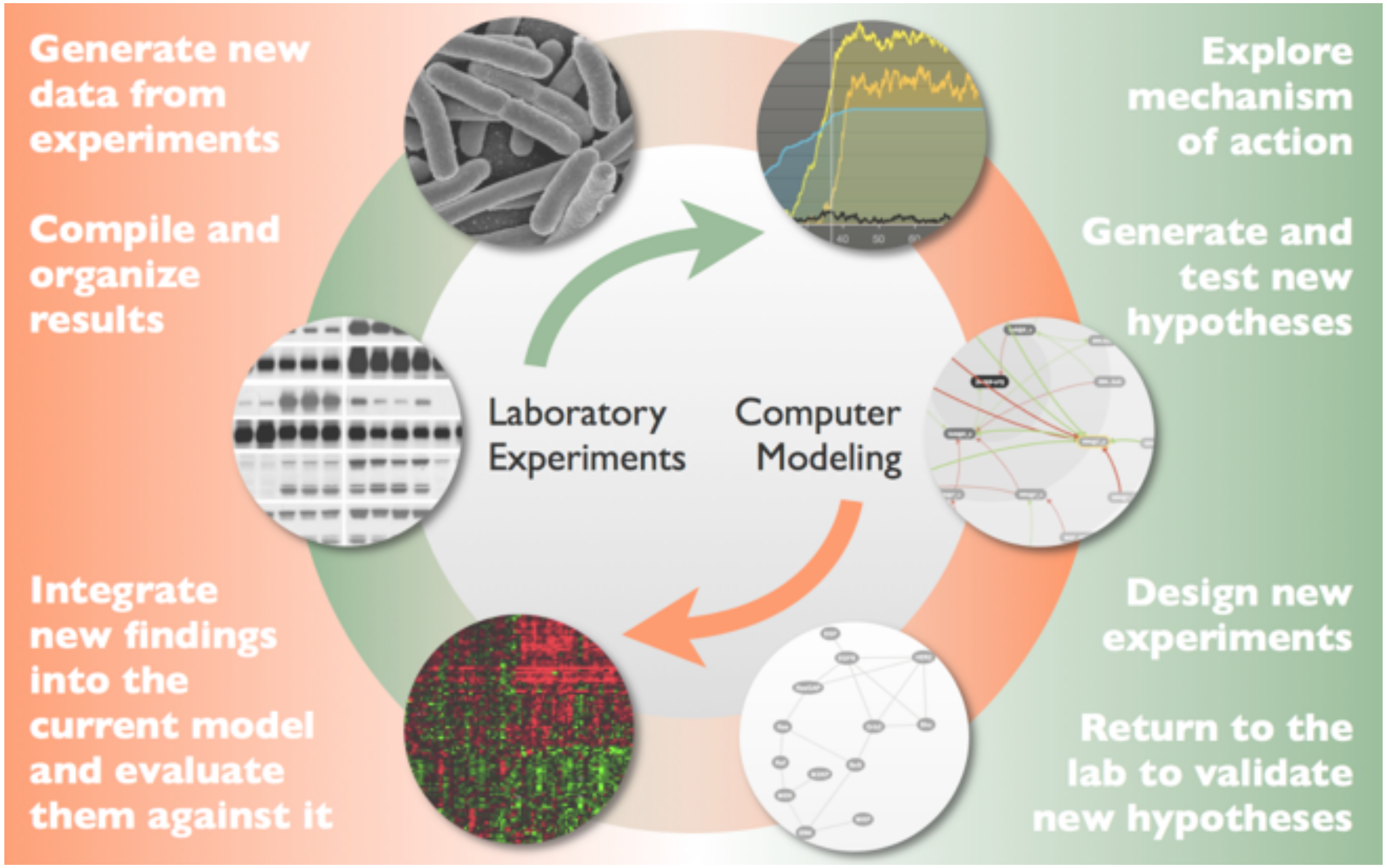


Generate new data from experiments

Compile and organize results

Integrate new findings into the current model and evaluate them against it

Laboratory Experiments

Computer Modeling

Explore mechanism of action

Generate and test new hypotheses

Design new experiments

Return to the lab to validate new hypotheses

---

# A FRAMEWORK FOR TEACHING MODELING TO BIOLOGISTS

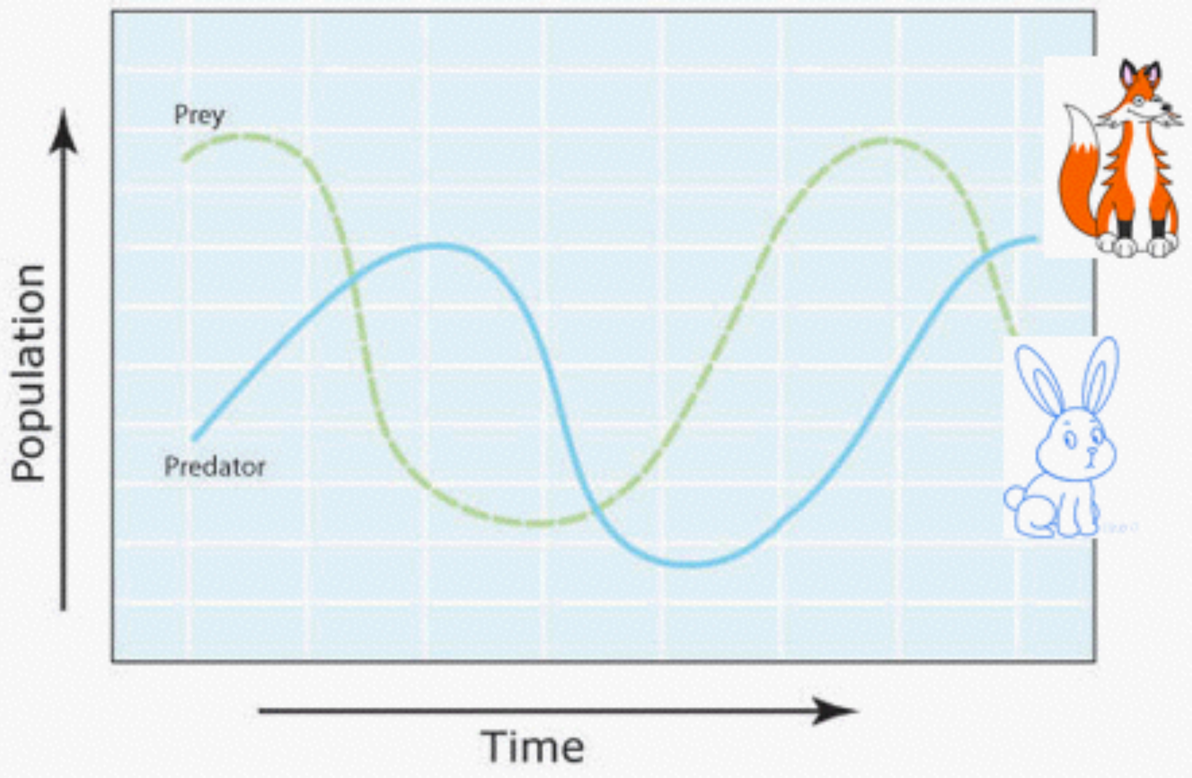
NIMBioS
National Institute for Mathematical
and Biological Synthesis

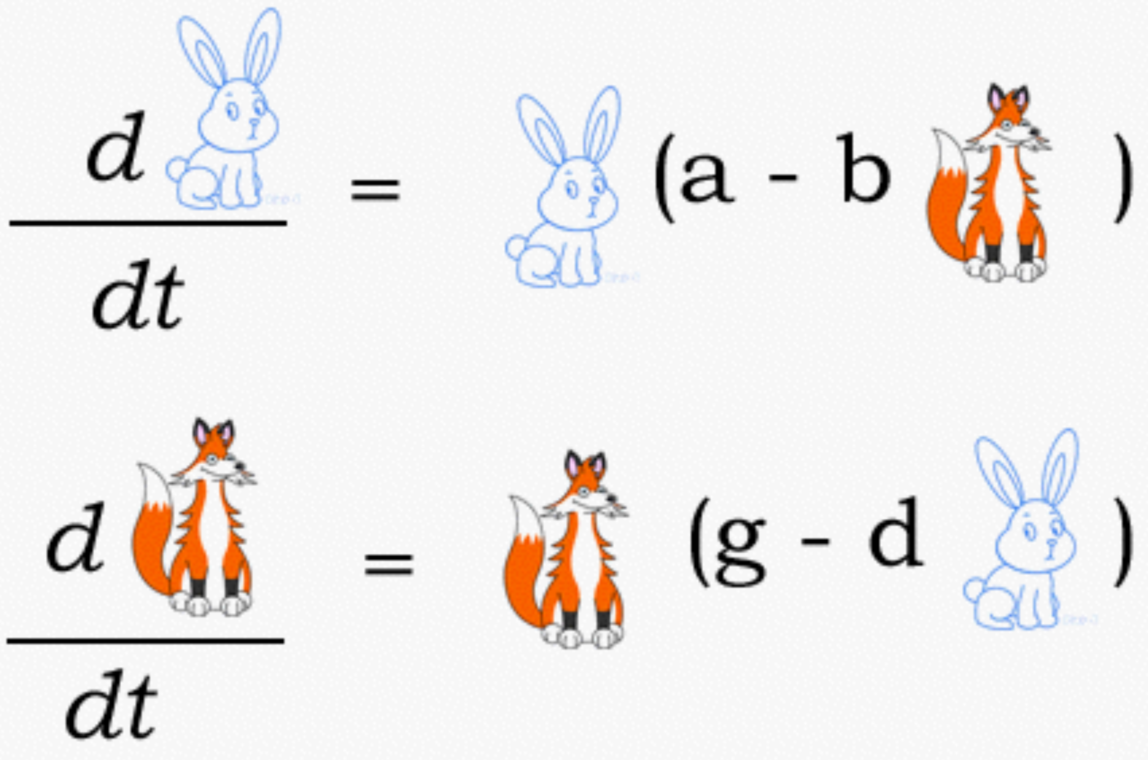
# WHAT IS MODELING IN BIOLOGY?

