MEETS BIOLOGY ENGINEERING
AT THE UNIVERSITY OF CINCINNATI

Snake Motion Lesson Overview

Title	Snake Motion
Grade Level Target / Range	11-12
Subject Area(s)	biology, physics, engineering, computer science
Time Required	6+ hours
Group Size	Part 1 Snake Locomotion: 2 per group Part 2 Bio-Inspired Snake Robotics: Up to 4 per group (dependent on supplies)
Materials Needed	Part 1 Snake Locomotion Introductory Video by Bruce Jayne Introductory Questions (for students) Motion Analysis Methods Part 1 Files Part 2 Bio-Inspired Snake Robotics Educational Snakebot Presentation (Slides) Educational Snakebot Presentation (Recorded Lecture) Snake Robots Pre-made Tunnels Snake videos from Part 1
Assessments	Part 1 Snake Locomotion Exercise Part 1 Snake Locomotion Exercise - Student Exemplar Part 2 Snake Robot Questions Part 2 Snake Robot Questions - Student Exemplar
Expendable Cost Per Group	*Prices are Estimates as of May, 2022* ● Part 1 does not require any materials to be purchased. ● The snake robots for part 2 are still being developed as an educational resource by ROBOTIS, Inc. Dynamixel XL Series Servomotors https://www.robotis.us/xl/ ● Snake "tunnels" will also need to be built to experiment with the robot snakes (expanded PVC cut to desired length)
Key Words	biology, physics, engineering, data analysis, snake movement, robotics, block programming, biomimicry

National Educational Standards	Next Generation Science Standards (NGSS) International Society for Technology in Education (ISTE)
State Specific Educational Standards	Indiana Science Standards Ohio Science Standards West Virginia Science Standards

Introduction

In this lesson, students will continue to work towards an understanding of how biology and engineering come together. In particular, they will focus on biological data collected from snake motion and the connections they can make to robotic motion. Students begin by learning how snakes move and how data can be collected and analyzed to describe the motion of a snake in different environments. They will then determine possible applications of robots that can move like snakes. Students will have an opportunity to experiment with snake robots and will come to understand the progress and challenges that exist today in creating robots that move like snakes.

This unit was created collaboratively by faculty from the University of Cincinnati College of Arts and Sciences, College of Engineering, and School of Education and in collaboration with the University of Akron. Combining biology with engineering activities provides students with a unique opportunity to understand the parallels between animal and robot behavior and sensory/sensor function and addresses broad Next Generation Science Standards (NGSS Lead States, 2013) and International Society for Technology in Education Standards (International Society for Technology in Education, 2022).

Investigating / Essential Questions

How can I use biological data to form and test hypotheses?

How do environmental structures affect snake locomotion?

How can we use information from living animals to improve human technology (biomimicry)?

How can a robot replicate snake concertina locomotion? What environmental factors affect its ability to do so?

How can robots be used to test biological hypotheses?

Learning Objectives

Students should be able to…

1) Identify major features of the environment that affect the ability of animals and robots to move, and explain what senses could be used to detect these features.
2) For the particular system we are studying, explain the key environmental factors that affect snake locomotion (friction, the shape of surfaces, the orientation of surfaces, the amount of available space).
3) Explain how snakes performing concertina locomotion form “anchoring regions” from which the body is pulled forward and pushed ahead.

4) Explain how snakes can change their locomotor speed by modulating the amplitude and duration of their movements (could be helpful to use sketches of plots of X versus time).
5) Predict how the environmental factors being studied would be expected to affect the speed and ease of movement.
6) Predict how the factors being studied might affect the modulation of movement amplitude and movement frequency.
7) Create an experimental design and summarize relevant data to test the predictions made.
8) Discuss whether the experimental manipulations resulted in only quantitative or also some qualitative changes in behavior.
9) Explain what conditions studied appeared optimal for locomotor speed.
10) Explain why the robot results matched those of the snake
11) Explain the benefits and drawbacks of using a robot to test hypotheses about biological systems
12) Discuss which aspects of snake locomotion would be beneficial to mimic in a robot

Prerequisite Student Knowledge

Students must be familiar with Microsoft Excel or Google Sheets. In addition, they should be familiar with forming and testing a hypothesis. Students should know how to find velocity and be familiar with the concept of a cycle or period. No prior programming or robotics knowledge needed.

