Bio-Design Fabrication and Soft Robots

Christopher Sweeney

CCA Baldi Middle School

Abstract

Bio-Design Fabrication and Soft Robots is a unit designed to introduce middle school students to using mycelium and other soft materials with robotics. This unit was designed for a course in an urban, public middle school for students in grades 6th, 7th, and 8th, where the students meet for two forty-five minutes periods twice a week on a rotating six day schedule cycle. The unit will be using elements of CAD (Computer Aided Design), CNC (Computer Numerical Control), coding, 3D printers, robotics, laser cutters, and more. One of the main elements of the unit is focusing on critical thinking. Project fabrication may be digitally oriented but it will not be limited to just these materials, tools and/or media as assembly is ultimately a hands-on enterprise, working with their mind and hands to create a robot using mycelium and other soft materials.

in an effort to meet the needs of a classroom that may feature students from a diverse array of educational, cultural, and linguistic backgrounds.

Key Words

Robotics, Soft robotics, Robots, Mycelium, Bio-Fabrication, Digital Fabrication, Design, Bio-Design

Introduction

I am an art teacher that runs a middle school makerspace that covers art, design and ste(A)m topics, and have a large interest in the student body to use and create robotics, as well as the coding/fabrication that goes with it. Since we fabricate through CNC, 3D printing, laser-cutting, and other means, (as well as having the tools and know-how to create something like soft robots in the makerspace), using soft robotics is something that would be of interest to my students who want to create and investigate material. This is especially true with mycelium and other bio-materials (which I have a personal interest in), and teach at other institutes to adult learners. A good portion of my students are mentally gifted and high achieving students going to the top schools in Philadelphia, so I would like to provide the experience of creating these soft robots in my makerspace with them, as this is something that they will likely not get anywhere else. The learning experience working with both hands, and mind, is very important to my pedagogy and my mindset I try to imply in my makerspace.

As I stated in the prior section, I run a makerspace that covers art, design and steAm topics in the largest middle school in the city, and soft robotics, mechanisms, etc. could help students ’design thinking skills, as well as incorporating 21st Century with traditional skills they learn. We already use servos with Arduino® devices, Micro:bit®, and others in the makerspace, as well as the Hummingbird®/Finch® robots from

Birdbrain Technologies. This is something that would be of interest to my students who want to create and investigate materials, especially with bio-materials. I would like to provide the experience of creating these soft robots in my makerspace with them, as well as any student interested in creating moving soft robots. A few objectives would be to master the fabrication needed to have a successful robot, especially with the mycelium, and other bio-materials used in conjunction with coding and servos (as per example the Hummingbird® kit). There are challenges, but since my students already use block coding such as Scratch and others, I see an entry level opening into furthering their interest with other languages such as Java, Python, Logo and other various coding platforms to be used with the soft robots. A main issue besides the fabrication skills and coding is the sheer size of my classes (I max at 33 students), which we are on a 6 day rotating schedule as my school has 1500 students, which I see the majority of them at some point in the four quarter school calendar. Even with all ten 3D printers, the sheer size of the work, and skills needed to be taught to non-gifted students (I max at 15 for this class, which is much more manageable).

I am envisioning that designing, creating, and fabricating might look different for sections, grades, and skill sets that I teach, as well as interests. I am interested in creating mini skill sections, much like we are learning in our soft robot seminar, with a section on code, servos, materials to be fabricated and so on. I want the students to pose their design questions, as I want them to have some sort of agency to their work, which I feel works best with engagement in my classes. This will of course have my insight and final judgment on whether it can be fabricated or not within the parameters of the project, and the tools we have available in the classroom makerspace. I would like their creations and designs to be very simple and streamlined, but use artistic and design skills, and basic hand-building skills, with using the high tech tools when only needed to create and have a successful and rewarding learning experience for the students.

Overview

I am not unfamiliar to coding and creating fabrications through digital and hand building means in the K-12 classroom, but working with soft robotics is new territory for me, especially mycelium based creations. With what I have learned about compliant robots in the seminar, origami, and using mold making (which I already employ in my design work), I feel there is much that the student can learn with me as we investigate how to best employ soft materials with our fabrications. Since I am not reinventing the wheel, I plan on using their prior knowledge in creating and fabricating robots via the laser cutter and hand techniques to employ the usage of mycelium as a soft building structure for whatever path they decide to take with their projects.