# WHAT IS MODELING IN BIOLOGY?

A *model* is a simplified, abstract/concrete representation of objects and their processes or relationships in the real world.

# Theoretical Ecology





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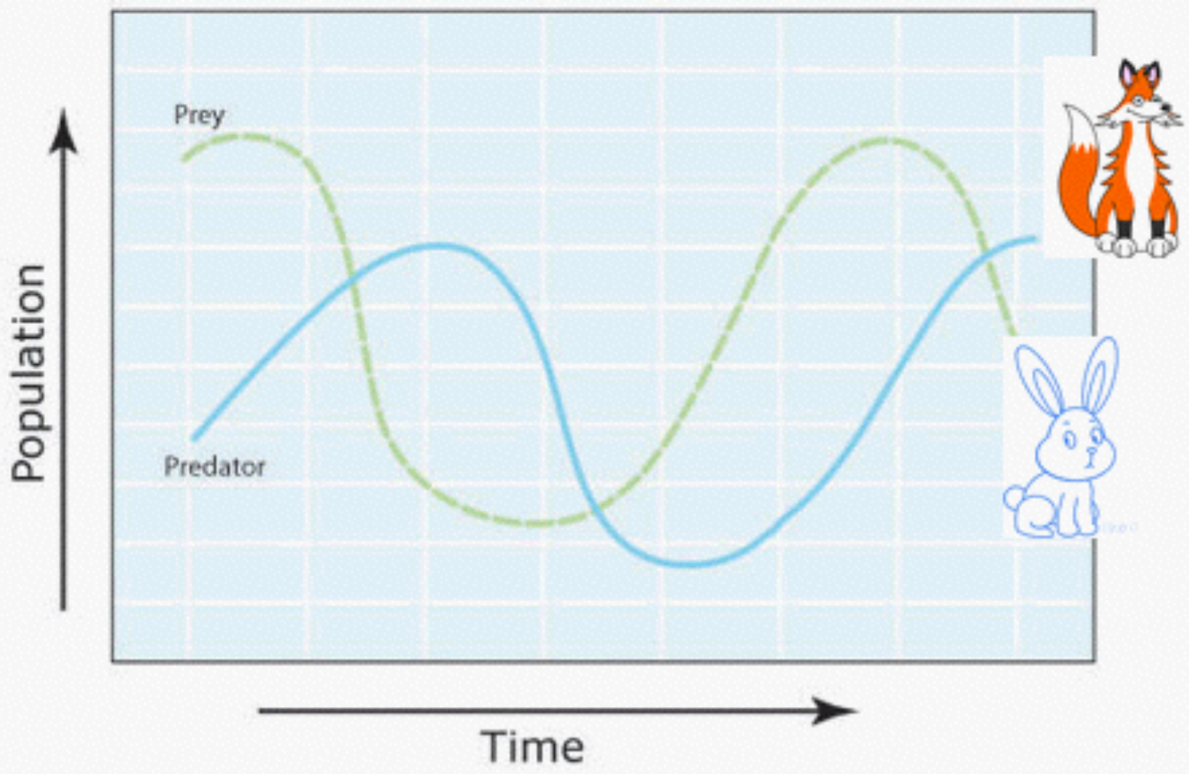
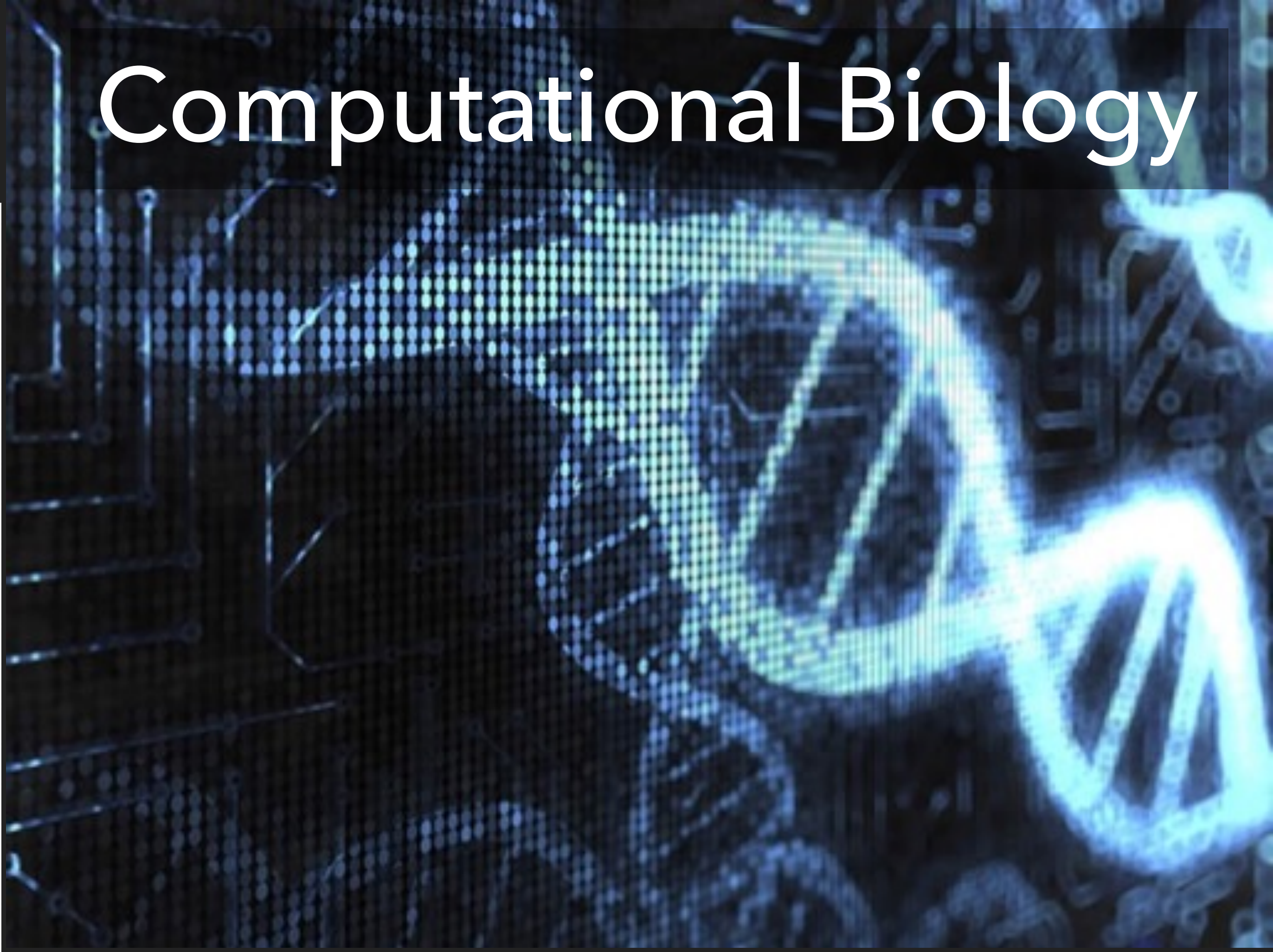


