Form and Function(s): A Sustainable Design meets Computation Design Plan

Introduction

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The Concept behind Form and Function(s): Sustainable Design meets Computation

When Architecture, the Natural Sciences, Mathematics and Computing intermingle something beautiful and purposeful occurs. Through this course of study students are challenged to think computationally by considering the notion of "design" through three perspectives on form and function. Through the first perspective, we challenge students to consider a structure's architectural form in the context of its function within the ecology in which it belongs. A second perspective on form and function is provided by way of the natural sciences, where students explore nature's designs, which are created through natural selection. Finally, form and function is further abstracted through a mathematical and computational perspective that focuses on how natural selection can be emulated through modelling and coding. The journey comes full circle, and the three perspectives coalesce, when students engage in a hack-a-thon in which they model and code evolutionary algorithms to design a better building.

Completion of the project in its entirety requires team teaching at the grade 11 level as the project spans the Career and Technology Studies (CTS), Biology 20, and Math 20 curriculums. Alternatively, selections from the design plan can be taught on their own, or mixed and matched as opportunities for collaborative teaching allow. As a whole, the materials are intended to provide teachers of grade 11 students an integrated STEAM approach to teach students to learn and apply computational thinking. However, the modular design of the learning activities will also allow secondary purposes to be fulfilled. Table 1. provides several pathways for the use of the learning activities (detailed in Section 3) and OER materials provided; however, teacher's are encouraged to mix and match to suit their needs. For example, a BioMath pathway could easily be created by combining the core elements of the Biology 20 and Math 20-1 pathways found in Table 1.

Table 1. Proposed options to complete

Pathway	Sequence of Learning Activities*																
	1	2	3A	3B	4	5	6A	6B	7A	7B	8	9	10	11A	11B	12	13
Complete – CTS, BIO 20, Math 20-1																	
Media/Design/Communication Arts (CTS)																	
Computer Science (CTS)																	
Biology 20 Science and Technology Emphasis																	

Math 20-1 Functions and Relations	■			■		■		■	■		■	■	■				

* Included Learning Activities are indicated with a coloured square.

More details on the project and its options can be found here (add link when materials are finalized and uploaded to host sites) and an overview of each of the above suggested pathways is provided below.

The Complete Pathway

The complete design plan touches on elements of the CTS Media/Design/Communication Arts cluster (MDC), Biology 20 Science and Technology Emphasis, Math 20-1, and CTS Computer Science curriculums. Our goal is to use the concept of design to teach students to learn and apply computational thinking. Using an integrated STEAM (Science, Technology, Engineering, Arts and Mathematics) approach, this project aims to introduce students to the notion of design through three perspectives via a series of process-based learning lessons and activities.

Architecture is a perfect way to introduce the notion of aesthetics through form and function. Here, we challenge students to think of design not only in terms of form but also in the context of function. We consider how, as a society, we might move beyond creating structures that impose upon the environment; instead creating structures that integrate into the ecologies they inhabit. For example, imagine a future in which our structures are more than just spaces, but contribute to the natural processes of the ecologies they inhabit, seamlessly integrating into the ecology's energy and geo-chemical cycles including solar, geothermal, water, oxygen and carbon dioxide cycles, to name a few. It's easy to envision the potential benefits of integration of our built environment into the natural ecology it inhabits, especially as we seek to reduce our environmental impact. Unfortunately, achieving ecological integration of our built environment is not an easy task.

Ecological integration is of course regularly achieved in nature, but how? In the second Inquiry, we challenge students to think about nature's designs. For example, why is an organism so well suited for the ecological niche it uniquely occupies? Here, students will be introduced to the concept of adaptation through the process of natural selection, by emphasizing that nature's designs are achieved through repeated iteration of a simple principle: better adapted individuals will prevail over less adapted ones. Can a similar process be used to achieve biomimicry of our built environment? Clearly, an exact real-world replication of natural selection is not a practical approach but, through mathematics and computing, we will emulate natural selection to achieve ecological integration.

In the third Inquiry we ask students to think about emulating the process of natural selection through computational means. In this way, students are introduced to mathematical modelling and the process of computer simulation and, in this context, students are encouraged to think about what it means for a mathematical model or computer simulation to be well-designed. Ultimately, we guide students to a basic understanding of how natural selection can be modelled, and how evolutionary algorithms can be used to emulate natural selection, with the goal of finding a better design. Summary performance activities cap off. learning. Students learn about passive solar capture and how a building's surface orientation affects its ability to capture the sun's energy, as well as the how the buildings envelop and window to wall surface area ratios affect energy loss. Students are then challenged to assemble what they have learned to develop their best design for building that maximizes the use of passive solar energy. The whole activity can be extended with a "Hack-a-thon".

CTS Media Design and Communication Arts and CTS Computer Science Pathways

The Media Design and Communication Arts and CTS Computer Science pathways follow the same basic course as the Complete pathway presented above. The MDC pathway places emphasis on design studies and deemphasizes the technical aspects associated with the Biology 20, Math 20-1, and Computer Science curriculums. In contrast, the Computer Science pathway places emphasis on mathematical and computer modelling and computational thinking and while deemphasizing aspects of Design Studies. Both allow the majority of learning activities to be included, but with some presented in an abridged version.