Students will be using many different micro boards and servos, but the base of the work will initially be focused on using the Hummingbird® kit from BirdBrain Technologies, which uses the Micro:bit® as the brains of the work. Most students will be using block coding in MakeCode, but some advanced students will be using Java, Python, and other languages that birdbrain uses in their robots.

Students will be creating a soft robot using the Hummingbird kit, MakeCode, and the Micro:bot. They will be creating and fabricating using mycelium based materials for the body and/or structure of the robot. They will be growing the mycelium kits, and creating the molds from which they will be making their robots, as well as using design thinking, drawing, measuring and 3D printing/laser cutting/CNC the structures.

6th graders will be making a basic crank, winch, cable system or piston device. 7th graders will be making simple robots such as a bot or rover, with 8th making more elaborate fabrications and devices involving the sensors and advanced features of the Micro:bit and Hummingbird kits.

Student will be creating soft robots using (but not limited too) mycelium as the main building materials to create a substructure for their robots. They will grow it from the inoculated mycelium that I use from Ecovative, and create molds and forms to be used with their designs. This will vary from project to project, and from student to student.

Rationale

In my art & ste(A)m class, I try to invoke a sense of wonder, creativity, investigation and curiosity to my students. It is not always a textbook way with which to look at a problem that they are used to in other areas of their education. My job is to make them think with their hands and their minds together. The real skill is that learning, through soft robotics, or otherwise.

"The one really competitive skill is the skill of being able to learn. We need to produce people who know how to act when they're faced with situations for which they were not specifically prepared." -Seymour Papert

Using these skills mixed with 21st century tools such as laser-cutters, 3D printers, micro-controllers and the like, we are helping our students foster an understanding of how to use traditional hand building skills and thought process with using their minds, with new and upcoming technologies that they might encounter in their jobs that might not even exist today, but could in the future.

In using soft robots as a theme for a project, the rationale is that with thinking about using something other than a hard metallic robot that you so often see destroying and crushing each other in battle-bots competitions that young people (and adults) tend to gravitate towards. This is a constructive activity which helps to build a growth mindset of learning and exploring, as well as working with their minds and hands.

Objectives

I would hope that working with their minds and hands, as well as a combination of traditional and 21st century tools and skills, would be an objective in and of itself. I would hope that skill-building and problem solving would also be something that comes of working with soft robots, and whether using origami, silicone, or bio-materials like mycelium, that they would come to appreciate the very nature of the material science and hands-on work that comes with making code work with servos, breadboards, and microchips.

The self-learning, problem solving, and work ethic of working on a project such as a soft robot that requires thinking outside of the box (with a more than cookie cutter solution) is something that is desirable as an object or rubric of success.A project that requires skill, planning, measurements with tools such as calipers, t-squares, and protractors are also an obtainable goal by learning by doing. These are skills that last a lifetime that can be applied to everyday life outside of a school environment.

“Give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking; learning naturally results.”- John Dewey

The last objective would be to have to be self-advocacy and self-realization ion the student through the work. These are not intrinsically graded or looked upon in the todays classroom, but are nonetheless important with working and creating, whether it be the coding, fabrication, or the building.This is something that is very important and reach outside of the boundaries of a classroom and apply to the outside work, and how things work and are made.

“The place to improve the world is first in one's own heart and head and hands, and then work outward from there." -Robert M. Pirsig

Strategies

The most relevant teaching practices for the strategies of this unit are the open-ended questions, and having the students work with ones hands, whether it be through digital fabrication (i.e. laser cutting, 3D printing, etc.) or through the process of problem solving and working towards a goal of having created a successful project.

The first strategy would be for the students to have a grasp on the coding portion of the project, since this is just as important as the fabrication and construction of the body of the robots. Whether the students use MakeCode with block coding, Java, or Python, they should have some idea how the lights, servos (Positional and Rotational), and other components work with the Micro:Bit.