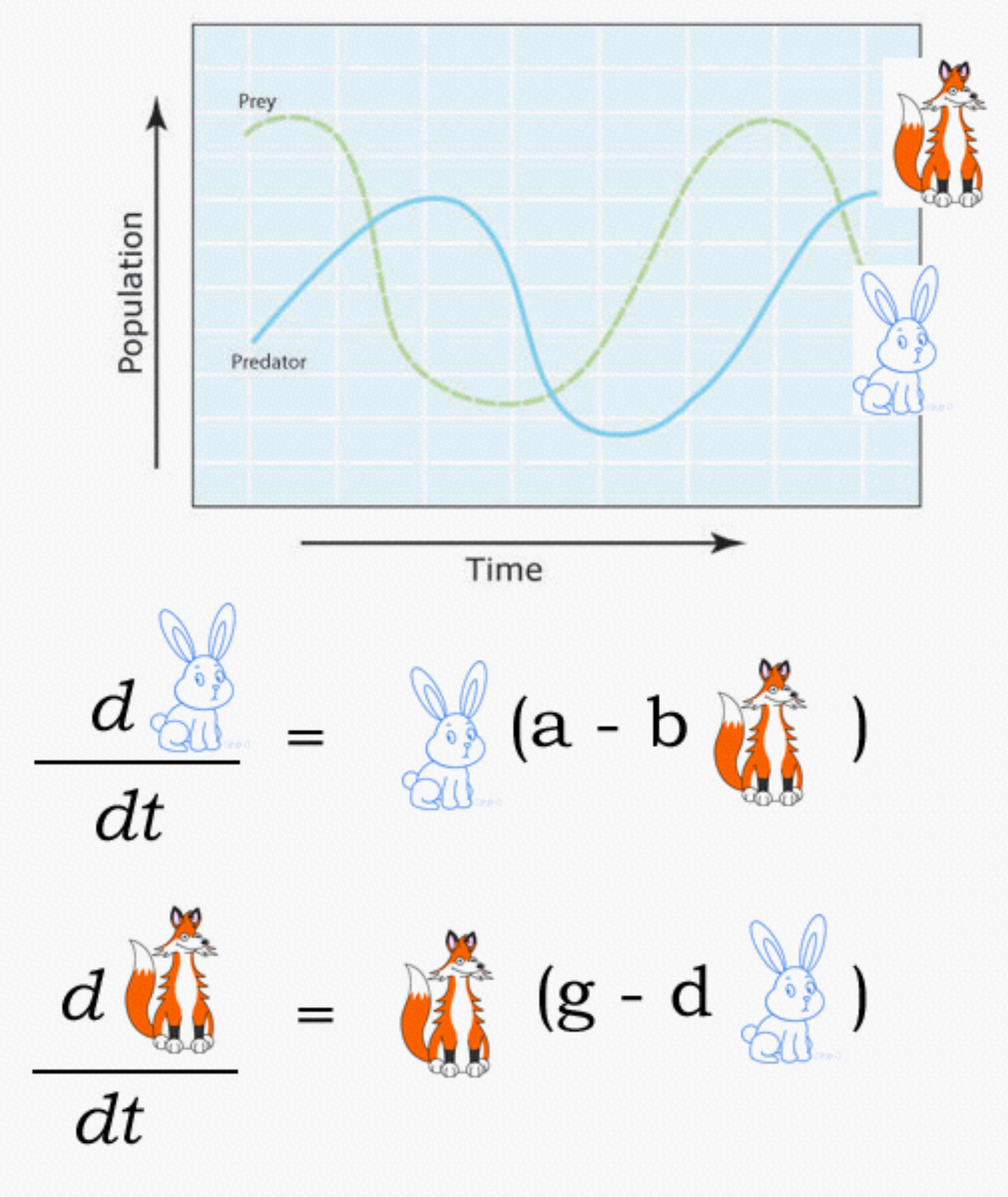
$$\frac{d\,🐇}{dt} = 🐇\,(a - b\,🦊)$$

$$\frac{d\,🦊}{dt} = 🦊\,(g - d\,🐇)$$

# Computational Biology



# Theoretical Ecology



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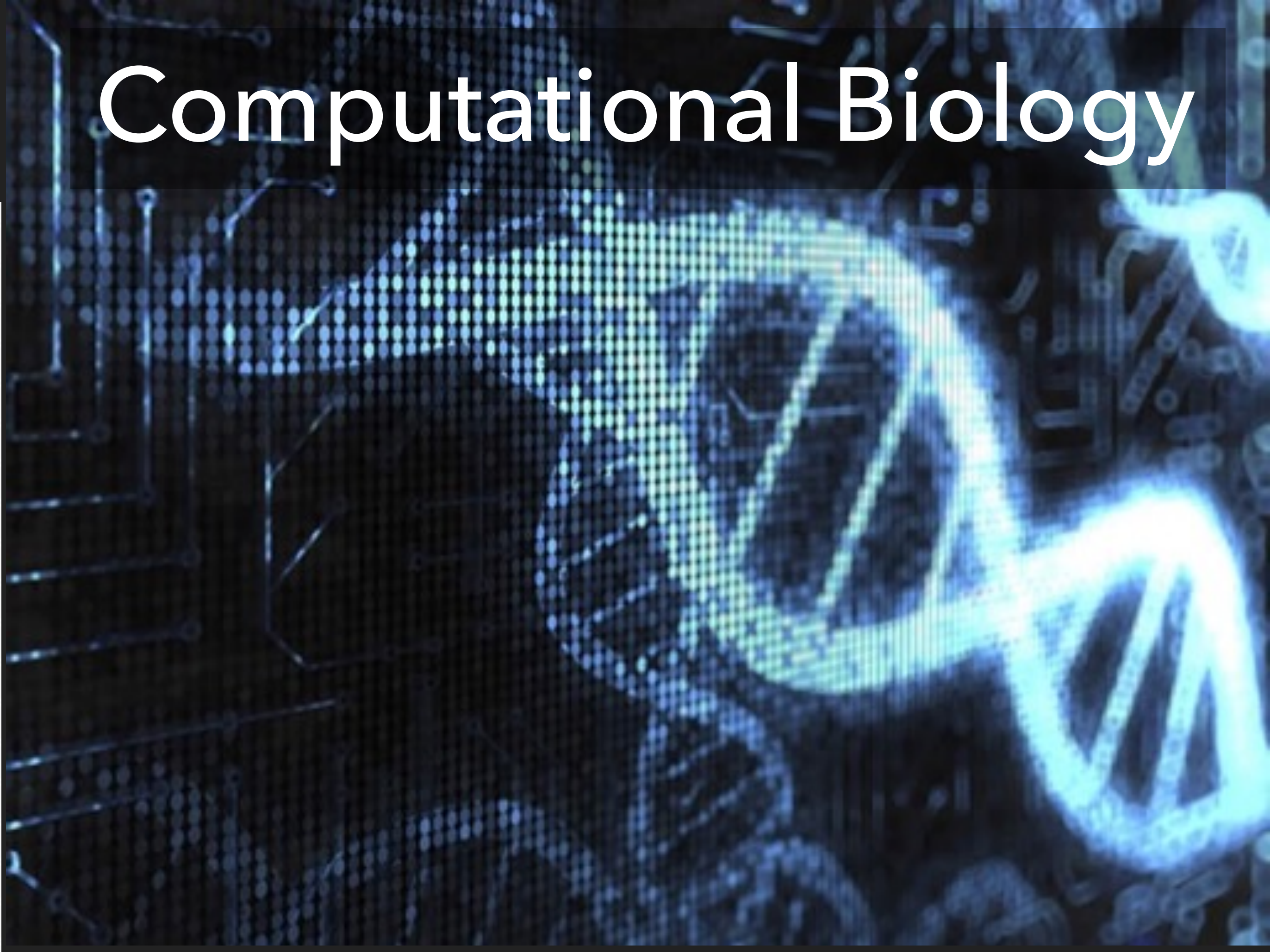
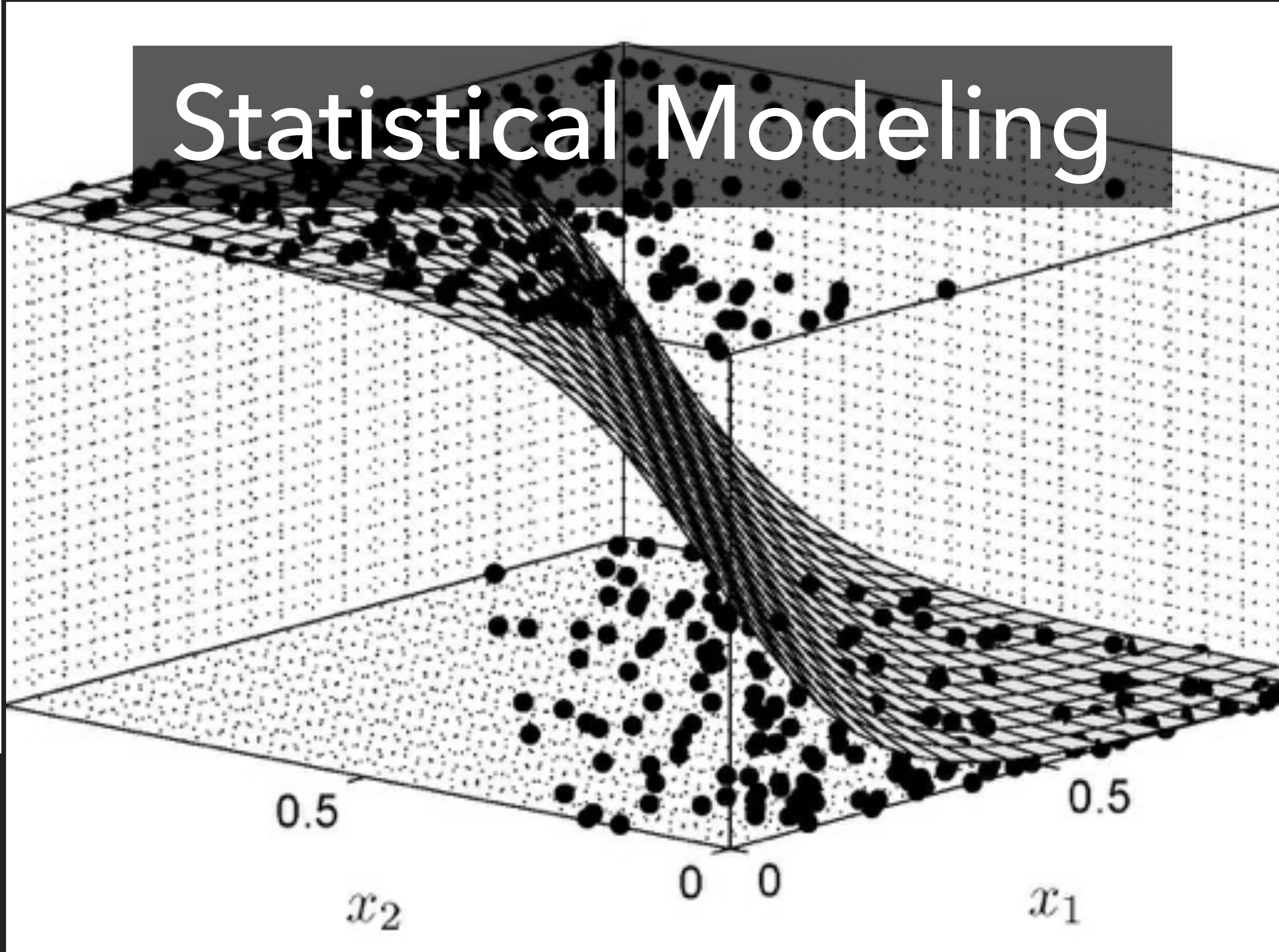
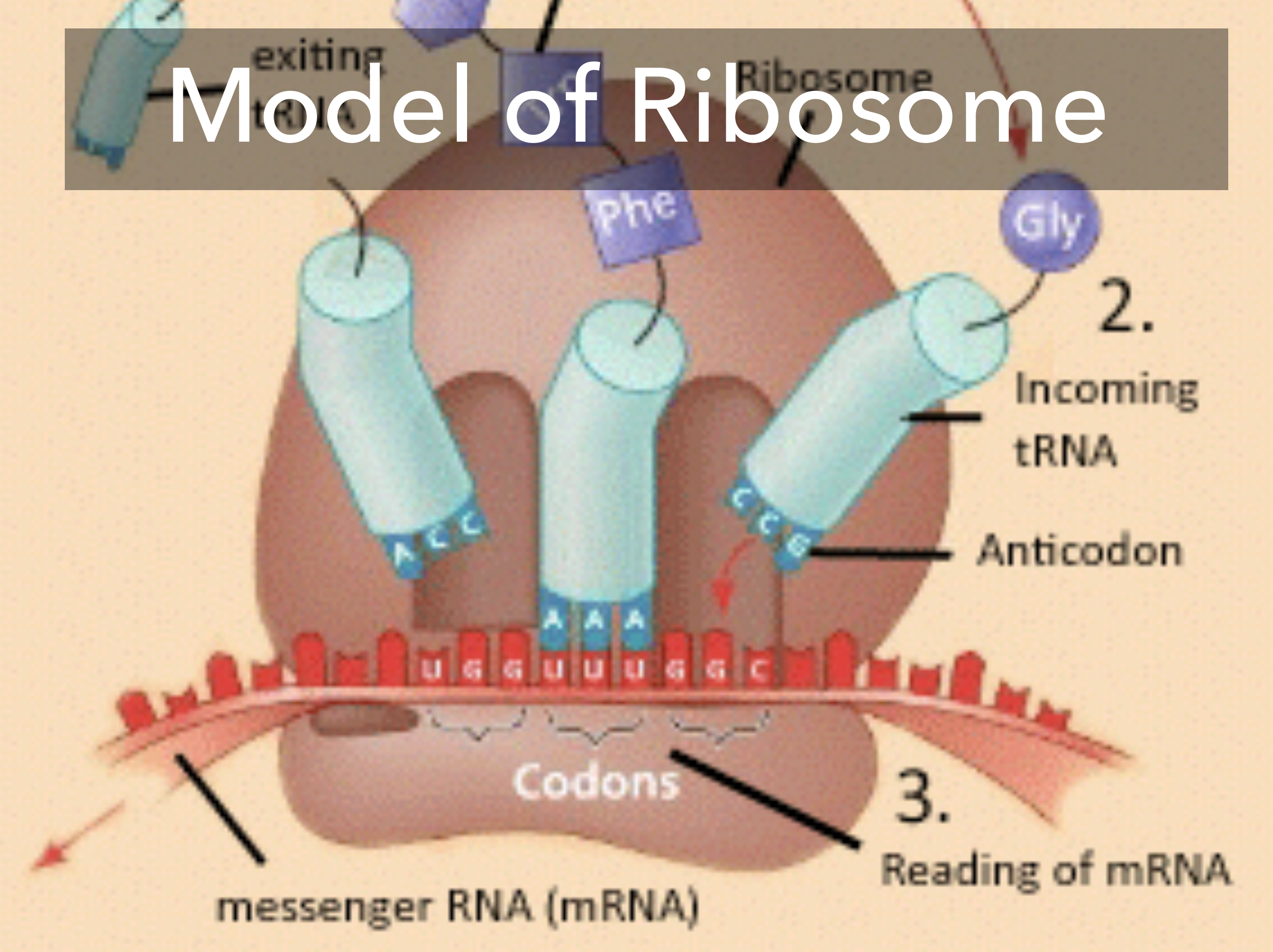


