Soft Robotics

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In a rapidly evolving and dynamically changing world, our understanding as well as that of our students on the topic of robotics may differ dramatically. In this unit we start with questioning, what is a robot? In this exercise one cannot help but wonder how long robots have been in existence, before we labeled these objects as such. This unit is designed to give the user an introductory exploration of the different types of robots in the realm of soft robotics.

The field of robotics has many specialized components that add complexity to make the system fully functional. In this unit students will be able to intuitively evaluate the use and attributes of everyday materials. These media/materials may be defined/and restructured so as to construct a device that can have a reasonable balance between rigid and non-rigid, based on the placement of the cuts, folds and creases, along with the thick and thinness of the material. These characteristics can lend themselves to function as 'the body' of the soft robot.

This unit does not focus on the electronic devices constructed to complete the soft robotic system. Software, new apps and google derived forms have defined the new norm of our most recent years. Users may consider further learning towards the electronic composition, programming and instructional coding, that is beyond the scope of this unit. In this discipline as automation and the use of robotic solutions increases, so does the demand for sensors. So, what is it about these technologies and materials, with which we are familiar and unfamiliar that we can further extrapolate and redefine for use? How can we analyze forms of movement and attempt to mimic nature in an attempt to resolve humanities' concerns? What are the benefits and limitations to how these devices can support our daily lives? This unit is an introductory exploration of soft robotics. High School science students are invited to look at robots beyond a rigid repetitive controlled artifact.

UNIT CONTENT

INTRODUCTION

It is inevitable that our students' lives will be infiltrated with robot technology irrespective of what they choose to do. This unit is designed as an introduction to robots and robotics especially with students that have little to no background exposure to robotics, coding or programming. It is designed to support students with Individual Education Plans (IEPs) that have intervention supports in place for math and literacy. The inquiry and hands-on opportunities enable all students to participate and access experiences. Students may be placed in mixed groups for web quests, so students with different abilities can work on a design project together.

Today, contemporary news covers reports of robots that are introduced into fast food locations, places that our students are familiar with, and where many high schoolers take on part-time employment. As students increase their exposure and learning in the field of robotics, perhaps the questions they will raise as users and creators - will be different. They may be poised to participate in the processes that require precision modifications, troubleshooting and feedback given to their institutions of employment, as the field of robotics continues to evolve. As students learn about the different components that go into the making of robots, they may consider design and implementation alternatives, as they gain experience and working knowledge.

The lessons are constructed as individual lessons connected to the whole experience of enabling students to work with a variety of approaches. The goal is for students to gain kinesthetic comfort and confidence in working with materials to establish flexibility to create soft robotic appendages. Lessons 1-3 are introductory and foundational to robots and the engineering design process. In lesson 4, students consider the use of hand movements by using a glove to create a clasping appendage. In contrast, Lesson 5 uses sheets of paper or plastic as materials using the techniques of folding in origami to create a variety of shapes and movements. Lessons 1 and 2 may be completed in two 1 hr. class periods. Lessons 3-5 directions and instructions may be done within a 1-1 ½ hr. time period, however the implementation by students may need to be extended over 2-3 class periods depending to the teacher's discretion and the need of the particular student population or group.

BACKGROUND

The word robot can have so many interpretations amongst us. The ideas may have arisen through science fiction movies along with various influencing outlets that may include business, educational, commercial, social and network enterprises. Some reports may argue that the development of robots arose in the second half of the 20^{th} century. We need to start by looking at the word robot, how do we categorize or encapsulate the essential capabilities – of a robot?

Today's mainstream media constantly informs us of innovations such as autonomous driving vehicles. To capture human attention, the delivery of the information more commonly appears as 'disasters,' which really are moments in the process that amplify the junctions where different or more research, perspectives and troubleshooting is required. Then there is the current Pizza delivery pilot testing in Texas, and Walmart partnering with Zipline running a test pilot operation with drone deliveries in rural Arkansas with over-the-counter pharmaceutical products. This may perhaps be attractive and novel to some, yet societally and economically beneficial to others.

