# TrEnCh-Ed Undergraduate Teacher Guide

## Introduction

This teacher guide will provide you with a better understanding as to how the tools of the [TrEnCh-Ed](https://trench-ed.github.io/#) program are organized and how they can be potentially used in your classroom. We describe how the tools are aligned with the AAAS Vision and Change report and BioCore Guide.

TrEnCh-Ed is the educational extension of the [TrEnCh Project](https://trenchproject.github.io/). This project, based in the [Buckley Lab](http://faculty.washington.edu/lbuckley/) at the University of Washington, Seattle, was designed to build computational and visualization tools to **Tr**anslate **En**vironmental **Ch**ange into organismal responses. The project was funded by a National Science Foundation Division of Biological Infrastructure grant (DBI#1349865). The hope is that educators use these tools to educate their students about how living things on our planet are impacted by the current global scale climate change.

Each module consists of a visualization including introductory material and an accompanying worksheet. TrEnCh-Ed consists of the following visualizations:

* **Metabolic Impacts of Climate Change**: Use historic climate data and the temperature dependence of metabolism to compare climate impacts between temperate and tropical regions.
* **Energy Budgets**: Use weather and terrain data to explore how an energy budget is constructed and use it to estimate an organism’s body temperature.
* **Robomussels**: Use data from biomimetic temperature sensors to explore how organisms experience climate.
* **Butterfly Museum Specimens**: Use data from museum specimens to explore how temperature influences morphology and phenology.
* **Wildflower Phenology**: Use historical and resurvey data to explore how temperature influences phenology.
* **RMBL Phenology**: Use climate and phenological data from Rock Mountain Biological Laboratory to explore migration and overwintering species in a high-elevation ecosystem.
* **Grasshopper Resurvey**: Use historical and resurvey data to explore how temperature influences developmental rates and phenology.
* **Marine Range Shifts**: Use survey data to explore the range shifting of marine populations in response to climate change.

The modules above are arranged “from small to large” in that the first visualizations work at the level of single organisms, followed by those addressing population responses to climate change. The visualizations vary in complexity with the first two being the most accessible. The visualizations can be adapted for a range of pedagogies, but most worksheets incorporate inquiry-based learning.

## Core concepts and competencies

### We have designed our TrEnCh-Ed resources to align with the following biology education guidance documents:

* AAAS. 2011. [Vision and change in undergraduate biology education](https://visionandchange.org/): a call to action.
* Brownell, S.E., Freeman, S., Wenderoth, M.P. and Crowe, A.J., 2014. [BioCore Guide](https://sites.google.com/site/uwbioedresgroup/biocore-guide): a tool for interpreting the core concepts of Vision and Change for biology majors. *CBE—Life Sciences Education*, *13*(2), pp.200-211.
* Clemmons, A.W., Timbrook, J., Herron, J.C., and Crowe, A.J. [BioSkills Guide](https://qubeshub.org/publications/1305/5): Development and national validation of a tool for interpreting the Vision and Change Core Competencies. Forthcoming in *CBE-Life Sciences Education*. (https://www.biorxiv.org/content/10.1101/2020.01.11.902882v2)

### The AAAS Vision and change report outlines core concepts and competencies for an undergraduate education in Biology. The BioCore Guide provides a guide to interpreting the core concepts of Vision and Change. The BioSkills Guide provides a guide to interpreting the core competencies of Vision and Change.

### Core concepts

We list the principles and statements of the BioCore Guide that are well aligned with TrEnCh-Ed. The materials are well suited to teach principles in Physiology and Ecology/Evolutionary Biology. We omit principles from the Molecular / Cellular / Developmental Biology subdiscipline. However, mechanistic research examining the organismal responses to climate change explored by TrEnCh-Ed addresses many of the principles.