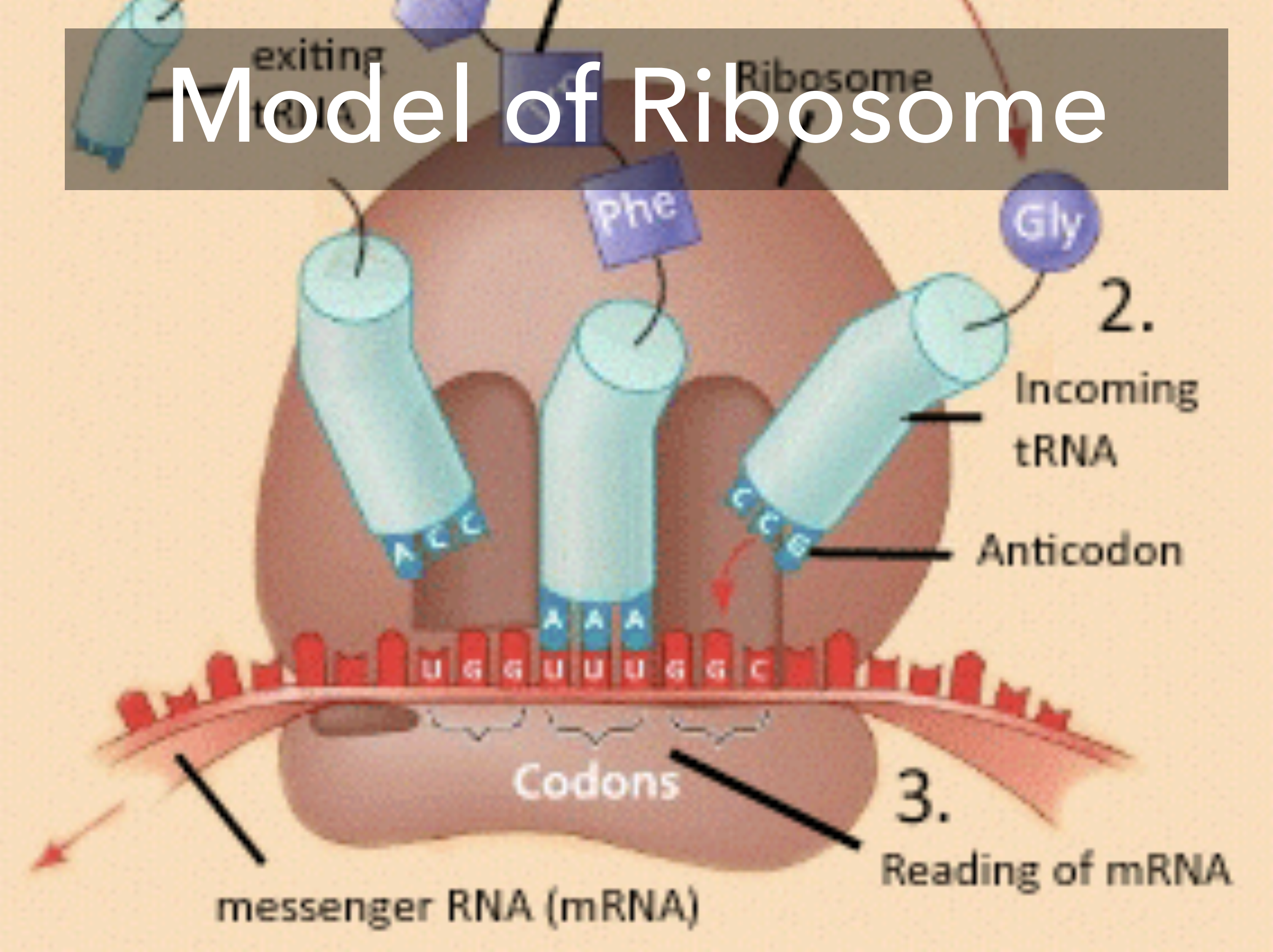
# Statistical Modeling



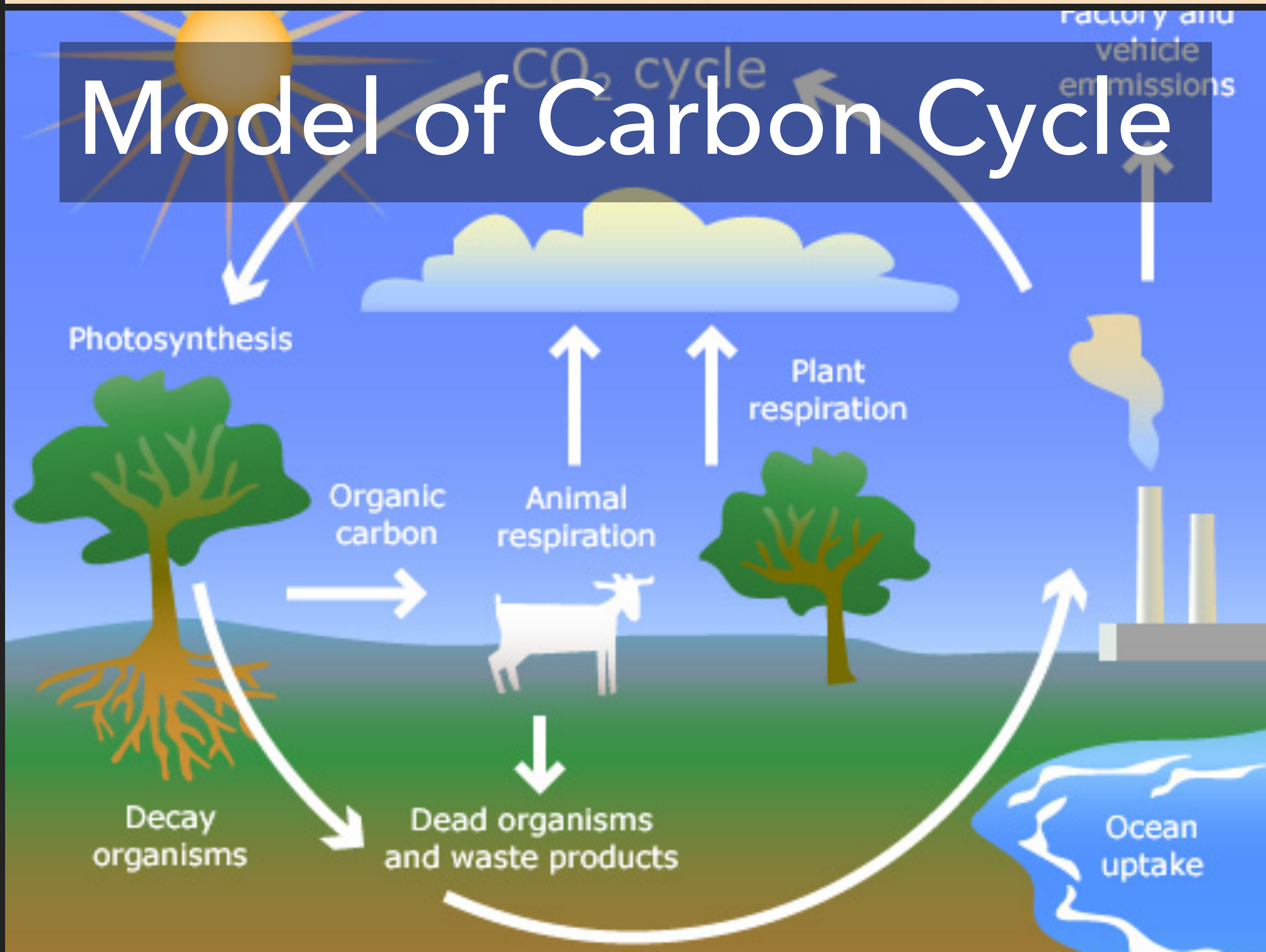
# Model of Ribosome



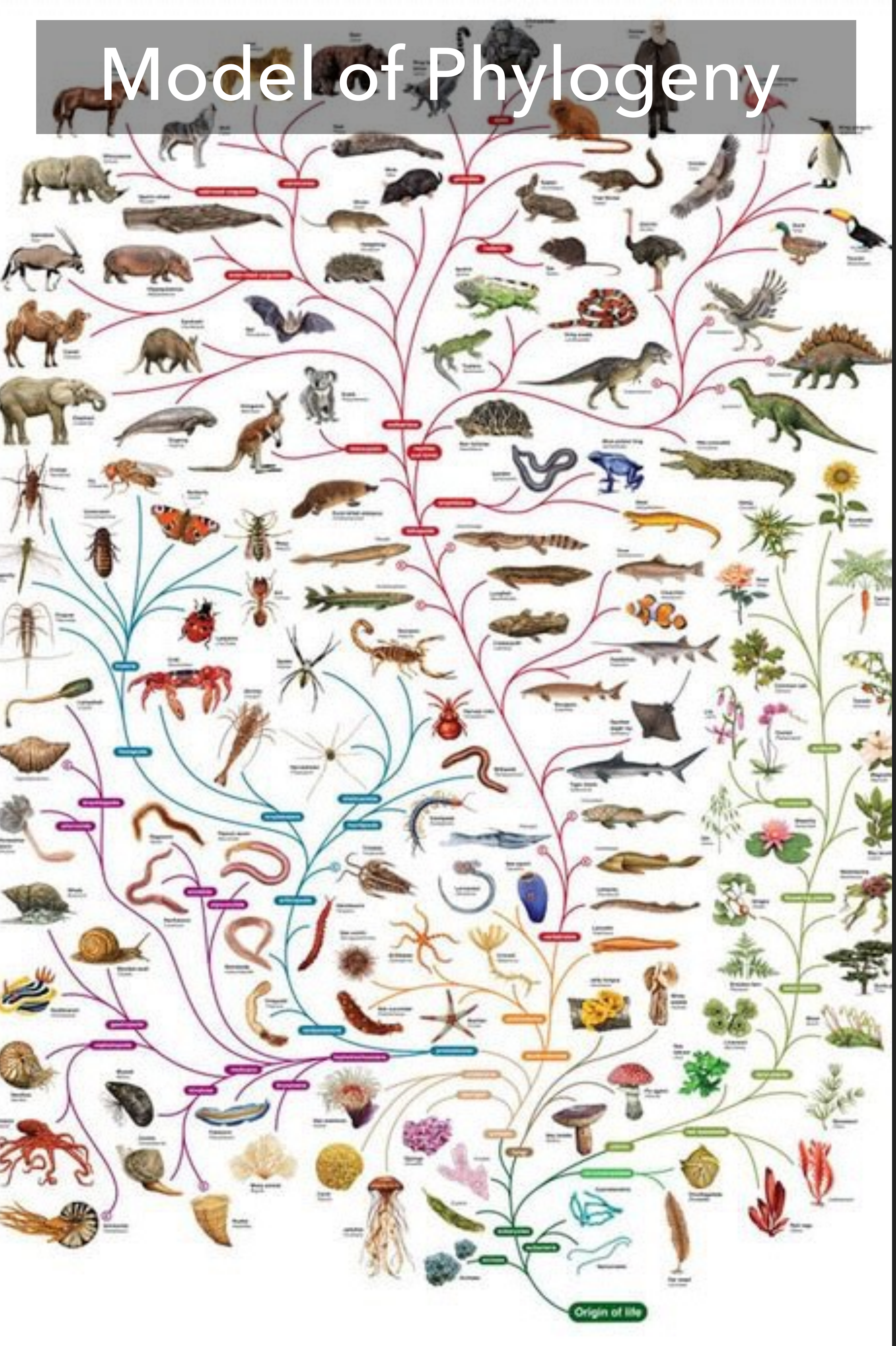