In our noisy information impounding seemingly chaotic world, we may have heard of humanoids, nanobots and animal robots as contemporary inventions, so again, how do we classify – a robot? Which prompts the question, what is a soft robot and how does that differ from any other? Some authors suggest in the near future as gains in traction and momentum accelerate between man and these machines – soft robot technologies will become normalized and required features that will be embedded in the design of all robotic capabilities. Until then, for our immediate attention in this unit we will seek to define the essential components of what makes a robot, and what makes a soft robot – different. We will then use everyday materials to design and create appendages that can be used as soft robots. The questions we will consider in the engineering design process are: How will we assemble the structure? How will it contract? How will it extend? How can we design it to do what we would want it to do? What is the purpose and what are the possible uses? What repetitive tasks can it do? What are the limitations?

The key advantages of soft robots over classic robots are that they are shape adaptable and thus can achieve complex motion that may absorb impact and reduce or prevent injury. Soft robots are – soft, elastically deformable and can be created using relatively low-cost materials. However, the potential drawbacks of soft robots are that they may be difficult to control, possibly less precise and powerful than classic robots and may need more developed electronics, beyond the on and off (tension and release) configuration explored in this unit.

The standards used in the compilation of this unit are the Common Core Standards: (**RST.11-12.9)** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concepts, resolving conflicting information when possible. (**HSN.Q.A.3),** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
The Pennsylvania Science and Technical Subjects Standards: **(C.3.5.9-10A),** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions, and **(CC.3.5.11-12.H),** Evaluate the hypotheses, data analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. The connected Next Generation Science Standards (NGSS, 2021) Standards **HS-PS3-2** Energy: Develop and use models to illustrate the energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects) **HS-PS3-5** Ask questions to determine quantitative and/or qualitative relationships between independent and independent variables. **HS-PS2-4** Develop and/or use models to illustrate/ generate data/ support explanations/ predict phenomena/ analyze systems/and or solve problems.

CONTENT OBJECTIVES

SOFT ROBOTS

In this unit students will first explore the key components that make up a robot and the current use of this form of technology. The teaching and learning are through inquiry, web quests and the use of the engineering design process to create models. Students will work with familiar materials that can be repurposed such as paper, textiles and plastic to explore various means of extending and contracting. Through the lessons they will be introduced to and focus on, the structure and design of the object. Students will gain an experiential understanding of the materials they choose to use and develop. They will investigate how they can increase and decrease the rigidity and flexibility of these materials and negotiate the endoskeleton and exoskeleton mechanisms, to create functional appendages for soft robots. This course is an introductory course designed to engage students in creating models. It is hoped that students will question how the computational mechanisms can be integrated to continue their quest into coding and programming, necessary components towards making an autonomous soft robot function.

TEACHING STRATEGIES

Direct Instruction: Teachers in some of the lessons will use the first 10-15 minutes of the lesson, to introduce an idea or topic for students to consider, further develop and investigate. This enables student to initiate their adventure with a focused starting point a with structured and/or facilitated guidance. It supports all students in an inclusive learning space, and enables students to amplify sections that intrigue them.

Project Model Based Learning: Teachers introduce an idea to students, students then research and gather credible information using guiding questions. During the active investigation and research learning time, the teacher will facilitate the learning by listening to students group discussions and conversations as they decide, design, troubleshoot, evaluate and select what they choose to embrace. At the end of the hands-on lesson/unit, students will present their models/ discoveries, reflections and learning, to their peers.

Photo Images: At the start of the unit, students use this visual tool to document and record process steps along with items of daily process and use. This form of communication is a pragmatic vehicle to record, explain, journal their progression, visually show and verbally tell, their approach. This provides an inclusive approach for students of different abilities that may have access and expression forms that are other than, at grade level math and literacy skills.

Observe, consider and reflect: This enables students to at times consider what they already know about an idea drawing from their own background knowledge and experiences. Alternatively, it is a time to step back from the information, evaluate it with minimal reaction and reflect on situations, to affirm or adjust. This strategy is used in an attempt to encourage students to approach discussions and conversations with claims, evidence and reasoning, and minimize students responding to situations with approaches of I believe, or I like.

CLASSROOM ACTIVITIES

Lesson #1

What is a robot?