Instructional Summary

During part one of this lesson, students learn how environmental structure affects snake locomotion. In addition, they practice formulating hypotheses and using data to prove or disprove them. They have an opportunity to manipulate data in a database and reformulate hypotheses as they learn more about the snake motion through the data. In part two, students will explore biomimicry and its purpose. Using the data and learnings about snake locomotion from part one, students will program a snake robot to move in concertina motion.

Instructional Plan

PART 1: Snake Locomotion

1.1 Introduction and Motivation

Show students several of the snake videos. Have them write down their noticings and wonderings. Ask them to consider some variables that one might look at when observing snake motion, in particular the speed and apparent efficiency of movement. Create a list of possible variables.

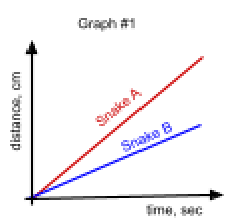
Next, have students watch the introductory video by Bruce C. Jayne, Department of Biological Science at the University of Cincinnati.

1.2 Procedure

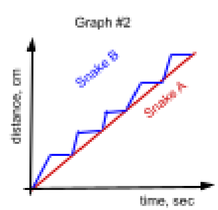
Point out to students that most animals move with different gates to attain different speeds. With snakes, they move differently based on their environment. The purpose of today's lesson is to explore how environmental structures affect snake locomotion as well as to practice formulating and testing hypotheses with data.

Have students work in groups to answer the following questions based on their learning from the introductory video.

1. What are some characteristics of concertina movement?
   Large periodic changes in head-to-tail distance
   Sliding and static contact
   Some regions move while others do not
   Regions of bending create static "anchoring" region
   No consistent propagation of bending along entire length
2. If snakes move using concertina locomotion, what is one thing they must do to move?
   Use static friction to anchor the body
3. What is something snakes in concertina motion do that you could observe with your eyes?
   The angle of the body in crossing regions
   The number of crossovers
4. In graph #1, which snake is moving faster and why?
   Snake A (greater distance per time, steeper slope)



5. In graph #2, which snake is moving faster? How does the average velocity of each snake compare?



   Snake B at times moves faster or slower, however the snakes are moving at the same average velocity.

6. In graph #2, which type of movement (snake A or B) represents concertina movement? Why?

Snake B, because it moves and then stops and continues to repeat this cyclic pattern of stop and go motion.

Return to the list of possible variables that were generated during the notice and wonder. Explain the fully crossed, experimental design to the students using the chart below. In the experiments, there were 5 different tunnel widths, 2 different surface types, and three different angles.

Tunnel width (mm)

Surfaces	Incline	15	25	35	60	80
Rubber Wall + Sintra Floor	0					
	30					
	90					
Sintra Wall + Rubber Floor	0					
	30					
	90					

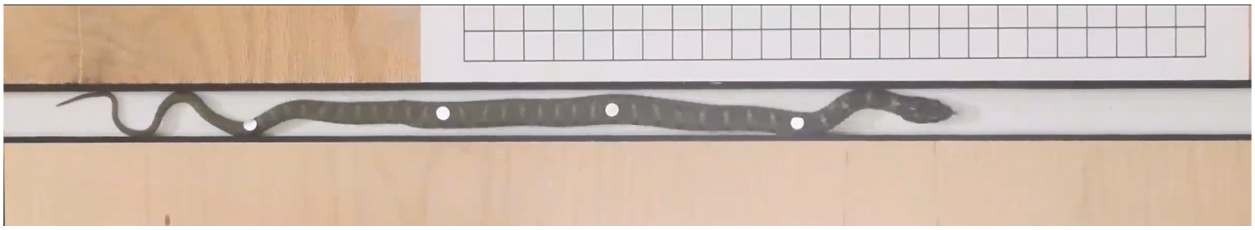
Open up one of the "combined data" spreadsheets and discuss with students the meaning of the variables in the spreadsheet.