## Model of Ribosome



## Model of Carbon Cycle



## Model of Phylogeny



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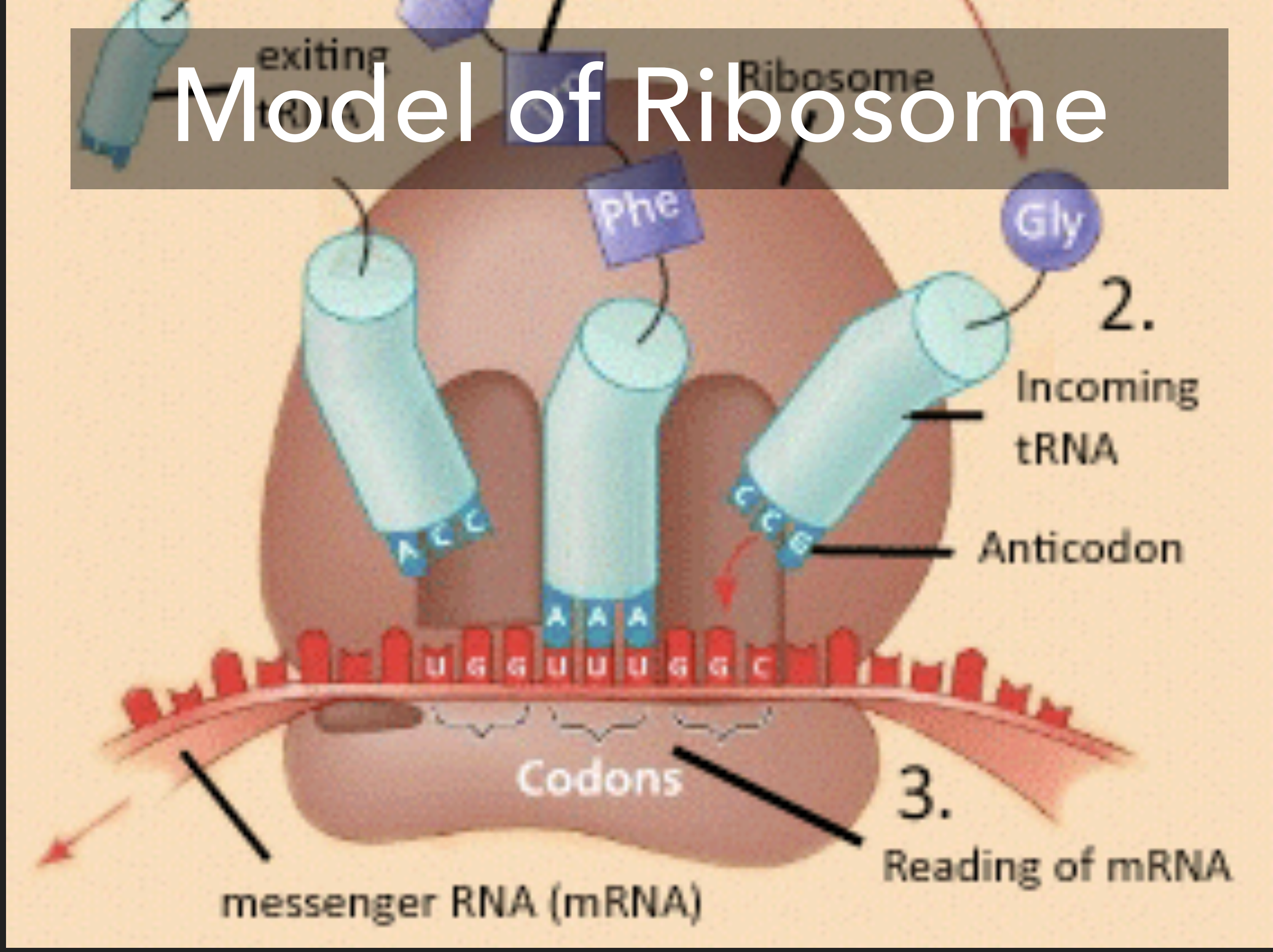
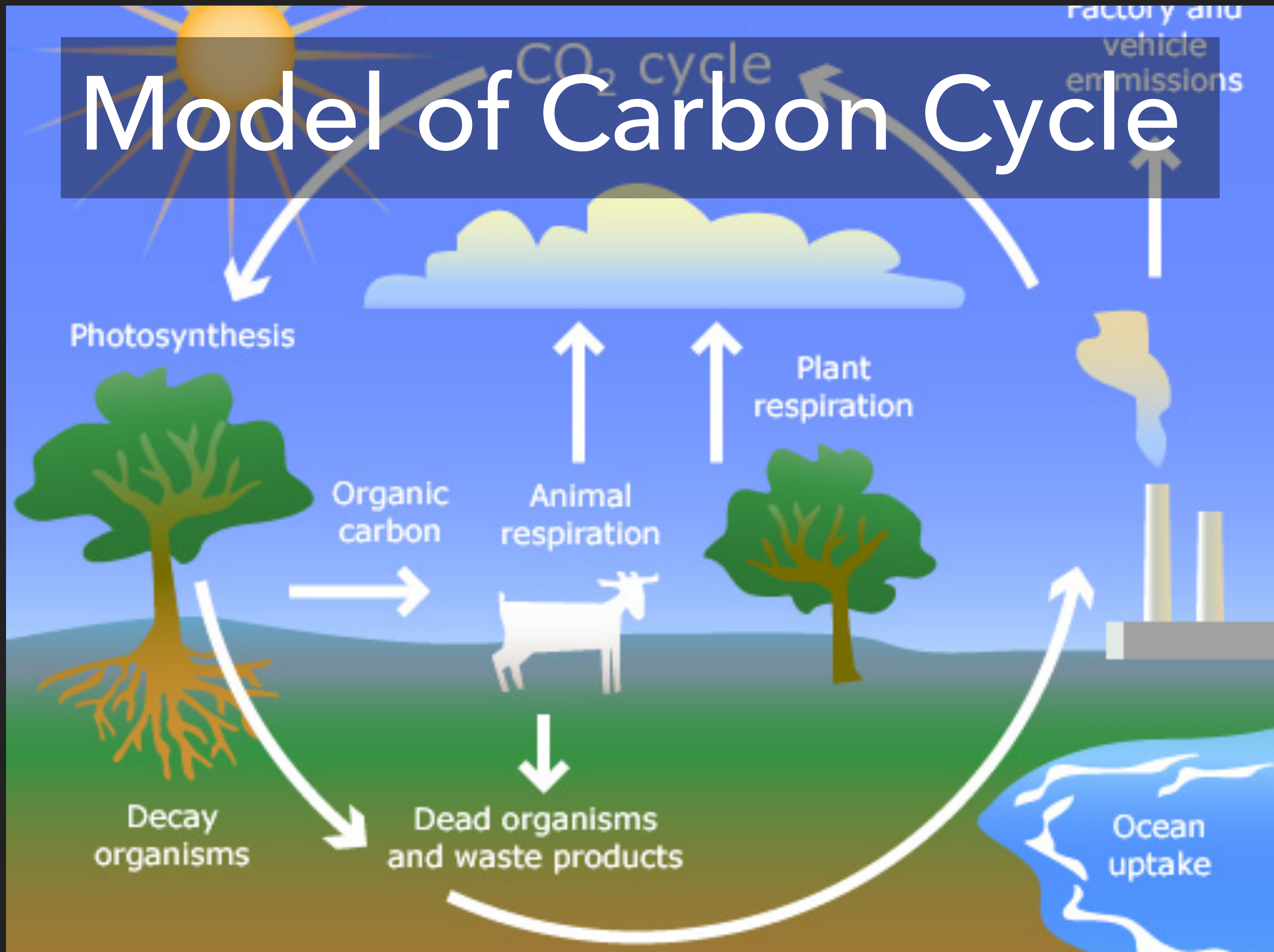