The first lesson is designed to get students thinking about what are the components that make a robot. Students will look closely at familiar and unfamiliar objects, that can be defined as a robot. At this stage students activate background knowledge, and ideas that have shaped their thinking. The goal of the lesson is for students to be able to define the key components that make a robot: a functional mechanical piece that is physically designed to do a task, a sensor that acts under specific conditions, a program or coding that has a set of instructions and an electrical component as an energy source to make it all happen. (1- 1½ hr. dependent on student population, which may extend to a 2^{nd} lesson and reviewed/summarized)

Objective: Students will be able to define a robot in order to analyze the complimenting components that enable the system to work.

1/ Teacher will open up a blank slide deck on the board with each of the following questions on the 3 slides, and take 5-10 minutes on each slide writing responses students give. Alternatively, the Padlet App can be used for student responses:
Slide 1: What is a robot?
Slide 2: How can we define the essential characteristics of a robot?
Slide 3: What are the components that make a robot?

2/ Teacher with guide student responses towards identifying robots as having a mechanical component that does a task, a sensor, and a program with a set of instructions for the task to happen, with a source of energy to make it happen.

When students have gained clarity of the components, the teacher will show images of daily items that complete tasks such as: a dishwasher, laundry washer dryer and ask students if these items are robots, why or why not. This will enable students to strengthen their inquiry and paradoxically leave a sense of open comfortable confusion.

3/ Teacher will ask students to research and find an image and reading regarding a type of robot and create a Google Slide to share what the robot is designed to do, what the essential components are that make up the design, and the programmable instructions that might be required. Thinking about the sensor - that would activate the on and off switches. At this point encourage students to define the action steps the robot will do. This is to engage students into thinking the limits and parameters of the device to work, and then to switch off. Allow 5-10 minutes.

4/ Students will share slides with the class, allow 1-2 minutes per student, allowing student peers to ask and discuss student share outs.

5/ At the end of the lesson as students to complete an exit ticket that states:
3 interesting ideas that resonated with them from the lesson
2 facts that changed how they thought about robots
1 question that comes to mind, that makes them wonder

Lesson #2

In this lesson students will differentiate between a robot and soft robots. They will gain an understanding of why soft robots are necessary to perform tasks that need to navigate and function in environments that are non-box-like structures. In this lesson students will observe soft robot structures and uses. Students will also take every day materials and explore ways in which these materials may be modified (folding, cutting, creasing etc.) to lend 'non-rigid' deployable characteristics. The materials that can be used for the activity are: paper of a variety of thicknesses, cut up corrugated and simple cardboard sheets from boxes, a variety of plastic sheets from plastic bags, sheet protectors, binders, used disposable water bottles. (1- 1½ hr. dependent on student population)

Objective: Students will be able to investigate familiar materials used in daily living in order to explore how they can be modified and repurposed to create flexible, rigid, non-rigid and/or deployable expansion and contraction characteristics.

1/ Teacher will:
Introduce the word Soft Robots and ask students to complete a KWL (Know, Want to Know, Learned) chart, with connections to those words. Alternatively, Padlet may be used for a group mind exploration on the topic of Soft Robots, to activate student minds and build on the ideas of the previous lesson.

Students will complete KWL chart 5-15 minutes, and share out Know and Want to Know ideas with peers.

2/ Teacher will introduce Soft Robots definition and video examples using web links and videos. 5-10 mins.
Examples of possible sites:
https://turbofuture.com/industrial/Soft-Robotics
https://www.engineersgarage.com/soft-robotics-robots-featuring-biological-movements/

Students will then be placed in mixed groups of 2- 4 students and be assigned a section of the reading on uses. Students will need to: Read a section, create a Google Slide to share with the class summarizing the device purpose, describing the construct and uses. Students are inclined to add their personal perspectives and comments, these are encouraged as it indicates vested interest in the subject.
Example of possible site use:
http://biorobotics.harvard.edu/research.html

3/ Teacher will place materials at 4 Stations and assign mix groups at each station:
Station 1: Variety of paper with different thicknesses
Station 2: Variety of plastic sheets, different types with a variety of thicknesses

Station 3: Variety of empty disposal water bottles in size and thicknesses (different brands!)
Station 4: Variety of cardboard such as empty cake box, carton, corrugated board.