Δx = forward movement per cycle
Cycle duration = 1 period
Average Vx per cycle = forward velocity per cycle (Δx/cycle duration)
*To calculate average speed for a specific treatment: average (p5:p8) on combined data spreadsheet

Notes:
1) If the snakes are on the Sintra floor without any walls, they can do nothing to prevent sliding downhill on the 30 deg inclines, whereas the friction of the rubber is sufficiently high so that the snake can remain stationary without doing anything.
2) Although the rubber floor is good for preventing sliding down the 30 deg incline, it also makes it more difficult for the snakes to slide forward on both the 0 and 30 deg surfaces.
3) Unlike the surfaces of the floor, at all inclines higher friction of the walls (rubber) theoretically could be advantageous as it facilitates "anchoring". However, if the snake slides along the wall while pressing against it the rubber walls will impede movement.
4) When the incline is 90, the friction of the floor surface is irrelevant unless the snake presses against the roof of the tunnel (and they did do this especially in the wide tunnels).

You may want to go over with students what a cycle is. A cycle is the time taken for a homologous event to repeat (e.g. the beginning of static contact of a point on the snake until the subsequent beginning of static contact as shown in graph 2 and the figures below. The screenshots below illustrate one cycle (0 incline, 15mm width, rubber wall). Note the first white dot on the snake below and how it is stationary beginning at image 1, and it becomes stationary again in image 7. By using this point, both the cycle duration (period) and the forward movement per cycle can be calculated. See also [motion analysis methods] for more detail.

1



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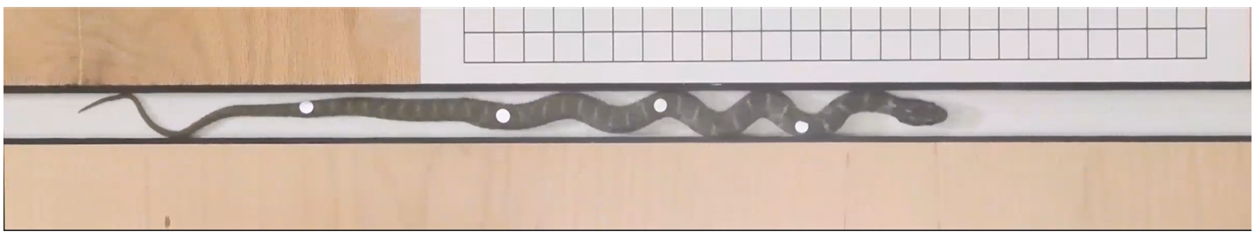

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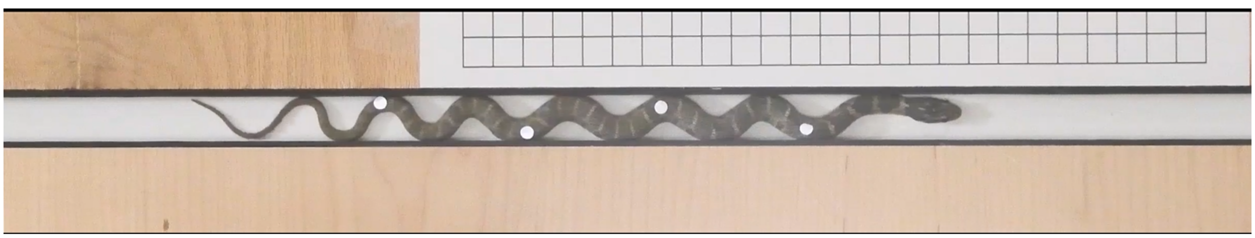