The narrative for both the MDS and Computer Science pathways remains largely unchanged. As before, students are challenged to think computationally by considering the notion of "design" through three perspectives on form and function. Architecture remains the point of entry and provides the first perspective on design. The notion of sustainable design is introduced, providing students with an understanding of the principles and objectives of sustainable design as well as an overview of the complex problems that arise. Natural selection is again used to transition from the architectural design to that of modelling, computational thinking and problem solving. Through their brief exploration of Natural Selection students are exposed to the idea of simulating Natural Selection as a means of problem solving, which in turn provides motivation to learn about Genetic Algorithms. Genetic Algorithms are then used as part of the "Hack-a-thon" that caps the activity off. Students learn about passive solar capture and how a building's surface orientation affects its ability to capture the sun's energy, as well as the how the buildings envelop and window to wall surface area ratios affect energy loss. Students are then challenged to assemble what they have learned to develop their best design for building that maximizes the use of passive solar energy.

Biology 20 Natural Selection Pathway

This design pathway is intended to augment the Biology 20 curriculum by expanding the exploration of Natural Selection as an evolutionary process both as it is operating in nature but also how the process of Natural Selection has inspired computational approaches to problem solving. As a standard part of the Biology 20 curriculum students are taught the principles of natural selection as they apply to populations of organisms in nature. This design pathway follows the standard curriculum approach and will enable students to understand and explore the mechanisms by which plants, animals and fungi change over time, in a process that itself is driven by continuous changes of their environment. Natural selection is a key mechanism for change in populations and species and therefore evolution. Although it is not the only driving force for evolutionary change it is the only evolutionary mechanism that drives adaptation. To better understand how Natural Selection operates students are introduced to the concept of modelling and learn about the role that modelling plays in science. Students are able to see the modelling process in action by exploring Fisher's Fundamental Theorem of Natural Selection, which serves as an example that highlights the use of mathematical modeling has played in the developing of Evolutionary Theory. Fisher's Fundamental Theorem of Natural Selection is a bit of an obscure result, but it's appeal here is that it is appropriate for this level with a simplified version and presentation available for a purely biological focus. An online Lab is provided via Jupyter Notebooks that allows students to explore how Natural Selection operates by simulating of the evolution of a virtual population of "stick ungulates". Through this project students are exposed to the idea of simulating Natural Selection as a means of problem solving, which then provides motivation to introduce students to learn about genetic algorithms.

Math 10/20 Functions and Relations Pathway

In this design plan students study Relations and Functions curriculum from Math 10 and Math 20 framed from the perspective of Mathematical modelling. First students are introduced to the concept of modelling in general terms, examining different types of model and their uses. Examples might include, 2D-visual models, 3D visual models, logic models, mathematical models and computer simulation models. Students learn that models are simplified representations of real-world systems that play important roles in the development of theory, the application of theory in problem solving and the transmission and translation of knowledge.

To start the unit on Relations and Functions and to provide context for the study of mathematical modelling the students are presented with a real-world problem. Specifically, we challenge students to consider how, as a society, we might move beyond creating built structures that impose upon the environment; instead creating structures that integrate into the ecologies they inhabit. For example, imagine a future in which our structures are more than just spaces, but contribute to the natural processes of the ecologies they inhabit, seamlessly integrating into the ecology's energy and geo-chemical cycles including solar, geothermal, water, oxygen and carbon dioxide cycles, to name a few. Students will work on this challenge as their "building green" project that serves as the unit's summative performance task.

To provide the students with the necessary knowledge and skills to tackle the summative performance task, students will first be introduced to modelling and analysis by way of considering how nature achieves ecological integration. Here, the students are briefly introduced to the concept of adaptation as a result of natural selection. Next, students will see the modelling process in action by exploring Fisher's Fundamental Theorem of Natural Selection, which serves as an example that highlights the use of mathematical modeling in the developing Scientific Theory. As noted above, Fisher's Fundamental Theorem of Natural Selection is a bit of an obscure result, but it's appeal here is that it is appropriate for this level; its development and analysis drawing on the math 10C and Math 20 Relations and Functions curriculum, which is detailed below.

The Callysto Jupyter Notebook

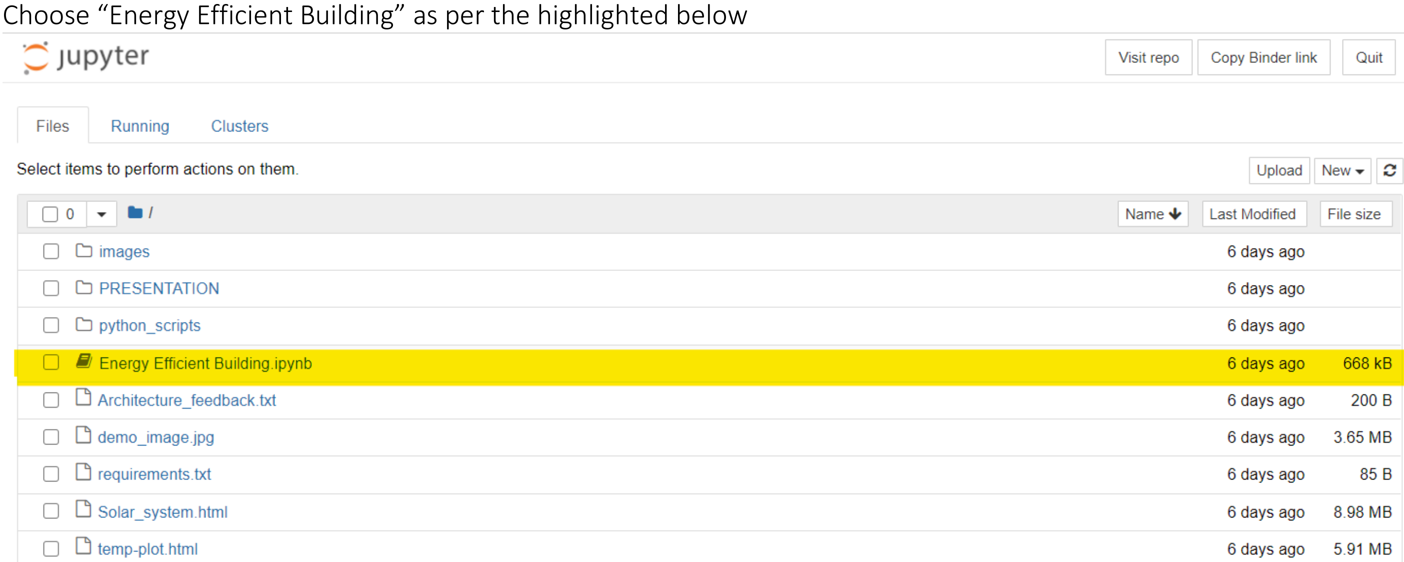
Jupyter Notebooks are interactive platforms that allow learners to easily interact with computational approaches. These notebooks help learners explore how ideas can be computationally implemented. The Jupyter notebook for this project is hosted on the Callysto site.