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| EVOLUTION  Overarching Principles:  All living organisms share a common ancestor.  Species evolve over time, and new species can arise, when allele frequencies change due to mutation, natural selection, gene flow, and genetic drift. | |
| Most organisms have anatomical and  physiological traits that tend to increase  their fitness for a particular environment. | The characteristics of populations  change over time due to changes in  allele frequencies. Changes in allele  frequencies are caused by random  and nonrandom processes--  specifically mutation, natural  selection, gene flow, and genetic  drift. Not all of these changes are  adaptive. |
| Physiological systems are constrained by  ancestral structures, physical limits, and  the requirements of other physiological  systems, leading to trade-offs that affect fitness. | Fitness is an individual's ability to  survive and reproduce. It is  environment-specific and depends  on both abiotic and biotic factors.  Evolution of optimal fitness is  constrained by existing variation,  trade-offs and other factors. |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| INFORMATION FLOW  Overarching Principles:  Organisms inherit genetic and epigenetic information that influences the location, timing, and intensity of gene expression.  Cells/organs/organisms have multiple mechanisms to perceive and respond to changing environmental conditions. | |
| Organisms have sophisticated mechanisms for sensing changes in the internal or external environment. They use chemical, electrical, or other forms of signaling to coordinate responses at the cellular, tissue, organ, and/or system level. | Individuals transmit genetic  information to their offspring; some  alleles confer higher fitness than  others in a particular environment. |
|  | A genotype influences the range of  possible phenotypes in an  individual; the actual phenotype  results from interactions between  alleles and the environment. |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| STRUCTURE FUNCTION  Overarching Principles:  Biological structures exist at all levels of organization, from molecules to ecosystems. A structure's physical and chemical characteristics influence its interactions with other structures, and therefore its function.  Natural selection leads to the evolution of structures that tend to increase fitness  within the context of evolutionary, developmental, and environmental constraints. | |
| The size, shape, and physical properties of organs and organisms all affect function. The ratio of surface area to volume is particularly critical for structures that function in transport or exchange of materials and heat. | Natural selection has favored  structures whose shape and  composition contribute to their  ecological function. |
| Structure constrains function in  physiology; specialization for one function  may limit a structure's ability to perform  another function. | Competition, mutualism, and other  interactions are mediated by each  species' morphological,  physiological, and behavioral traits. |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| TRANSFORMATIONS OF ENERGY AND MATTER  Overarching Principles:  Energy and matter cannot be created or destroyed, but can be changed from one form to another.  Energy captured by primary producers is necessary to support the maintenance, growth and reproduction of all organisms.  Natural selection leads to the evolution of efficient use of resources within constraints. | |
| Organisms have limited energetic and  material resources which must be  distributed across competing functional  demands. These include movement of  material across gradients, growth,  maintenance, and reproduction, inevitably  leading to trade-offs. | Energy captured by primary  producers is stored as chemical  energy. At each trophic level, most  of this energy is used for  maintenance, with a relatively small  fraction available for growth and  reproduction. As a consequence,  each trophic level in an ecosystem  has less energy available than the  preceding level. |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| SYSTEMS  Overarching Principles:  Biological molecules, genes, cells, tissues, organs, individuals, and ecosystems interact to form complex networks. A change in one component of the network can affect many other components.  Organisms have complex systems that integrate internal and external information, incorporate feedback control, and allow them to respond to changes in the environment. | |
| An individual's physiological traits affect its interactions with other organisms and with its physical environment. | The size and structure of  populations are dynamic. A species'  abundance and distribution is  limited by available resources and  by interactions between biotic and  abiotic factors. |
| In the face of environmental changes,  organisms may maintain homeostasis  through control mechanisms that often use negative feedback; others have  adaptations that allow them to acclimate  to environmental variation. | Ecosystems are not isolated and  static--they respond to change,  both as a result of intrinsic changes  to networks of species and as a  result of extrinsic environmental  drivers. Within an ecosystem,  interactions among individuals form  networks; changes in one node of a  network can cause changes in other  nodes--directly or indirectly. |

Below, we repeat the above tables to indicate how the TrEnCh-Ed materials address the statements. We also list the modules most closely related to each statement.

