part 1' questions to make an inference about the SDM Finger movement. Short class discussion to share answers.
- Lesson - Claim, Evidence, Reasoning (5 min): This resource can help introduce the CER strategy.
- CER Practice (15 min): Students use the CER Graphic Organizer Template to practice writing a practice CER (see resource for examples).

Lesson Plan - Day 3:

- Fabrication Part 3 (15 min): Complete fabrication steps #19-20 in SDM Finger Educator's Guide.

- SDM Finger Worksheet (10 min): Students complete 'While Curing - Part 2' questions to make inferences about the silicones. Short class discussion to share answers.
- Video (5 min): Students watch TED-Ed What triggers a chemical reaction? to introduce chemical reactions.
- Chemical Reactions Practice (15 min): Students practice identifying chemical reactions based on physical and chemical changes (see resource).

Lesson Plan - Day 4:

- Fabrication Part 4 (15 min): Complete fabrication steps #21-23 in SDM Finger Educator's Guide.
- SDM Finger Worksheet (15 min): Students complete 'Post-Activity Reflection' questions to reflect on the device's structure. Short class discussion to share answers.
- CER on SDM Finger Usage (15 min): Students write a CER answering the question "How does the SDM Finger work?".

Lesson 4: Designing a Manually-Actuated Gripper (1 Day)

Objective: Students will implement the Engineering Design Process to brainstorm a gripper solution. Students will create a manually actuated gripper.

Materials:

- SDM Finger Bill of Materials
- Engineering Design Process Handout
- Whiteboards (DIY Tutorial Guide), whiteboard markers

Lesson Plan:

- Whiteboard Modeling - Make a Hypothesis (5 min): Students will hypothesize how to create a manually actuated gripper in groups, based on the Engineering Design Process. Students will sketch their model on the whiteboard.
- Build the gripper and test the Hypothesis (25 min): Students will work in groups to create the gripper design they came up with.
- Class Presentation of grippers (10 min): Students will present their group's gripper to the class.

- Exit Ticket - Writing to Learn (5 min): Students will individually explain whether or not the Engineering Design Process helped or hindered their ability to come up with a gripper design.

Lesson 5: Performance Assessment (1 Day)

Objective: Students will explain rationale for their robot design based on evidence. Students will apply design methodology to a new use case.

Materials:

- CER Graphic Organizer Template
- STEM Career Interest Questionnaire

Lesson Plan:

- CER on Gripper Design & Design Challenge Assessment (40 min): Students will complete a two-part assessment for the unit.
    - Part 1: CER that answers the question "How does your gripper design pick up a ball?". Justify your answer based on evidence. Explain how the evidence supports your claim.
    - Part 2: Design challenge - Design a solution for "detecting a gesture". Follow the steps of the Engineering Design Process and explain how you followed the process.
- Post-Unit Survey (5 min): Students complete the STEM Career Interest Questionnaire to gain post-unit understanding of students' interest in STEM.

Resources

Works Cited

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Annotated Bibliography

The following resources were sourced from the seminar professor, Cynthia Sung, and seminar colleagues. These can be used as references for instruction:

- Slides: Robotics Overview
- Slides: Soft Robotics Videos
- Slides: Soft Robots Fabrication
- Slides: Cooper Hewitt - What is Design?

The engineering portion of the unit, where students create an SDM Finger and Manual Gripper, are based on the following resources from the Soft Robotics Toolkit:

- SDM Finger
- SDM Finger Worksheet
- SDM Finger Worksheet Answer Key
- SDM Finger Bill of Materials
- SDM Finger Cost per Student
- SDM Finger Educator's Guide
- Manual Gripper

To review all of the resources referenced above, please see this Google Drive Folder: https://drive.google.com/drive/folders/1f9YmzW5ICyKVUD9DA9HlwkDNKPI7TbR6?usp=sharing

Appendix

Content Standards: Pennsylvania Core

- **3.5 Reading Informational Text:** Reading for Science and Technical Subjects
- **3.6 Writing:** Writing in Science and Technical Subjects

Next Generation Science Standards

- **HS-PS1-2.** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- **HS-PS3-1.** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- **HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.