The Jupyter Notebook is an integral part of this project. Click on the link, below, to take you to the Jupyter Notebook and then read on to see how to use it.

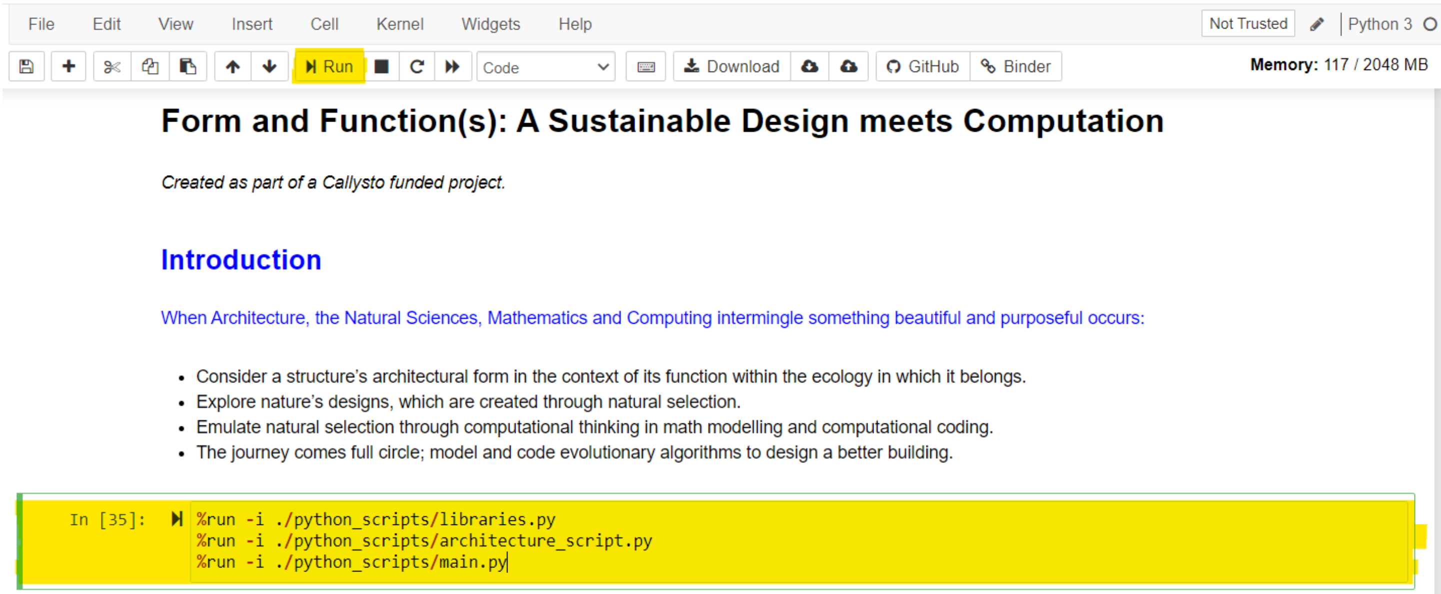
CLICK HERE TO ACCESS THE JUPYTER NOTEBOOK

Instructions:

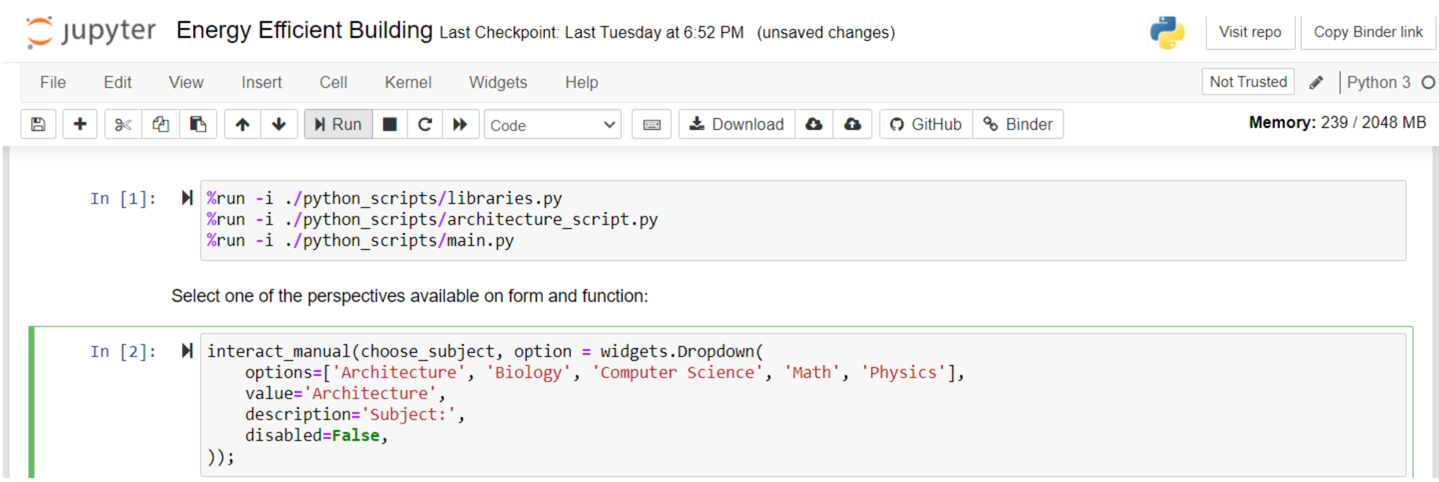
1) Click on the JUPYTER NOTEBOOK LINK
2) Choose "Energy Efficient Building" as per the highlighted below