## Model of Carbon Cycle

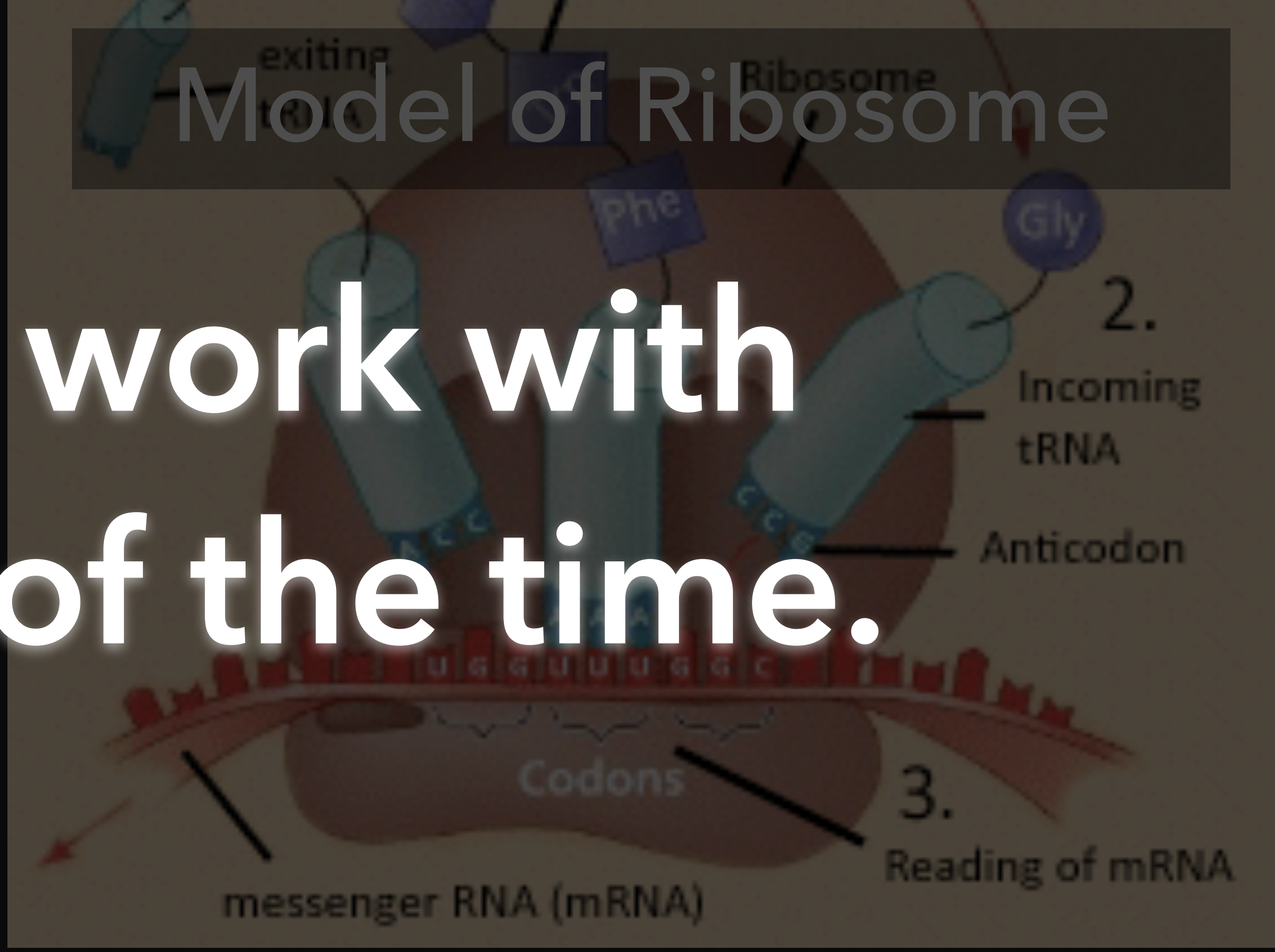


# Biologists work with models all of the time.

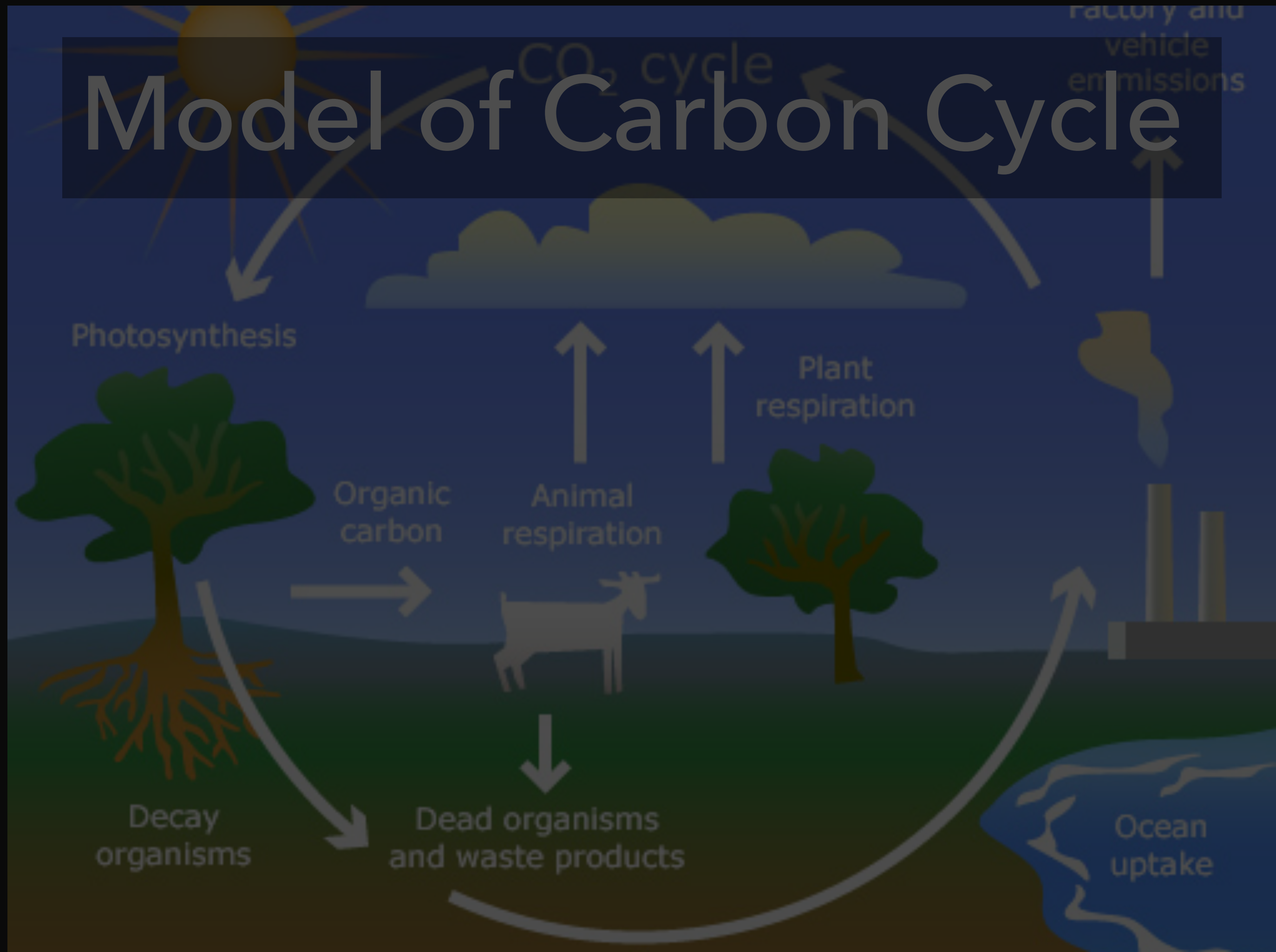
Model of Phylogeny

Origin of life

Model of Ribosome



Model of Carbon Cycle