Students will be asked to write down what they observe about the materials and discuss in their groups how they might 'distort' (cut, fold, crease) the material to create contraction and extension mechanisms. Allow 15-20 minutes for students to investigate and explore the materials.

4/ Ask students to summarize there KWL charts, and complete the Learned Section. Ask each group to share out their investigations and at least 3 key discoveries they experienced through the process. 5-10mins. Allow extended time if needed.

Lesson #3

In this lesson students will visit the engineering design process. To make it accessible to all students different video options and website links examples are offered. Students will then be asked to solve a problem using the process, and documenting steps. (1- 1½ hr. may be extended to multiple class periods, dependent on teacher discretion and student population)

Objective: Students will be able to identify steps in the engineering design process in order to categorize steps as they design a robotic appendage for NASA scientists.

Teacher will:
Explain the engineering design process to students using videos and web graphics. Possible options are listed below.
Teacher will then have a table available with scissors, string, tape, measuring tape, ruler, markers, paper, cardboard, different materials that can be repurposed from the previous lesson, plastic, paper, board, bottles.

Examples:
Video
https://www.youtube.com/watch?v=pSmz1r3l3tE
Video expanding on different types of engineering
https://www.youtube.com/watch?v=nMwG1wnESDA
Video shared experiences
https://www.youtube.com/watch?v=oBqGoXCBHtk

Students will:
Identify the steps as they document their design process from the lesson video and teacher explanations. 10-15 mins.

Students in small groups are assigned with the following challenge for the lesson. One student will need to ensure the process is documented as they work on their solution.

The Challenge:
Scientists will need to bring back rock samples from a region of Mars that have objects that appear to have a thin coating of rock-like material, they are the size of coconuts the scientists suspect these rocks contain a liquid inside. The Spaceship needs as arm that can extend 5 meters to grasp these objects to return back to earth. The NASA Rocket Engineers state they only have $0.5m^3$ of space available for the appendage on board the space ship. Design this appendage, and document the process with your team.

Wrap-up:
15 min. Student groups share design and process with the class.

Lesson #4

In this lesson students will design and create a soft robot appendage by creating a clasping action that can grasp an object that is curved. To prepare for this the teacher will ask students to bring a fabric/textile glove, string and a needle that has a large hole to thread the string. Pairs of scissors to cut the string. Drinking straws, for those students negotiating an endoskeleton in the design process. Students will gain hands-on experiences designing so that there is an action – tension created through the pull of string, and release when the string is released. The tension or the idea of an 'on' switch enables the glove to clasp a small ball or curved object, by reducing the length of the string. The 'off' switch releases the length of the string allows the 'hand' glove to release a curved object. (1- 1½ hr. may be extended to multiple class periods, dependent on teacher discretion and student population. Students may need multiple lessons to implement the design.)

Objective: Students will use a glove, string and every day materials in order to design a soft robot that may clasp and release small curved objects.

Teacher will:

- Ask students to wear the glove and observe their hand movements. Allow students to think aloud and share and show.
- Ask students, where they might place the start mid and end points using string to create movement (when the glove – is not on their hand!) Allow students to think aloud and show.
- Ask students if they feel straws could or would help in their design. Allow think time, think aloud and share out time.

Students will then be asked to create a photo documentary of their design using the Engineering Design Process. To assist students with organizing their Google Slides create a template slide desk.
The 5 slides should have each of the following words:

1. Explain the need (To be able to grasp an object using a hand-like appendage.)
2. Develop a solution (How can you solve this problem using available materials?)
3. Plan and design (How will you use these materials and make it work)
4. Test and Evaluate (Does the appendage work according to plan? What changes are necessary?
5. Modify and improve (How can the protype/model be modified to increase performance?)

Wrap-up:
Students share their processes, status and outcomes. If needed additional lesson time may be offered according to class scheduled and student population needs.

Lesson #5

In this lesson students will use techniques from the art of folding paper known as origami to design a soft robot. Focus will be on a binary switch – on and off, or contract and release. After creating their design students can test their model using strings to create the pull/tension and release on their paper model. Students may choose and use video instructions for a structured step by step introduction to origami. Students may work independently or in groups so they may peer collaborate as they develop their design. Sample videos are included. (1- 1½ hr. may be extended to multiple class periods, dependent on teacher discretion and student population. Students may need multiple lessons to implement the design.)