3) Click on the first line of code and hit "Run"



4) Click on the second line of code and hit "Run" again



Now, you could pick a subject that interests you to see the interactive exercises we have designed. Enjoy!

Stage 1 – Desired Results	
ESTABLISHED GOALS	*Transfer*
	Students will be able to independently use their learning to…

Demonstrate an understanding of Design in various contexts including Architectural, Biological, Mathematical and Computational contexts.

Demonstrate that mathematical modeling and computer coding can be used to emulate natural selection. This can be used to solve issues in structural design so that those structures may be incorporated into the natural ecosystem.

Meaning

UNDERSTANDINGS
Students will understand that…

Biology 20 understanding
- The growth and interactions of life forms within their environments reflects their uniqueness, diversity, genetic continuity and changing nature
- All natural entities are modified over time; the direction of change might be predicted and, in some instances, the change can be controlled.

Math 10/20-1 understanding
- Modelling is an integral study of mathematics
- Modelling allows us to: develop theory, apply theory and transmit and translate theory to other contexts.
- Modelling is a powerful tool in problem solving by allowing us to explore "what if scenarios" to enable informed decision making.

ESSENTIAL QUESTIONS

MDC (CTS) Essential Questions
- What is the relationship between form and function in the design of architecture?
- How can we move toward creating structures that integrate into the ecologies they inhabit?
- Can a building be more than a beautiful space, by contributing to the natural processes of the ecologies they inhabit, integrating into the ecology's energy and geo-chemical cycles including solar, water, oxygen, and carbon dioxide cycles?
- Can a building or community produce more energy, clean water, or clean air than it consumes?

Biology 20 Essential Questions
- How is it that an organism can be so well suited for the ecological niche it uniquely occupies?
- How does natural selection work?
- Can natural selection be emulated to solve real world problems?

Math 10/20-1 Essential Questions

- What are models, how do we construct models and why do we construct them?
- How is the language of mathematics and /or coding used in modelling?

		● How are mathematical and/or computer models used to develop and test theory? ● How are mathematical and/or computer models used to problem solve? Computer Science (CTS) ● How can structured programming be used in mathematical modeling?
	Acquisition	
	Competencies: Critical Thinking, Problem Solving and Communication	Processes: 1. Communication 2. Mental Mathematics and Estimation 3. Making Mathematical Connections 4. Problem Solving 5. Reasoning 6. Technology integration 7. Visualization 8. Measurement *9.* Relations and Functions
	Students will know… MDC ● How to begin the design process in order to produce a designed solution ● How to identify and practice 2D and 3D design techniques ● Use CAD tools to create 2D and 3D architectural designs Biology 20 ● explain that variability in a species results from heritable mutations and that some mutations may have a selective advantage ● discuss the significance of sexual reproduction to individual variation in populations and to the process of evolution ● explain speciation and the conditions required for this process	*Students will be skilled at…* MDC ● Identifying the steps in the design process ● Applying steps in the design produce through production of a designed solution ● Identify and practice 3D design techniques ● Use CAD tools to create 2D and 3D drawings ● Demonstrating the competencies (communicate; manage information; use numbers; think and solve problems) Biology 20 ● analyze data and apply mathematical and conceptual models to develop and assess possible solutions ● analyze data, actual or simulated, on plants and animals to

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- describe modern evolutionary theories; i.e., punctuated equilibrium, gradualism.

Math 10/20-1

Linear models (Math 10 curriculum)

- Linear relationships are described by functions of the form $y = mx + b$.
- The graph of a linear function $y = mx + b$ is a line with a slope of m and a y intercept equal to b.
- The slope of a linear function, m, describes the rate of increase, or proportional increase, of the variable y with respect to the variable x.
- Many real-world relationships between continuous variables can be modeled as linear functions

Quadradic models (Math 20 curriculum)

- Quadratic functions are described by functions of the form $yx^2 + bx + c, a \neq 0$
- The graph of a quadratic function $yx^2 + bx + c, a \neq 0$ is a "U-shaped" curve called a parabola.
- Quadratic functions can be written in vertex form: $y = a(x - p)^2 + q$ where the vertex of the parabola is given by (p, q).
- Quadratic functions can be written in factored form: $y = (ax + b)(cx + d)$ where the roots of the parabola are given by $x = -\frac{b}{a}$ and $x = -\frac{d}{c}$..
- The location of a quadradic function's vertex identifies the function's maximum or minimum value, which is often of interest in optimization problems.
- Many real-world relationships between continuous variables can be modeled as quadratic functions