The second would be to have a grasp on how to use the digital fabrication tools, and the software that goes with it (i.e. Cura for the 3D printers, Glowforge’s web based interface). Once that is tested and understood, the correct fabrications can be used.

*Since we will be using Ecovatives's mycelium (https://www.ecovative.com) (or https://grow.bio/collections/shop/products/grow-it-yourself-material if you want to grow it beforehand) to use as the body of the soft robots, a portion of the digital fabrication section will be to properly grow sheets of 20"x1" sheets of grown mycelium to be used in lieu of wood for the frame of the robots. It is good to note that I use a website called MakerCase (https://www.makercase.com/#/) that you and your students can use to create the svgs that will make your robots bodies.

The last strategy would be the hand building with working with the materials. Safety with using cutting devices such as electric cutter, saws, and the like will be shown and discussed, and how to properly implement them to create the best way to get the maximum results. Also, finishing touches and connecting the Hummingbird/Microbit with the servos will be shown.

Classroom Activities

Overview

Intro:

Students will be introduced to the several portions of the project (i.e. coding, growing mycelium/fabrication, implementation, etc.) as well as the design process. They will also be introduced to mycelium and the post-growth process. Soft robotic examples will be introduced and discussed. Examples of prior student work will be shown.

Objectives:

Students will work on understanding the basic elements of design thinking and other 21st Century skills sets via a design challenge.

Essential Question:

How can you create a soft robot using mycelium and other soft agents with the martial presented?

Whole Group Instruction:

Introduce the Design Thinking process.

Introduce maker technology including digital fabrication, working with bio-materials such as mycelium, coding, 3D printing/modeling via Tinkercad and Morphi, and others, as well as laser cutting .

Students will be guided via the design cards, and then given tutorials on how to use MakeCode software. Prior knowledge of block coding software will be used, but students will be given new tutorials to create and design their creations if they are beginners to coding in general.

Differentiation

Students will be coding, drawing, mapping, labeling, and creating designs to be rendered into the Glowforge software (https://glowforge.com).There is a wide range of avenues that the students can express their designs.

Small Group Instruction:

Students will be guided via the design cards, and then given tutorials on how to use the Micro:bit software and the Hummingbird.Prior knowledge of block software will be used, but students will be using tip sheets, videos, and prompts to work on their projects independently. The below links are the ones out of many that will instruct them how to code, fabricate, and the materials needed to create the soft robots using mycelium instead of wood and cardboard.

https://learn.birdbraintechnologies.com/finch/resources/block-descriptions/

https://www.birdbraintechnologies.com/downloads/Coding-Cards-makecode.pdf

https://makecode.microbit.org/#editor

https://learn.birdbraintechnologies.com/hummingbirdbit/build/

Introduction

This lesson plan includes several sections, since this unit is an eight week project that would take up to one quarter of our school year. First section will be an introduction to using MakeCode, Javascript, and Python coding with the Micro:bit, the second part of this would be to transfer that knowledge to using it with the Hummingbird kit via the code and using it to move the servos motors, turn lights on, and using the basic sensors. The last portion will include growing the mycelium (and post-production) for use in fabrication for the robot, and understanding how to use hand tools such as the Worx ZipSnips (https://www.worx.com) to cut the bio-material to shape it into bodies for the soft robots. As well as hand fabrication, laser cutting will be explained and shown, as well as how to implement the Gowforge software.This will be in conjunction with the robot tutorial for the Hummingbird., which is listed in this document.

Student Objectives

After completing this lesson and others, etc., students should understand the following concepts: Mycelium; block vs. Java/Python coding; using servos; digital fabrication using 3D printing, laser cutting, etc.

Overview of Lesson Process

**Since this will be an eight week unit, these introductions and demonstrations will be staggered as needed depending on the class.*

Introduce MakeCode (as well as Java and Python) and the Micro:bit and the tutorials they will need to use to have a grasp on controlling their soft robots.

Demonstrate how to grow the mycelium using Ecovatives' guide (https://s3-us-west-2.amazonaws.com/ecovative-website-production/documents/Grow-It-Yourself-Instruction-Manual-v1.0.pdf) and go over the process and steps they will need to be successful in the growth of their material.