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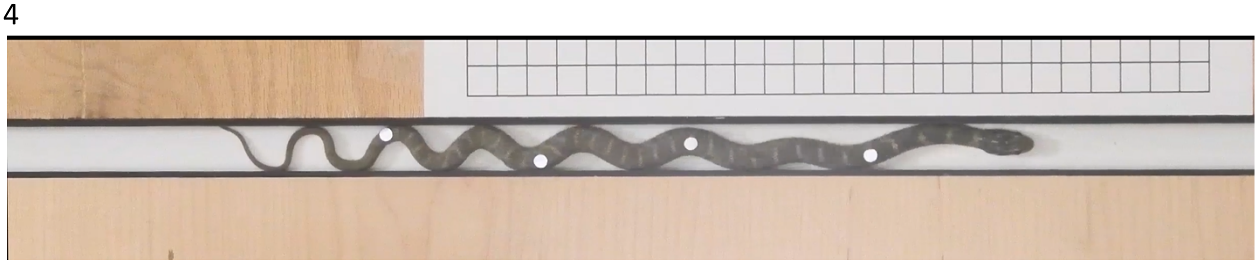

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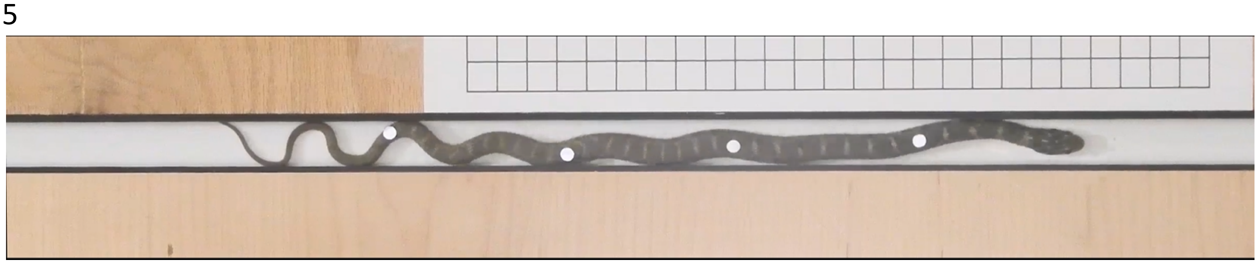

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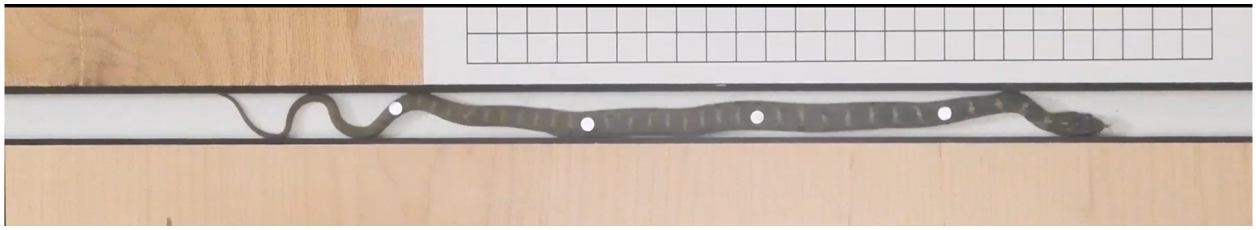

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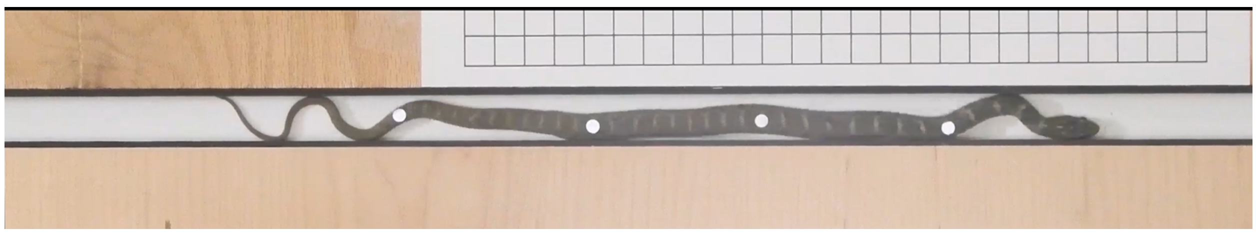

Tell students that you know from personal experience that you can run faster on a flat road than you can going uphill, so you are going to hypothesize that the snake speed decreases as incline increases. Have students look through the data to determine what should be used to prove / disprove this hypothesis.