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demonstrate how morphology changes over time;

- conduct investigations into relationships between and among observable variables and use a broad range of tools and techniques to gather and record data and information
- gather data, actual or simulated, on organisms to demonstrate how inherited characteristics change over time, as illustrated by Darwin's finches, peppered moths, bacteria and domesticated plants and animals

Math 10

Linear models will highlight the Math 10 curriculum: Relations and Functions: Students will be able to

1. Interpret and explain the relationships among data, graphs.
2. Demonstrate an understanding of relations and functions.
3. Demonstrate an understanding of slope with respect to rise and run; line segments and lines; rate of change; parallel lines; perpendicular lines.
4. Describe and represent linear relations using: words; ordered pairs; tables of values; graphs; equations.
5. Determine the characteristics of the graphs of linear relations, including the: intercepts; slope; domain; range.
6. Relate linear relations expressed in: slope–intercept form (y = mx + b); general form (Ax + By + C = 0) ; slope–point form (y – y1 =m(x – x1)) to their graphs.
7. Determine the equation of a linear relation, given: a graph; a point and the slope; two points; a point and the equation of a parallel or

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		perpendicular line to solve problems. 8. Represent a linear function, using function notation. 9. Solve problems that involve systems of linear equations in two variables, graphically and algebraically. Math 20-1 Quadratic models will highlight the Math 20 curriculum: Relations and Functions. Students will be able to: 1. Factor polynomial expressions of the form: $ax^2 + bx + c, a \neq 0$; $a^2x^2 - b^2y^2, a \neq 0, b \neq 0$; $a(f(x))^2 + b(f(x)) + c, a \neq 0$; $a^2(f(x))^2 - b^2(f(y))^2, a \neq 0, b \neq 0$where a, b and c are rational numbers. 2. Graph and analyze absolute value functions (limited to linear and quadratic functions) to solve problems. 3. Analyze quadratic functions of the form $y = a(x-p)^2 + q$ and determine the: vertex; domain and range; direction of opening; axis of symmetry; x- and y-intercepts. 4. Analyze quadratic functions of the form $y = ax^2 + bx + c$ to identify characteristics of the corresponding graph, including: vertex; domain and range; direction of opening; axis of symmetry; x- and y-intercepts and to solve problems. 5. Solve problems that involve quadratic equations. 6. Solve, algebraically and graphically, problems that involve systems of linear-quadratic and quadratic-quadratic equations in two variables. 7. Develop algebraic and graphical reasoning through the study of relations.

		8. Solve problems that involve linear and quadratic inequalities in two variables. 9. Solve problems that involve quadratic inequalities in one variable 10. Analyze arithmetic sequences and series to solve problems. 11. Analyze geometric sequences and series to solve problems. 12. Graph and analyze reciprocal functions (limited to the reciprocal of linear and quadratic functions). COMPUTER SCIENCE (CTS) ● Students explore software and processes. This includes an introduction to the algorithm as a problem-solving tool, to programming languages in general and python in particular, to the role of programming as a tool for implementing algorithms.

Stage 2 – Evidence and Assessment	
Evaluative Criteria	Assessment Evidence
	[Overview] MDC 1. Using knowledge of form and function creating architectural designs using CAD. 2. Hackathon to test architectural design. 3. Answering of the essential questions Hackathon See below for details Math 10/20-1 Students develop an understanding of mathematical modelling and how mathematical modelling is used to both to further our understanding of natural phenomenon and its application in problem solving. Students will learn to write and use mathematic relations and functions to model natural phenomenon.

Students will learn to develop and analyze linear models and quadratic models.

Pre-assessment:
Compass Points routine - excitements, worries, needs and suggestions/next steps
Math Anticipation Guide & Pre-assessment

Formative Assessments:

- Math Journal/Sketch notes to demonstrate understanding of concepts.
- Anecdotal notes/conversations
- Feedback – Project Discussion and Development
- Practice Quizzes
- Textbook questions
- Math Labs – Jupyter Notebooks Hosted with Callysto

Summative Assessments:

- Unit Exam and or Project
- Assessments - teacher generated - digital as well as paper/pen

Project "Building Green"
Math 10C, Math 20 and Computer Science (CTS)

Aim to create optimal buildings that can together save energy.

- Model development – construct a model describing how a buildings energy consumption is related to its envelope and how the capture of solar energy is related to the surface area of the solar capture surface.

  Building Envelopes and Heat loss: Model Energy loss as a linear relation.
  Solar Energy Generation: Model Solar Energy capture as a linear relation and/or quadratic relation.

  Costs: Model Materials costs as linear functions.

- Model Analysis - connections to the math 10C and Math 20 Relations and Functions curriculum are made when students analyze their model for building green.

- Simulate the process of natural selection (using genetic algorithm approach) to optimise energy use (generation from solar and consumption of energy) using the math models produced as evaluative fitness functions.
  From a 'chromosome' that describes the aspects of the building, develop descriptions for buildings that:
  1. Optimise the orientation of the building and natural aspect of the landscape to create an efficient solar powered insulated house that is comfortable to live in all year round.