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| EVOLUTION | |
| Several modules examine how anatomical and physiological traits mediate organismal responses to environmental conditions. In turn, the traits determine fitness in response to environmental variability and change.    **Modules**: Energy Budgets, Butterfly Museum Specimens, Wildflower Phenology | Central to several modules is how the interaction of traits with environmental conditions determines selection gradients. How processes change allele frequencies--  specifically mutation, natural  selection, gene flow, and genetic  drift-- is central to evolution is response to climate change. The topic is not addressed in the modules, but is a ready area for extending the materials. The potential for mal-adaptation in response to climate change is an active research topic.  **Modules**: Energy Budgets, Butterfly Museum Specimens |
| The modules link physiological limits on performance and heat and energy balances to fitness. Trade-offs such as specialist and generalist thermal tolerances are apparent.  **Modules**: Energy Budgets, Butterfly Museum Specimens, Marine Range Shifts | Underlying most modules is how interactions between organisms and their environment and their energetic implications shape reproduction, survival, and ultimately fitness  **Modules**: Temperature Metabolism, Butterfly Museum Specimens, Grasshopper Resurvey, Marine Range Shifts |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| INFORMATION FLOW | |
| The modules extensively address heat and energy balances. Although the modules do not address sensing mechanisms and cellular, tissue, organ, or system level responses to changes in the internal and external environment, the activities can be extended to address these underlying processes.  **Modules**: Temperature Metabolism, Energy Budgets | Although the modules focus on traits that confer higher fitness than others in particular environments, the link to alleles can be established.  **Modules**: Butterfly Museum Specimens |
|  | Phenotypic plasticity in response to environmental conditions is central to climate change biology. Additionally, phenology is often considered a plastic phenotype.  **Modules**: Butterfly Museum Specimens, Grasshopper Resurvey |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| STRUCTURE FUNCTION | |
| How the size, shape, and physical properties of organisms influence their response to their environment is central to the modules. The ratio of surface area to volume is central to rates of metabolism and heat exchange.  **Modules**: Temperature Metabolism, Energy Budgets, Robomussels, Butterfly Museum Specimens | How natural selection favors structures that promote function in particular environments is explored through several modules.  **Modules**: Energy Budgets, Butterfly Museum Specimens |
| The introductory materials address specialist-generalist physiological trade-offs. | Although the modules are largely focused at the population level, several address implications for interactions within communities.  **Modules**: Robomussels, RMBL Phenology |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| TRANSFORMATIONS OF ENERGY AND MATTER | |
| Several modules explore energy balances and can be readily extended to address energy allocation.  **Modules**: Temperature Metabolism, Energy Budgets | The module investigating the temperature dependence of metabolism provides a solid foundation for addressing energy needs. Modules investigating energy balances and thermal limits on activity can be extended to address energetic costs and the flow of energy across trophic levels.  **Modules**: Temperature Metabolism, Butterfly Museum Specimens, Marine Range Shifts |

|  |  |
| --- | --- |
| Physiology | Ecology/Evolutionary Biology |
| SYSTEMS | |
| Several modules examine how physiological traits affect interactions with the physical environment.    **Modules**: Energy Budgets, Butterfly Museum Specimens, Wildflower Phenology | The phenology modules address how the environment shapes distribution through time.  **Modules**: Wildflower Phenology, RMBL Phenology, Grasshopper Resurvey, Marine Range Shifts |
| The modules use energy budgets to explore the maintenance of homeostasis and acclimation to environmental variation.  **Modules**: Energy Budgets, Butterfly Museum Specimens, Marine Range Shifts | The modules provide a strong basis for examining shifts in species interactions and ecosystems in response to environmental change.  **Modules**: Wildflower Phenology, RMBL Phenology, Grasshopper Resurvey, Marine Range Shifts |

### Core competencies

The [Vision and Change report](https://visionandchange.org/) identifies the core competencies listed below to be achieved through an undergraduate biology education. Using the [BioSkills Guide](https://qubeshub.org/publications/1305/5), we list the Competencies and the best aligned Program-Level learning outcomes and describe the details of their alignment with TrEnCh-Ed. The TrEnCh-Ed materials are well suited to teach all of the Vision and Change Competencies and the worksheets and implementation of the modules in your class can be edited and modified to align with nearly any of the Program-Level or Course-Level Learning Outcomes listed in the BioSkills Guide. The mechanistic research examining the organismal responses to climate change explored by TrEnCh-Ed embodies many of the competencies so these modules are a natural choice for teaching these competencies.