Demonstrate the Hummingbird kit and show how to setup the Micro:Bit to work with the servo motors, lights, sensors, other components.

Discuss and go over the options each group has via the robot project cards, and the fabrications they will need to make it successful and functional design.

Demonstrate the various hands-on and digital fabrication techniques that can be used to create the body of the robot (i.e. hand cut vs. using the laser cutter with files from the MakerCase).

Show finished pieces either through video/photos, or from prior student work.

Procedures

Since this is an eight week project, I would like to break down the procedures and give a quick time line. While this is not a definitive or complete list of what goes into the project, it can be a guide to help steer the course of the unit.

Week 1-2: Students will be using MakeCode, Javascript, and Python coding with the Micro:bit, working on tutorials and uploading to the Micro:Bit.

Week 3-4: Students will be getting familiar with setting up and using the Hummingbird kit and using all the components. Using the robot guide, students will start to add only the components they will be using on their soft robots. Since it will take almost two weeks for the mycelium to grow, each group will be growing their mycelium for their project. They will be making the measurements to figure out what container they need to mold the mycelium in according to how much space they need.

Week 5-6: Students will starting to design and fabricate using the mycelium and other materials to create the body and to add the robotic sections a(s well as the Hummingbird and battery pack) to their designs.

Week 7-8: Students will be finishing the soft robotics, testing, reevaluating, and recoding to have a completed soft robot.

Wrap-up discussion

Which robots worked the best with their appointed task, and which didn’t work as well? Discuss which pieces were fabricated the best, while others needed more help. Which ones used the servos, sensors, and lights the best of their ability according to their designs?

Materials

Micro:Bit

Micro USB Cord

Hummingbird Kit (which include LED lights, sensors, servos motors (360 degrees and 180, two of each) and the board, and a battery pack needed to run the servos.

AA batteries

1/8” baltic birch plywood for laser cutting

Chipboard 24”x 12”

Glowforge (or any laser cutter with a work area of 20”x 12”)

3D modelling app (https://www.morphiapp.com)

3d printer and filament (http://ultimaker.com)

Mycelium (http://grow.bio)

**For growing the mycelium you will need the following: Sterile nitrile gloves, growing tubs, 90 percent isopropyl alcohol, flour, water, measuring cup, hydrogen peroxide, etc. according to the Ecovative guide.*

Hot glue guns

Glue sticks

Acrylic paint

Brushes (various sizes)

Ball bearing(s)

Xacto blade

Ruler

Cutting mat

T-square

Worx ZipSnips

Sharpies

Tips for Safety

Much care and demonstrations will be shown on how to properly use the Xacto blades and the cutting mats, the hot glue guns, and the ZipSnips for cutting cardboard. Extra explicit care and demonstrations will be given on how to use the Glowforge laser cutter and it's web-based software.

Resources (included in the Lesson Plan)

https://makecode.microbit.org

https://s3-us-west-2.amazonaws.com/ecovative-website-production/documents/Grow-It-Yourself-Instruction-Manual-v1.0.pdf

https://www.makercase.com/#/

Possible Bibliographies/Works Cited/Resources and Standards

Standards

9.1.12.B.4 Visual Arts

9.1.12.B.4.1 Paint

CCSS.Math.Content.K.MD.A.1 Describe measurable attributes of objects, such as length or weight. Describe several measurable attributes of a single object.

CCSS.Math.Content.K.MD.A.2 Directly compare two objects with a measurable attribute in common, to see which object has "more of"/"less of" the attribute, and describe the difference.

CCSS.Math.Content.1.MD.B.3 Tell and write time in hours and half-hours using analog and digital clocks.

CCSS.Math.Content.1.MD.C.4 Organize, represent, and interpret data with up to three categories; ask and answer questions about the total number of data points, how many in each category, and how many more or less are in one category than in another.

CCSS.Math.Content.2.MD.A.1 Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.

CCSS.Math.Content.2.MD.A.2 Measure the length of an object twice, using length units of different lengths for the two measurements; describe how the two measurements relate to the size of the unit chosen.