	2. Optimise the position of the house in the landscape with weather records and grey water system efficiencies to create a house that has abundant water all year. Hack-a-thon: Extended activity: Using the candidate buildings produced previously, take a co-opetition (co-operative competition) approach and propose a settlement of buildings that are optimised not for themselves individually, but for the whole settlement by being able to share resources and functional capacity.
	OTHER EVIDENCE:

Stage 3 – Learning Plan

Summary of Key Learning Events and Instruction

Learning Activity 1– Introduction

The hook. To provide context for our exploration of design and computational thinking students are presented the animation *Form and Function(s): Sustainable Design Meets Computational Thinking*. The animation provides an introduction and overview for the course of study that follows.

Following the animation, class discussion is to consider how, as a society, we might move beyond creating structures that impose upon the environment; instead creating structures that integrate into the ecologies they inhabit. For example, imagine a future in which our structures are more than just spaces, but contribute to the natural processes of the ecologies they inhabit, seamlessly integrating into the ecology's energy and geo-chemical cycles including solar, geothermal, water, oxygen and carbon dioxide cycles, to name a few. It's easy to envision the potential benefits of integration of our built environment into the natural ecology it inhabits, especially as we seek to reduce our environmental impact. Recognizing that achieving ecological integration of our built environment is a complex task motivates the ensuing learning activities.

Animation: Form and Function: Sustainable Design Meets Computational Thinking

Learning Activity 2: Architectural Design - What is design?

In this lesson, students are introduced to the architectural design thinking and process, combining both artistic and scientific skills. Students will firstly analyze the needs of a project, such as the context of the building and the functions it needs to fulfill, and then come up with a form responding to these.
Vitruvius describes the three virtues of architecture as Utilitas (Function), Firmitas (Strength) and Venustas (Beauty), and it the balance and integration of these that make a good building. These virtues will be a theme that will be revisited throughout the 3 modules (i.e. architecture, biology, computation) of the project. "Form follows Function", a principle of design process developed by architect Louis Sullivan will be adopted to understand how Form & Function relate to each other.
A number of direct connections will be made to Alberta Career and Technology Studies (CTS) curriculum and specifically to the Media/Design/Communication Arts (MDC) Cluster. Some examples of the MDC learning outcomes to which we will align include:

- identifying the steps in the design process, including the elements and principles of design, e.g., balance, emphasis, proportion (scale), repetition (rhythm/pattern), unity, contrast, harmony, proximity and variety, as they apply to form and function

- applying the steps in the design process through production of a designed solution
- selecting and using appropriate tools and materials to achieve a designed solution
- effectively communicating intentions and decision making related to the design project; e.g., form, function, aesthetics
- demonstrating basic competencies including, communication, numeracy, problem solving, teamwork and participation in projects and tasks

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Learning Activity 3a: Architectural Design - What is sustainable design?

In this lesson, the class is introduced to sustainable design. Sustainable design endeavors to create built environments that comply with the principles of sustainable ecology. Here, students are provided with an overview of sustainable design including the challenges facing our societies that motivate sustainable design, the theory and design principles that underly sustainable design, it's aspects or characteristics and applications.

At the end of the activity students are informed that they will be completing a project focused on sustainable design as the basis for their summative performance task, which is described in Learning Activity X: the "building green" project. A brief overview of the project could be presented at this time to whet the students' appetite. An overview of the course of study leading up the project is presented so students know what to expect in terms of learning objectives and outcomes.

Learning Activity 3b: Introducing the Building Green Project

To provide context for our exploration of mathematical modelling we first ask students to consider how, as a society, we might move beyond creating structures that impose upon the environment; instead creating structures that integrate into the ecologies they inhabit. For example, imagine a future in which our structures are more than just spaces, but contribute to the natural processes of the ecologies they inhabit, seamlessly integrating into the ecology's energy and geo-chemical cycles including solar, geothermal, water, oxygen and carbon dioxide cycles, to name a few. It's easy to envision the potential benefits of integration of our built environment into the natural ecology it inhabits, especially as we seek to reduce our environmental impact. Unfortunately, achieving ecological integration of our built environment is not an easy task.

At the end of the activity students are informed that this challenge will form the basis for the unit's summative performance task, which is described in Learning Activity 10 and 12 the "building green" project. A brief overview of the project could be presented at this time to whet the students' appetite. An overview of the course of study leading up the project is presented so students know what to expect in terms of learning objectives and outcomes.

Learning Activity 4: Architectural Design - Factors involved in sustainable design and its calculations

In this lesson, students are exploring the principles of energy efficiency in greater detail, including how energy flows, sources of energy and the causes of energy loss. Principles of thermodynamics are studied, and students learn how calculations are performed to inform sustainable design by considering how changes to a building's variables such as its dimensions, its window to wall surface ratio, its envelope, etc., impact the buildings need for energy and ability to retain energy.

Using an OER Jupyter Notebook simulator, students experiment with changing the variables of a simple building and observe their impact on the building's energy use and the building's cost. In doing so, students observe that there is a seemingly endless number of ways to design a building, with each design differing in its need for and ability to retain energy as well as its cost. An important question to consider is whether there a best design, i.e. one that is most energy efficient while not too costly? How might we find that design amongst the seemingly infinite possibilities?

Learning Activity 5: Modelling - What is a model and why do we use them? (Single Lesson)

Shifting gears, in this activity students are introduced to the concept of modelling as an important design tool.

The concept of modelling is first introduced in general terms, examining different types of model and their uses. Examples might include, 2D-visual models, 3D visual models, logic models, mathematical models and computer simulation models.

Students will learn that models are simplified representations of real-world systems that play important roles in the following:

- the development and conception of ideas and theory,
- the application of theory and
- the transmission and translation of knowledge.