Calculating the average forward velocity for each data set tells us that this hypothesis does not appear to be correct for all combinations of incline, tunnel width, and surface friction.

15 mm width, rubber wall, sintra floor
0 degree: 8 cm/s
30 degree: 4 cm/s
90 degree: 4.5 cm/s

15mm width, sintra wall, rubber floor
0 degree: 5.8 cm/s
30 degree: 5.8 cm/s
90 degree: 4.6 cm/s

Place students in groups of 2. They should now begin to generate their own hypotheses to be tested. The first hypothesis should be about the effect of one of the three environmental variables on the speed of the snake. Subsequent hypotheses could involve other environmental variables and speed, and/or other environmental variables and the amount of forward movement or duration per cycle. Out of the 30 video clips, students will select 6-10 videos and corresponding spreadsheets to test the hypotheses of interest. Students should be looking to determine answers to the questions below.

> What are the effects of environmental structures on speed?
> What are the effects of environmental structures on behavior?

Students should identify their first hypothesis and get teacher approval before beginning to test.

Examples:
Hypothesis 1: Forward speed increases with increased wall friction.
Data/Evidence: We used data from table rows/columns XXX….
Conclusion: XXXX

Hypothesis 2: Forward movement per cycle increases with increased tunnel width.
Data/Evidence: We used data from table rows/columns XXX….
Conclusion: XXXX

PART 2 Bio-Inspired Snake Robotics

2.1 Introduction and Motivation

Ask students to brainstorm why we might want a robot to move like a snake? List all possible answers on the board. Some possibilities might include using a snake robot to fix parts in a car that are hard to get to without taking it apart and sending snake robots into disaster areas to determine if people are alive under rubble.

Next, show them this video.

Lastly, have them read (or summarize) this article. Highlight the areas of biomimicry that Mercedez Benz did well but also what they overlooked when designing the new concept car.

2.2 Procedure

Have students watch the presentation by Dr. Henry C. Astley (University of Akron - Biomimicry Research & Innovation Center). Go over any questions students might have.

Students will be working in groups of 4. The snake robots have been pre-programmed such that students will place them in a series of 6 different positions, recording each one (like stop motion animation). The robot will then repeat the sequence continuously until it is reset. Students are challenged to mimic the live snake concertina motion from the videos (one full period) so that they can achieve the most forward motion per cycle. The robot will consistently repeat the motions at the same rate, so the speed cannot be altered, but the amount of movement during the cycle should be maximized.

Have students test out different tunnel widths and maximize the forward movement for each. Set up a contest for which group can make a snake robot move the most distance in 3 cycles of movement (note: speeds may differ depending on the version of the code used).

Extensions

The data from the snake locomotion trials can be further analyzed to predict speed by looking at cycle amplitude (forward progress), cycle period, tunnel body-crossings.

Assessments
Part 1 Snake Locomotion Exercise
Turn in a document you create that contains:

- Your hypotheses (4 of them), including any helpful tables, etc, that may make the hypotheses more clear.
- A table created in a spreadsheet that includes the data used to test the hypotheses, along with any necessary explanation.
- Conclusions for each hypothesis tested, may include graphs. Must be a compelling fact based argument.

Part 2 Snake Robot Questions

Student Exemplars
Part 1 Snake Locomotion Exercise - Student Exemplar
Part 2 Snake Robot Questions - Student Exemplar

Supporting Activity Information / Background

What Defines Different Modes of Snake Locomotion?