CCSS.Math.Content.2.MD.A.3 Estimate lengths using units of inches, feet, centimeters, and meters.

CCSS.Math.Content.2.MD.A.4 Measure to determine how much longer one object is than another, expressing the length difference in terms of a standard length unit.

CCSS.Math.Content.3.MD.D.8 Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters.

CCSS.Math.Content.4.MD.B.4 Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8). Solve problems involving addition and subtraction of fractions by using information presented in line plots.

CCSS.Math.Content.4.MD.C.5a An angle is measured with reference to a circle with its center at the common endpoint of the rays, by considering the fraction of the circular arc between the points where the two rays intersect the circle. An angle that turns through 1/360 of a circle is called a "one-degree angle," and can be used to measure angles.

CCSS.Math.Content.4.MD.C.5b An angle that turns through n one-degree angles is said to have an angle measure of n degrees.

CCSS.Math.Content.4.MD.C.6 Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

CCSS.Math.Content.4.MD.C.7 Recognize angle measure as additive. When an angle is decomposed into non-overlapping parts, the angle measure of the whole is the sum of the angle measures of the parts. Solve addition and subtraction problems to find unknown angles on a diagram in real world and mathematical problems, e.g., by using an equation with a symbol for the unknown angle measure.

CCSS.Math.Content.K.G.A.1 Describe objects in the environment using names of shapes, and describe the relative positions of these objects using terms such as above, below, beside, in front of, behind, and next to.

CCSS.Math.Content.K.G.A.2 Correctly name shapes regardless of their orientations or overall size.

CCSS.Math.Content.K.G.A.3 Identify shapes as two-dimensional (lying in a plane, "flat") or three-dimensional ("solid").

CCSS.Math.Content.K.G.B.4 Analyze and compare two- and three-dimensional shapes, in different sizes and orientations, using informal language to describe their similarities, differences, parts (e.g., number of sides and vertices/"corners") and other attributes (e.g., having sides of equal length).

CCSS.Math.Content.K.G.B.5 Model shapes in the world by building shapes from components (e.g., sticks and clay balls) and drawing shapes.

CCSS.Math.Content.K.G.B.6 Compose simple shapes to form larger shapes.

CCSS.Math.Content.2.G.A.1 Recognize and draw shapes having specified attributes, such as a given number of angles or a given number of equal faces. Identify triangles, quadrilaterals, pentagons, hexagons, and cubes.

CCSS.Math.Content.2.G.A.2 Partition a rectangle into rows and columns of same-size squares and count to find the total number of them.

CCSS.Math.Content.2.G.A.3 Partition circles and rectangles into two, three, or four equal shares, describe the shares using the words halves, thirds, half of, a third of, etc., and describe the whole as two halves, three thirds, four fourths. Recognize that equal shares of identical wholes need not have the same shape.

CCSS.Math.Content.5.G.A.1 Use a pair of perpendicular number lines, called axes, to define a coordinate system, with the intersection of the lines (the origin) arranged to coincide with the 0 on each line and a given point in the plane located by using an ordered pair of numbers, called its coordinates. Understand that the first number indicates how far to travel from the origin in the direction of one axis, and the second number indicates how far to travel in the direction of the second axis, with the convention that the names of the two axes and the coordinates correspond (e.g., x-axis and x-coordinate, y-axis and y-coordinate).

CCSS.Math.Content.5.G.A.2 Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

CCSS.Math.Content.6.G.A.1 Find the area of right triangles, other triangles, special quadrilaterals, and polygons by composing into rectangles or decomposing into triangles and other shapes; apply these techniques in the context of solving real-world and mathematical problems.

CCSS.Math.Content.6.G.A.2 Find the volume of a right rectangular prism with fractional edge lengths by packing it with unit cubes of the appropriate unit fraction edge lengths, and show that the volume is the same as would be found by multiplying the edge lengths of the prism. Apply the formulas $V = l\ w\ h$ and $V = b\ h$ to find volumes of right rectangular prisms with fractional edge lengths in the context of solving real-world and mathematical problems.