## 

|  |  |
| --- | --- |
| **PROCESS OF SCIENCE** | |
| **Program-Level Learning Outcome** | **Alignment with TrEnCh-Ed** |
| **QUESTION FORMULATION**Pose testable questions and hypotheses to address gaps in knowledge**DATA INTERPRETATION & EVALUATION**Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world. | The TrEnCh-Ed visualizations are designed to guide students through asking questions and then refining the questions in response to data on climate change responses. Most of the interactive visualizations allow the user to select what to plot on axes to enable posing and investigating questions.TrEnCh-Ed includes the stories of the scientists and the research behind the data to facilitate students understanding the process of science. We also include interviews with the scientists that aim to highlight the diverse backgrounds of scientists and the variety of paths they follow into science. We hope that they will expand the number of students who recognize aspects of themselves in scientists. |

|  |  |
| --- | --- |
| **QUANTITATIVE REASONING** | |
| **Program-Level Learning Outcome** | **Alignment with TrEnCh-Ed** |
| **NUMERACY**Use basic mathematics (e.g., algebra, probability, unit conversation) in biological contexts.**QUANTITATIVE & COMPUTATIONAL DATA ANALYSIS**Apply the tools of graphing, statistics, and data science to analyze biological data. | The TrEnCh-Ed visualizations are designed for students to participate in analyzing and interpreting data. Students choose what to graph based on hypotheses they develop. The visualizations span a variety of data types from the temperatures of intertidal mussels to the traits of museum specimens to the field surveys of grasshoppers. We also introduce statistical regression analysis to detect trends in the data. |

## 

|  |  |
| --- | --- |
| **MODELING** | |
| **Program-Level Learning Outcome** | **Alignment with TrEnCh-Ed** |
| **MODEL APPLICATION**Make inferences and solve problems using models and simulations. | TrEnCh-ed focuses on using models to understand how organisms experience their environment. Translating environmental conditions into how organisms experience their environment is central to understanding biological responses to climate change. The activities guide students through engaging with a variety of models ranging from energy budgets to understand heat flow between organisms and their environment to physical replicas of intertidal mussels to investigate patterns of thermal stress. We highlight the role of mathematics and computation in understanding how organisms interact with their environments. |

|  |  |
| --- | --- |
| **INTERDISCIPLINARY NATURE OF SCIENCE** | |
| **Program-Level Learning Outcome** | **Alignment with TrEnCh-Ed** |
| **CONNECTING SCIENTIFIC KNOWLEDGE**  Integrate concepts across other STEM disciplines (e.g., chemistry, physics) and multiple fields of biology (e.g., cell biology, ecology). | Climate change biology is inherently interdisciplinary. It highlights the importance of linking physical and biological sciences to understand responses to climate change. Climate change biology also integrates biological subdisciplines including physiology, behavior, ecology, and evolution. |

|  |  |
| --- | --- |
| **COMMUNICATION & COLLABORATION** | |
| **Program-Level Learning Outcome** | **Alignment with TrEnCh-Ed** |
| **COMMUNICATION**  Share ideas, data, and findings with others clearly and accurately.    **COLLABORATION**  Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives | The interactive components of the visualization allow students to form their own hypotheses and test the hypotheses with data. How instructors ask students to report their findings can take many forms and can provide students opportunities for Communication, Collaboration, Collegial Review, or Metacognition. For example, the modules are well suited for students to work in small groups and to hone their science communication skills through oral or visual presentations. Furthermore, additional procedural steps such as collegial review or additional questions could be added to probe metacognition. |

|  |  |
| --- | --- |
| **SCIENCE & SOCIETY** | |
| **Program-Level Learning Outcome** | **Alignment with TrEnCh-Ed** |
| **SOCIETAL INFLUENCES**  Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.    **SCIENCE’S IMPACT ON SOCIETY**  Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale. | Society is both driving climate and other environmental changes and influenced by climate change biology, making the field an ideal venue for exploring the relationship between science and society. Biological responses to climate change impact biodiversity and the functioning of ecosystems, both of which have substantially societal implications. |

## Materials and resources

Materials can be found at <https://trench-ed.github.io/#resources>.

**Resources for introducing approaches**

While the activities are designed to guide students through the data collection, analysis, and interpretation, additional background knowledge in presenting and analyzing data may facilitate this process. We highlight some of the resources available online below.

Presenting biological data: <https://openoregon.pressbooks.pub/mhccmajorsbio/chapter/presenting-data/>

<https://www.biologyforlife.com/graphing.html>

Regressions:

<http://www.colby.edu/bio/statistics-and-scientific-writing/regression-analysis/>