National Educational Standards

NGSS	**Disciplinary Core Ideas:** LS1.A: *Structure and Function* Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. **Crosscutting Concepts:** *Cause and Effect* Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. *Scale, Proportion, and Quantity* Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). *Systems and System Models* Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. **Science and Engineering Practices:** ● Asking Questions and Defining Problems ● Developing and Using Models ● Planning and Carrying out Investigations ● Analyzing and Interpreting Data ● Using Mathematics and Computational Thinking ● Constructing Explanations and Designing Solutions ● Engaging in Argument from Evidence ● Obtaining, Evaluating, and Communicating Information
ISTE Standards	1.1 Empowered Learner c. Students use technology to seek feedback that informs and improves their practice and to demonstrate their learning in a variety of ways. d. Students understand the fundamental concepts of technology operations, demonstrate the ability to choose, use and troubleshoot current technologies and are able to transfer their knowledge to explore emerging technologies. 1.3 Knowledge Constructor d. Students build knowledge by actively exploring real-world

	issues and problems, developing ideas and theories and pursuing answers and solutions. 1.4 Innovative Designer c. Students develop, test and refine prototypes as part of a cyclical design process. d. Students exhibit a tolerance for ambiguity, perseverance and the capacity to work with open-ended problems. 1.5 Computational Thinker a. Students formulate problem definitions suited for technology-assisted methods such as data analysis, abstract models and algorithmic thinking in exploring and finding solutions. b. Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem-solving and decision-making. c. Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem-solving. d. Students understand how automation works and use algorithmic thinking to develop a sequence of steps to create and test automated solutions. 1.7 Global Collaborator c. Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.

State Specific Educational Standards

Ohio Science Standards	**P.M.1 Motion Graphs** **P.M.2 Problem Solving** **Cognitive Demands for Science** ***Designing Technological/Engineering Solutions Using Science Concepts*** ● Requires students to solve science-based engineering or technological problems through application of scientific inquiry. Within given scientific constraints, propose or critique solutions, analyze and interpret technological and engineering problems, use science principles to anticipate effects of technological or engineering design, find solutions using science and engineering or technology, consider consequences and alternatives, and/or integrate and synthesize scientific information. ***Demonstrating Science Knowledge*** ● Requires student to use scientific practices and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather and organize data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. ***Interpreting and Communicating Science Concepts*** ● Requires students to use subject-specific conceptual knowledge to interpret and explain events, phenomena, concepts and experiences using grade-appropriate scientific terminology, technological knowledge and mathematical knowledge. Communicate with clarity, focus and organization using rich, investigative scenarios, real-world data and valid scientific information. ***Recalling Accurate Science*** ● Requires students to provide accurate statements about scientifically valid facts, concepts and relationships. Recall only requires students to provide a rote response, declarative knowledge or perform routine mathematical tasks. This cognitive demand refers to students' knowledge of science fact, information, concepts, tools, procedures (being able to describe how) and basic principles.

Indiana Science Standards	**11-12.LST.7.1:** Conduct short as well as more sustained research assignments and tasks to answer a question (including a self-generated question), test a hypothesis, or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. **PI.1.4** Describe the differences between the terms “distance,” “displacement,” “speed,” “velocity,” “average speed,” and “average velocity” and be able to calculate any of those values given an object moving at a single constant velocity or with different constant velocities over a given time interval. **Science and Engineering Process Standards (SEPS)** SEPS.1 Posing questions (for science) and defining problems (for engineering) SEPS.2 Developing and using models and tools SEPS.3 Constructing and performing investigations SEPS.4 Analyzing and interpreting data SEPS.5 Using mathematics and computational thinking SEPS.6 Constructing explanations (for science) and designing solutions (for engineering) SEPS.7 Engaging in argument from evidence SEPS.8 Obtaining, evaluating, and communicating information
West Virginia Science Standards	**S.11-12.L.16** Conduct short as well as more sustained research assignments and tasks to answer a question (including a self-generated question), test a hypothesis, or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

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