Link to Support Document "Why Model"

Learning Activity 6a: Natural Selection

Firm connections to the Biology 20 curriculum are established as focus shifts from sustainable design to Natural Selection. For this activity, teachers can adopt and adapt their pre-existing curriculum materials and learning plans used for teaching Unit B: Ecosystems and Population Change. In working towards Unit B's General outcome 2, which tasks the student to understand the mechanisms involved in the change of populations over time students will explore the mechanisms by which plants, animals and fungi change over time, in a process that itself is driven by continuous changes of their environment. Natural selection is a key mechanism for change in populations and species and therefore evolution. Although it is not the only driving force for evolutionary change it is the only evolutionary mechanism that drives adaptation. A foundational understanding of Natural Selection and its operation then serves as platform to introduce students to the concept of modelling and to learn about the role that modelling plays in the development of Scientific Theory, which is explored in the next lessons.

Link to Animation "How does Natural Selection work"

Learning Activity 6b: Natural Selection – a conceptual model for design (Single Lesson)

To shift our focus from the sustainable design to mathematical and computer modelling we draw inspiration from nature. Here, the class is lead in a discussion based on the observation that Ecological integration is regularly achieved in nature. The question is how? In this learning activity, we challenge students to think about nature's designs. For example, why is an organism so well suited for the ecological niche it uniquely occupies? Here, students are introduced to the concept of adaptation through the process of natural selection, by emphasizing that nature's designs are achieved through repeated iteration of a simple principle: better adapted individuals will prevail over less adapted ones.

Students will learn about Darwin's theory of Natural selection as a conceptual model (Theory) explaining why organisms' traits seem so perfectly adapted to their function.

Link to Animation "How does Natural Selection work"

Learning activity 7a: Mathematical Modelling

In this activity students see the modelling process pushed further by working through an example that highlights modeling's use in developing Scientific Theory, while also connecting to the ideas of natural selection which were introduced in the previous learning activity.

What is a mathematical model and how are mathematical models constructed and analyzed?

Students are introduced to mathematics as a language that has a natural use for modelling.
An outline the modelling process is presented. This includes:

- How we model the system in common language (English, French, etc.)
- How we model the system in the language of mathematics.
- How we analyze the mathematical model to further our understanding of the system.

Fisher's Fundamental Theorem of Natural Selection: Developing a model of Darwin's Theory of Natural selection and as an Exemplar of how mathematical models used to develop and test theory

Students reconstruct Fisher's model of natural selection, drawing on the math 10C and Math 20 Relations and Functions curriculum. It is expected that students will: "Develop algebraic and graphical reasoning through the study of relations" Specifically, students will develop the skills highlighted in points 1 and 2 in *Evaluation criteria for Linear Models* listed above.

Link to Support Document "Fisher's Fundamental Theorem"

Learning activity 7b: A Mathematical Model of Natural Selection

In this activity students see the modelling process pushed further by working through an example that highlights modeling's use in developing Scientific Theory, while also connecting to the ideas of natural selection which were introduced in the previous learning activity.

Students are introduced to mathematics as a language that has a natural use for modelling and a mathematical model of Natural selection is presented. The model is analyzed graphically providing a visual and intuitive understanding of how natural selection can lead to adaptation under different ecological conditions. The model is used in Learning Activity 9, which allows students to explore how Natural Selection operates by simulating of the evolution of a virtual population of "stick ungulates".

Link to Support Document "Fisher's Fundamental Theorem"

Learning activity 8: Mathematics - How's your Kung-fu? Developing the mathematical skills to analyze our model of Natural selection.

Connections to the math 10C and Math 20 Relations and Functions curriculum are made when students analyze Fisher's model of Natural Selection – proving the Fundamental theorem of Natural selection.
To do so, students will examine the model in both of its Linear and Quadratic forms.

Linear Model outcomes.
In order to analyse the linear model of Fisher's Theorem of Natural Selection students will need to acquire the understanding and skillsets identified in the Math 10 Curriculum, which are outline in Stage 1 of this design Plan.

Specifically, Students will continue to develop algebraic and graphical reasoning through the study of relations as outlined in the listed Competencies and Mathematical Processes provided in the Acquisition section of Stage 1 of this design Plan. For this activity, teachers can adopt and adapt their pre-existing curriculum materials and learning plans, drawing connections between key learning outcomes in their existing learning plans and the analysis of Fundamental theorem of Natural selection.

Quadratic Model outcomes.
In order to analyse the quadratic model of Fisher's Theorem of Natural Selection students will need to acquire the understanding and skillsets identified in the Math 20 Curriculum. Specifically, Students will continue to develop algebraic and graphical reasoning through the study of relations as outlined in the listed Competencies and Mathematical Processes provided in the Acquisition section of Stage 1 of this design Plan. For this activity, teachers can adopt and adapt their pre-existing curriculum materials and learning plans, drawing connections between key learning outcomes in their existing learning plans and the analysis of Fundamental theorem of Natural selection.

Learning Activity 9: Mathematical Modelling and Natural selection - The Evolution of Stick ungulates.

In this "Lab" activity students use mathematical modelling to explore the process of adaptation through Natural Selection via an OER Jupyter Notebook. Before completing this lab, students should be familiar with the basic model describing Natural Selection acting at a single diploid gene locus with two alleles, which is developed in Learning Activity 6. The lab uses this model to consider how populations of stick ungulates evolve under different selective pressures, created by different environments. Students run a set of three trials to observe how three different populations inhabiting three different environments evolve under the actions of Natural Selection.

As part of the lab, students are asked to write up a report detailing their experiment and its outcomes. In particular, students are asked to consider how the process of natural selection lead their populations to become better adapted to each of the three environments they created. In doing so, students will need to consider the differences in the environments, how these differences impacted how natural selection shaped their population of stick ungulates.