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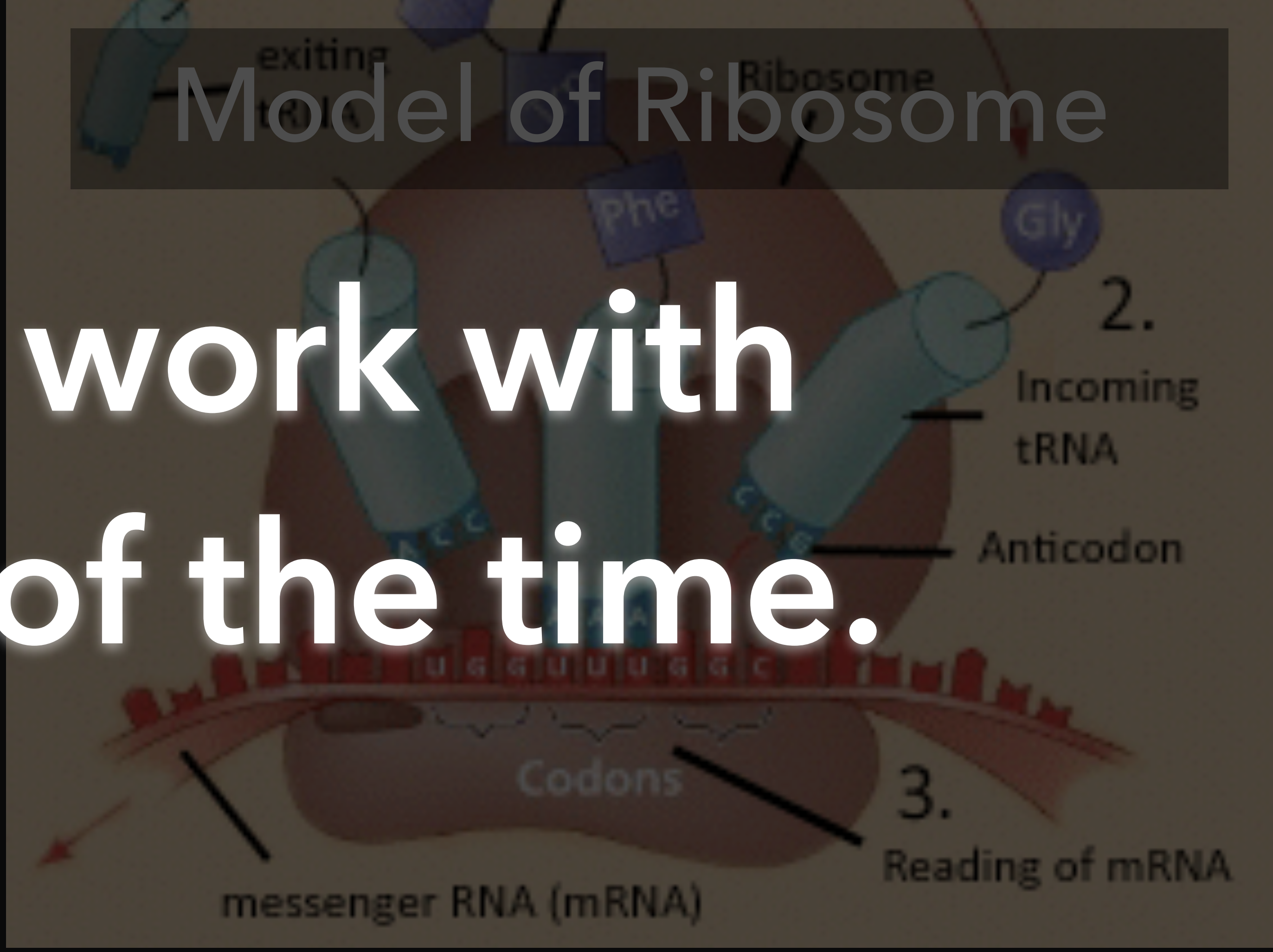

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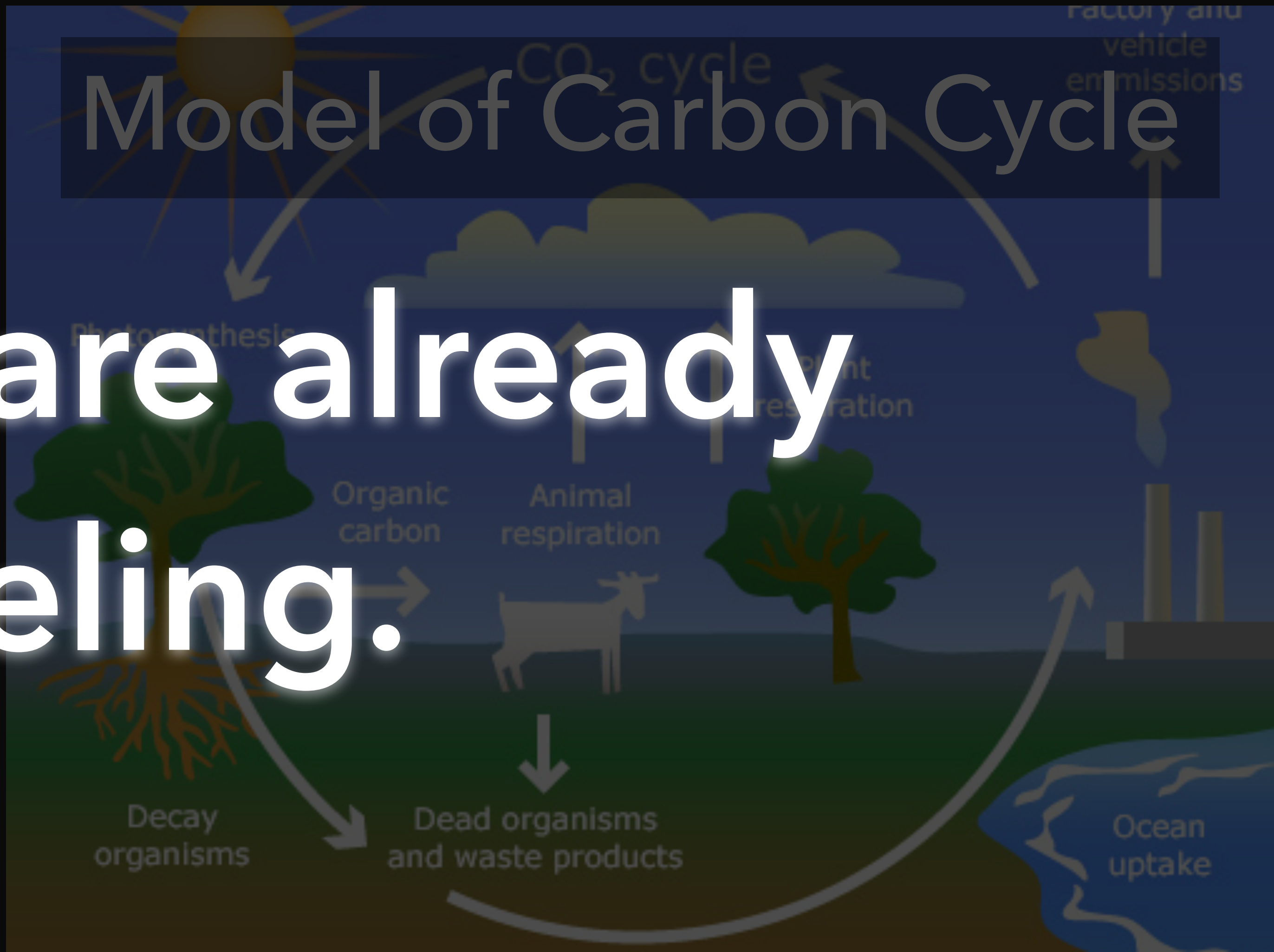
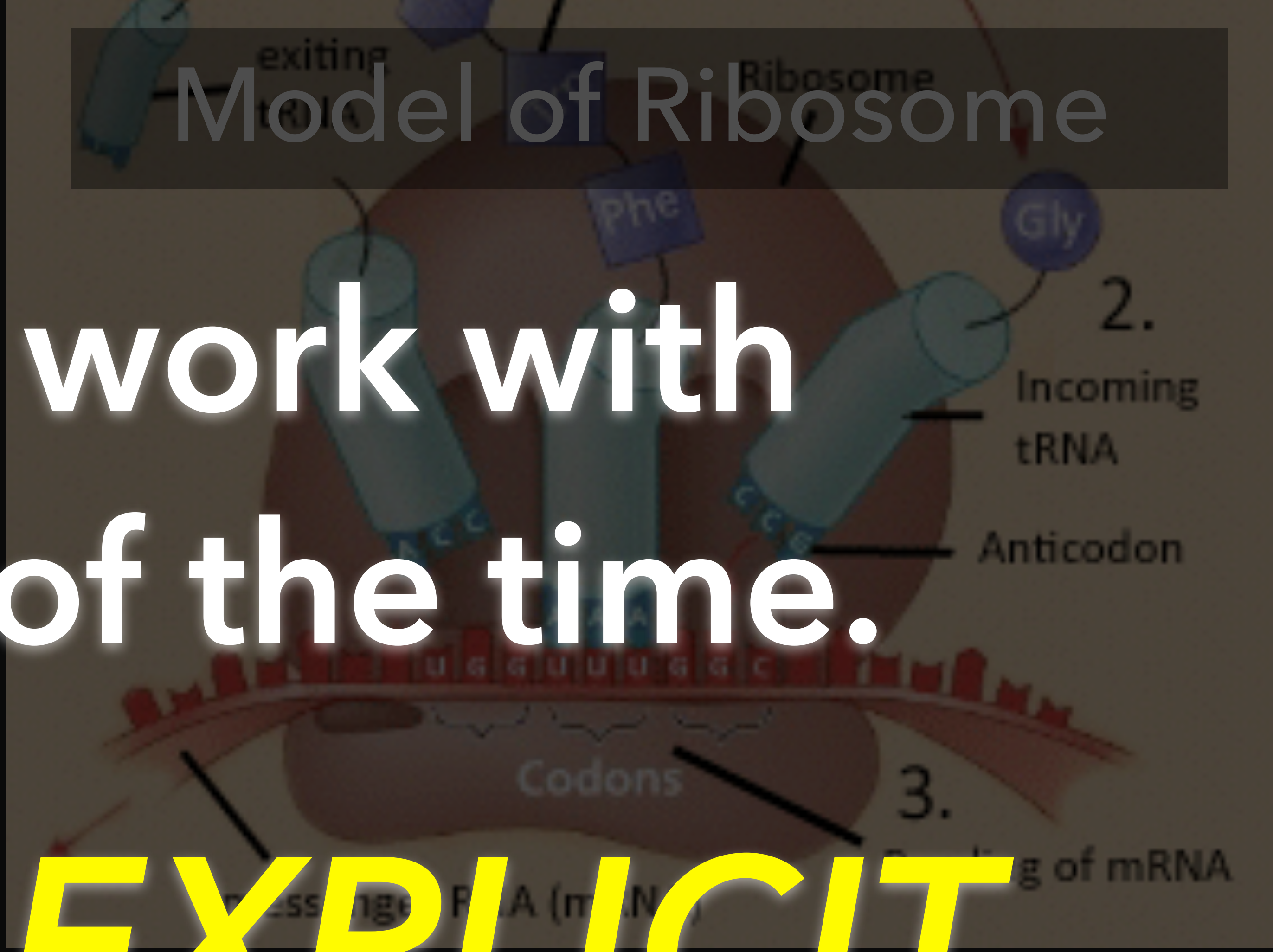


Model of Carbon Cycle

Biologists work with models all of the time.