CCSS.Math.Content.6.G.A.3 Draw polygons in the coordinate plane given coordinates for the vertices; use coordinates to find the length of a side joining points with the same first coordinate or the same second coordinate. Apply these techniques in the context of solving real-world and mathematical problems.

CCSS.Math.Content.6.G.A.4 Represent three-dimensional figures using nets made up of rectangles and triangles, and use the nets to find the surface area of these figures. Apply these techniques in the context of solving real-world and mathematical problems.

CCSS.Math.Content.7.G.A.1 Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

CCSS.Math.Content.7.G.A.2 Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions. Focus on constructing triangles from three measures of angles or sides, noticing when the conditions determine a unique triangle, more than one triangle, or no triangle.

CCSS.Math.Content.7.G.A.3 Describe the two-dimensional figures that result from slicing three-dimensional figures, as in plane sections of right rectangular prisms and right rectangular pyramids.

CCSS.Math.Content.7.G.B.4 Know the formulas for the area and circumference of a circle and use them to solve problems; give an informal derivation of the relationship between the circumference and area of a circle.

CCSS.Math.Content.7.G.B.5 Use facts about supplementary, complementary, vertical, and adjacent angles in a multi-step problem to write and solve simple equations for an unknown angle in a figure.

CCSS.Math.Content.7.G.B.6 Solve real-world and mathematical problems involving area, volume and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.

CCSS.Math.Content.HSG-SRT.A.1a A dilation takes a line not passing through the center of the dilation to a parallel line, and leaves a line passing through the center unchanged.

CCSS.Math.Content.HSG-SRT.A.1b The dilation of a line segment is longer or shorter in the ratio given by the scale factor.

CCSS.Math.Content.HSG-SRT.A.2 Given two figures, use the definition of similarity in terms of similarity transformations to decide if they are similar; explain using similarity transformations the meaning of similarity for triangles as the equality of all corresponding pairs of angles and the proportionality of all corresponding pairs of sides.

CCSS.Math.Content.HSG-SRT.A.3 Use the properties of similarity transformations to establish the AA criterion for two triangles to be similar.

CCSS.Math.Content.HSG-SRT.B.4 Prove theorems about triangles.

CCSS.Math.Content.HSG-SRT.B.5 Use congruence and similarity criteria for triangles to solve problems and to prove relationships in geometric figures.

CCSS.Math.Content.HSG-SRT.C.6 Understand that by similarity, side ratios in right triangles are properties of the angles in the triangle, leading to definitions of trigonometric ratios for acute angles.

CCSS.Math.Content.HSG-SRT.C.7 Explain and use the relationship between the sine and cosine of complementary angles.

CCSS.Math.Content.HSG-SRT.C.8 Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems.

CCSS.Math.Content.HSG-SRT.D.9 (+) Derive the formula A = 1/2 ab sin(C) for the area of a triangle by drawing an auxiliary line from a vertex perpendicular to the opposite side.

CCSS.Math.Content.HSG-SRT.D.10 (+) Prove the Laws of Sines and Cosines and use them to solve problems.

CCSS.Math.Content.HSG-SRT.D.11 (+) Understand and apply the Law of Sines and the Law of Cosines to find unknown measurements in right and non-right triangles (e.g., surveying problems, resultant forces).

CCSS.Math.Content.HSG-C.A.1 Prove that all circles are similar.

CCSS.Math.Content.HSG-C.A.2 Identify and describe relationships among inscribed angles, radii, and chords.

CCSS.Math.Content.HSG-C.A.3 Construct the inscribed and circumscribed circles of a triangle, and prove properties of angles for a quadrilateral inscribed in a circle.

CCSS.Math.Content.HSG-C.A.4 (+) Construct a tangent line from a point outside a given circle to the circle.

K-PS2-1 Plan and conduct an investigation to compare the effects of different strengths or different directions of pushes and pulls on the motion of an object.

K-PS2-2 Analyze data to determine if a design solution works as intended to change the speed or direction of an object with a push or a pull.

3-PS2-1 Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

3-PS2-2 Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.

Patterns in the natural and human designed world can be observed and used as evidence.