Objective: Students will use origami in order to design a soft robot model

Teacher will:
Introduce origami as a paper folding method and show samples of 'how to' videos:
Suggested samples:
Inspirational Origami Physicist Artist
https://www.youtube.com/watch?v=DJ4hDppP_SQ
Origami Butterfly https://www.youtube.com/watch?v=cZdO2e8K29o
Origami Birds https://www.youtube.com/watch?v=QJbq72yA29M
Origami Lotus Flower https://www.youtube.com/watch?v=LWsL-_pgmTc
Origami Circular Shape https://www.youtube.com/watch?v=JywnOQfsdZc

Students will:
Choose a model they wish to create and document it on Google Slides using the Engineering Design process. They will share their process, Google Slides at the end of the lesson, or if additional time is needed, the following lesson may be considered for presentations.

Resources

The following website and video links support teaching and learning for the first lesson and enables us to consider the word robots and how specific aspects are accentuated depending on the institution and the author.
https://softroboticstoolkit.com/components
https://www.youtube.com/watch?v=uoC2ZGRI8a8
https://www.youtube.com/watch?v=sZ_-yb-TN9M

The websites below range from a site that has user-friendly overviews of a variety of soft robots and uses and the components that make them. It makes it accessible and inclusive for first time direct robotic experiences. There are videos and sites that inform teachers and learners of the uses for the second lesson.
https://www.engineersgarage.com/soft-robotics-robots-featuring-biological-movements/
https://turbofuture.com/industrial/Soft-Robotics
http://biorobotics.harvard.edu/research.html

For the third lesson the following video websites shed light on the engineering design process. Variation supports and is intentional to engage the variety of students and an invitation to increase access for all learners.
https://www.youtube.com/watch?v=pSmz1r3l3tE
https://www.youtube.com/watch?v=nMwG1wnESDA
https://www.youtube.com/watch?v=oBqGoXCBHtk

The following website for the fourth lesson has connections to hand movements. The visual enables students to consider movements, as they look at the glove to simulate hand movements.
https://www.frontiersin.org/articles/10.3389/fbioe.2020.548947/full

The fifth lesson has relevance to 'Robogami' and inspiring links to the happenings at the Labs at the University of Pennsylvania, if you get the privilege to visit, simply put -go!
https://www.youtube.com/watch?v=Q1G3LIL4CjY
https://sung.seas.upenn.edu/

The following links can be used to create a presentation rubric for students based on the teacher's particular student population.
https://link.springer.com/article/10.1007/s11423-021-10030-7/figures/1
https://www.teacherspayteachers.com/Product/Google-Slide-Presentation-Rubric-4914418
https://www.teacherspayteachers.com/Product/FREEBIE-Presentation-Rubric-EDITABLE-in-Google-Docs-810784

APPENDIX

COMMON CORE STANDARDS

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concepts, resolving conflicting information when possible.
HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

PENNSYLVANIA STATE STANDARDS

C.3.5.9-10A Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
CC.3.5.11-12.H Evaluate the hypotheses, data analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information

NEXT GENERATION SCIENCE STANDARDS

HS-PS3-2 Energy: Develop and use models to illustrate the energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects)
HS-PS3-5 Ask questions to determine quantitative and/or qualitative relationships between independent and independent variables.
HS-PS2-4 Develop and/or use models to illustrate/ generate data/ support explanations/ predict phenomena/ analyze systems/and or solve problems.

SUMMARY

This unit attempts to engage students into looking at robots beyond sci-fi movies, and participate as contributing citizens in the design and creative process. To encourage access to student of different abilities the approach towards entry into the content is intentional. The materials chosen to create models are also available through repurposing readily available packaging material. In environments with no 3D printers and specialized equipment students can enter, access and participate in the process. Students will learn not only about the many uses of soft robots, but also that these mechanisms contribute to solve humanities concerns, in a non-box-like fashion! In alignment with Next Generation Science Standards the process invites students to think critically and mindfully about materials, with which they are familiar. It gives students an opportunity to deeply investigate a medium, and amplify their sensory exploration of that material (paper/plastic/cardboard/textile) and maximize the potential or capabilities of that medium towards making a soft robot.