Lin to Word Document "The Evolution of Stick Ungulates"
Link to Jupyter Notebook "The Evolution of Stick Ungulates"

Learning Activity 10. Summative Performance Based Assessment examining how mathematical models are used to problem solve. A study of "Building Green" by minimizing heat loss/gain and maximizing solar energy capture.

Students are introduced to the idea of "Building Green". The goal is to build more energy efficient and sustainable structures. In particular, students will investigate how a building's envelope affects its energy consumption, and how the energy consumption can be offset through solar energy capture. In doing so students must also consider how the cost of building increases as energy loss is decreased and solar consumption increases.

To achieve this, students will construct a model describing how a buildings energy consumption is related to its envelop, and how the capture of solar energy is related to the surface area of the solar capture surface. The model will draw on the math 10C and Math 20 Relations and Functions curriculum at the appropriate level: Linear models for Math 10, A mix of Linear and Quadradic models for Math 20. Students demonstrate their understanding of the Relations and Functions curriculum by analyzing their model for building green and presenting their results.

Results can be presented in written reports, or class presentations.

Learning Activity 11a – Genetic Algorithms (tech inclined students).

In this activity students consider the implementation of natural selection in the coding of a genetic algorithm. A genetic algorithm is implemented in a Jupyter notebook to solve the problem of navigating from one corner of a space to the diagonally opposite corner avoiding blocks. The implementation is in python and can be examined in the Jupyter Notebook. The parameters of the program are set by the students and the algorithm can be run to explore how the parameters impact its performance and ability to solve the problem.

- Prepare the idea of Genetic Algorithms inspired from nature as natural selection, animation, learning activity 7b and learning activity 9.
- Lesson about how a Genetic Algorithm is specified algorithmically and how they operate in an implementation.
- Explore, using the OER Jupyter Notebook, Genetic Algorithm Simulation. Students can enter the "rules" of a Genetic Algorithm and then see the results and impacts of how the Genetic Algorithm builds the optimal solution (or get stuck in a local optimum) from the starting conditions the students provided.

Link to Animation "How does Natural Selection work"
Link to Animation "Genetic Algorithms"
Genetic Algorithms Jupyter Lab
Link to Jupyter Notebook. Select the COMPUTING OPTION.

Learning Activity 11b – Genetic Algorithms (non technical approach).

In this activity student consider what an algorithm for natural selection might include. In computing this is termed a genetic algorithm. In this case study students study a genetic algorithm to solve the problem of navigating from one corner of a space to the diagonally opposite corner avoiding blocks. It is explored in this activity as a physical exercise. Students parse (run through) the algorithm to explore how options are generated and how they impact the algorithm's performance and ability to solve the problem.

- Prepare the idea of Genetic Algorithms inspired from nature as natural selection, animation.
- Lesson about how a Genetic Algorithm is specified algorithmically and how they operate in an implementation.
- An in-class role play activity, where students "manually" do what a GA does e.g., find a route through an environment of blocks using the GA algorithm provided.

Link to Animation "How does Natural Selection work"
Link to Animation "Genetic Algorithms"
Link to Supporting Document - Role Play simulating a genetic algorithm

Learning Activity 12. Summative Performance Based Assessment examining how simulating a search model increases capacity to find optimal solutions. A study of "Building Green" by minimizing heat loss/gain and maximizing solar energy capture.

Students are introduced to the idea of "Building Green". The goal is to build more energy efficient and sustainable structures. In this learning activity, students' goal is to simulate the search for energy efficient and sustainable structures using a genetic algorithm.

To achieve this, students will construct a structure descriptor (chromosome) which is made up of design factors (genes) and simulate a selection process either developing a genetic algorithm or adapting GA code. The code and descriptor together are used to create generations of potential structures and measure them against the fitness functions. Students' investigation in learning activity 10 (of how a building's envelope affects its energy consumption, and how the energy consumption can be offset through solar energy capture) provides the mathematical basis for the fitness function calculation needed to determine the fitness of each suggested solution.

Results can be presented in written reports, or class presentations.

STUB: Learning Activity 13 - Building Green Hack-a-thon

Building from Learning Activities 10 and 12 - Aim to create buildings that are energy efficient within their environment

- Model development – construct a model describing how a building energy consumption is related to its envelope and how the capture of solar energy is related to the surface area of the solar capture surface.

  Building Envelopes and Heat loss: Model Energy loss as a linear relation.
  Solar Energy Generation: Model Solar Energy capture as a linear relation and/or quadratic relation.

  Costs: Model Materials costs as linear functions.

- Model Analysis - connections to the math 10C and Math 20 Relations and Functions curriculum are made when students analyze their model for building green.

- Simulate the process of natural selection (using genetic algorithm approach) to optimise energy use (generation from solar and consumption of energy) using the math models produced as evaluative fitness functions.
  From a 'chromosome' that describes the aspects of the building, develop descriptions for buildings that:
  2. Optimise the orientation of the building and natural aspect of the landscape
  to create an efficient solar powered insulated house that is comfortable to live in all year round.
  3. Optimise the position of the house in the landscape with weather records and grey water system efficiencies to create a house that has abundant water all year.

Hack-a-thon: Extended activity:
Aim: to create optimal buildings that can together save energy.

Using the candidate buildings produced previously, take a co-opetition (co-operative competition) approach and propose a settlement of buildings that are optimised not for themselves individually, but for the whole settlement by being able to share resources and functional capacity.