Patterns in the natural world can be observed, used to describe phenomena, and used as evidence.

Patterns in the natural and human designed world can be observed.

Patterns in the natural world can be observed.

Patterns of change can be used to make predictions.

Similarities and differences in patterns can be used to sort and classify natural phenomena.

Similarities and differences in patterns can be used to sort and classify designed products.

Patterns can be used as evidence to support an explanation.

Similarities and differences in patterns can be used to sort, classify, communicate and analyze simple rates of change for natural phenomena.

Patterns can be used to identify cause and effect relationships.

Graphs, charts, and images can be used to identify patterns in data.

Patterns in rates of change and other numerical relationships can provide information about natural systems.

Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Empirical evidence is needed to identify patterns.

Simple tests can be designed to gather evidence to support or refute student ideas about causes.

Events have causes that generate observable patterns.

Cause and effect relationships are routinely identified.

Cause and effect relationships are routinely identified, tested, and used to explain change.

Cause and effect relationships are routinely identified and used to explain change.

Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Cause and effect relationships may be used to predict phenomena in natural systems.

Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.

Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.

Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Systems can be designed to cause a desired effect.

Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

People depend on various technologies in their lives; human life would be very different without technology.

Every human-made product is designed by applying some knowledge of the natural world and is built using materials derived from the natural world.

Possible Bibliographies/ Works Sited

Barth R. (2004). Learning By Heart. San Francsico: Jossey Bass

Browne H. (1974). *How I found Freedom In An Unfree World*: *A Handbook For Personal Liberty*. Great Falls,Mont: Liamworks.

Crawford M. (2009). *Shop Class as Soulcraft: An Inquiry Into the Value of* Work. New York,New York: Penguin Press.

Fox J. (2008). *Your Children's Strengths: Discover Them, Develop Them, Use Them*. . New York,New York: Viking Adult.

Gardner H. (1993). *Multiple Intelligences: New Horizons in Theory and Practice*:Basic Books

Jerold W. Apps (1996). *Teaching from the Heart*: Krieger Publishing Company.

Kozol J. (1991). *Savage Inequalities*.New York: Crown Publishers, Inc.

Maslow A (1962). *Toward a Psychology of Being*: Martino Books.

McDermott J. (1973*). The Philosophy of Dewey/The Lived Experience.*Capricorn Books.

Palmer P. (2007). *The Courage to Teach: Exploring the Inner Landscape of a Teacher's Life*: Jossey-Bass.

Perricone J (2005). *Zen and the Art of Public School Teaching*. Publish America.

Pirsig R. (1974). *Zen and the Art of Motorcycle Maintenance: An Inquiry Into Values*.Bantam Books.

Sterling P. (1972). *The Real Teachers* New York: Random House.

Suzuki S. (1970). *Zen Mind, Beginner Mind*.Weatherhill.

Journals:

White-Clark R. (2005). *Training Teachers to Succeed in a Multicultural Classroom* The Education Digest 70 no8 23-6 New York: National Association of Elementary School Principals.

Foster M.Lewis J., Onafowora L. (2005). *Grooming Great Urban Teachers* 62 no6 28-32 Durham, North Carolina: Educational Leadership.

Simpson, Judith W. (July, 1995). *Choices for urban art education* New York: Arts Education Policy Review.

Websites:

Bisgard D. (2005*) Diversity [15 Years From Now] Do we have 2020 vision?*
H.W. Wilson Company*:*http://www.nais.org

Charles G. (2005) *The Challenge of Diversity and Choice 101*
Educ Horiz 83 no2 ,H.W. Wilson Company: http://www.pilambda.org

Raymond A. and S. (1993,2005) *I Am A Promise: The Children of the Stanton Elementary School* DVD: New York: New Video Group, Inc.: http://www.videoverite.tv/pages/timelinemain.html#promise

https://www.birdbraintechnologies.com

https://www.ecovative.com

http://grow.bio

https://microbit.org

https://makecode.microbit.org

http://makercase.com

https://glowforge.com

https://www.worx.com

https://www.morphiapp.com

http://ultimaker.com

https://www.bantamtools.com