Biologists are already modeling.

Model of Phylogeny


Model of Ribosome

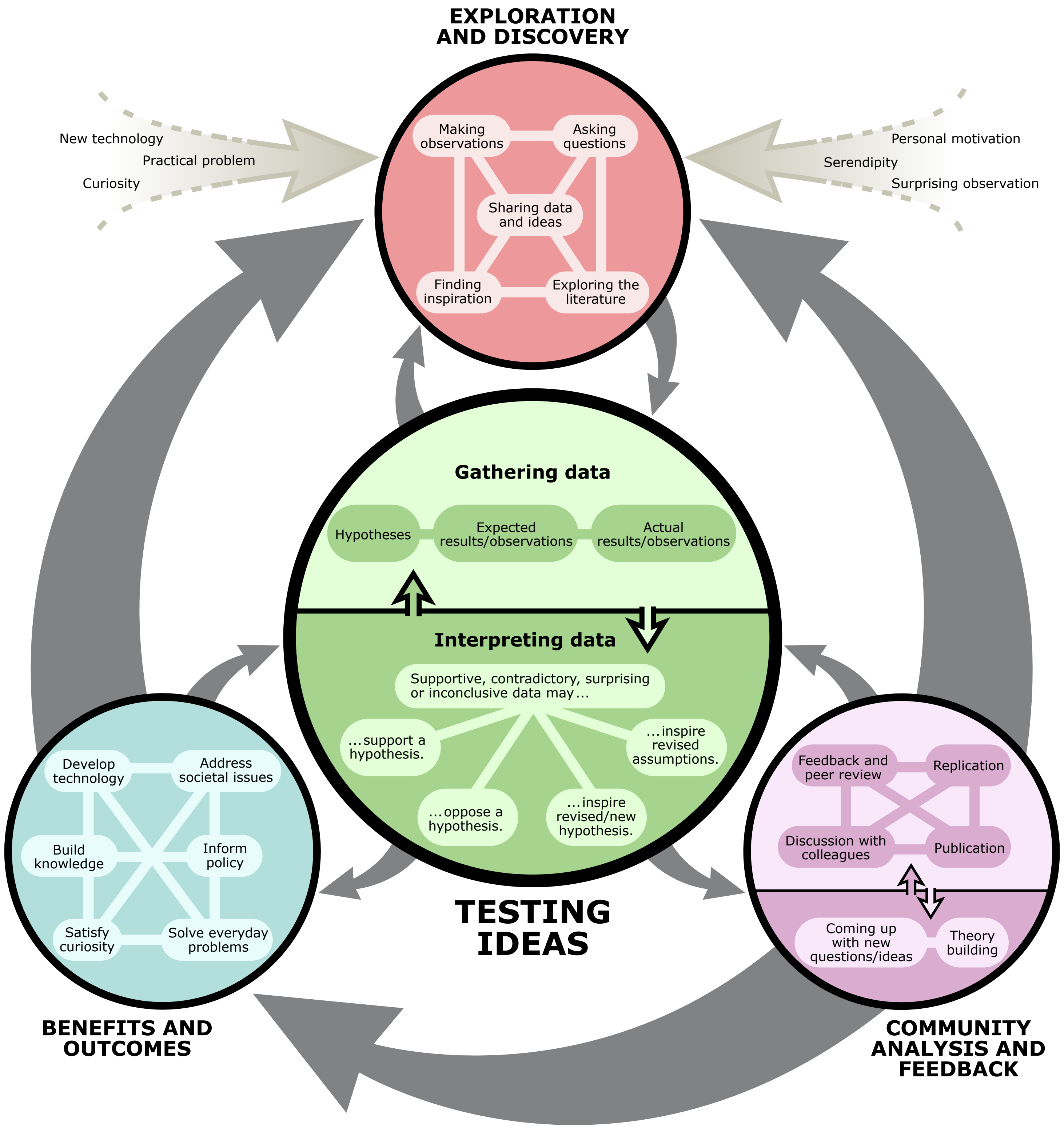
Model of Carbon Cycle

Biologists work with models all of the time.

*MAKE IT EXPLICIT*

Biologists are already modeling.

# How science works



**EXPLORATION AND DISCOVERY**

New technology
Practical problem
Curiosity

Personal motivation
Serendipity
Surprising observation

Making observations
Asking questions
Sharing data and ideas
Finding inspiration
Exploring the literature

**TESTING IDEAS**

**Gathering data**

Hypotheses
Expected results/observations
Actual results/observations

**Interpreting data**

Supportive, contradictory, surprising or inconclusive data may…
…support a hypothesis.
…oppose a hypothesis.
…inspire revised/new hypothesis.
…inspire revised assumptions.

**BENEFITS AND OUTCOMES**

Develop technology
Address societal issues
Build knowledge
Inform policy
Satisfy curiosity
Solve everyday problems

**COMMUNITY ANALYSIS AND FEEDBACK**

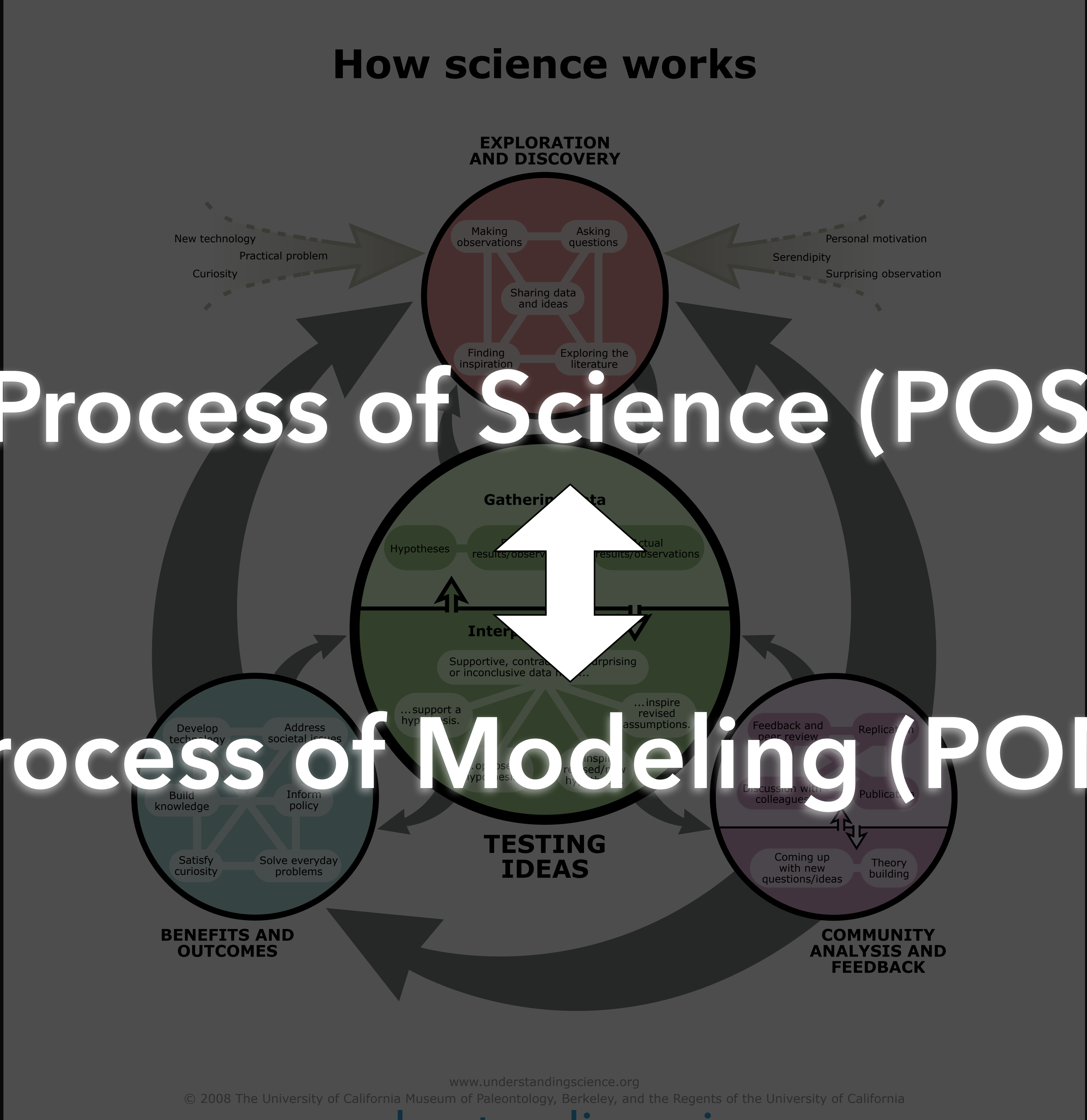
Feedback and peer review
Replication
Discussion with colleagues
Publication
Coming up with new questions/ideas
Theory building

www.understandingscience.org

www.understandingscience.org

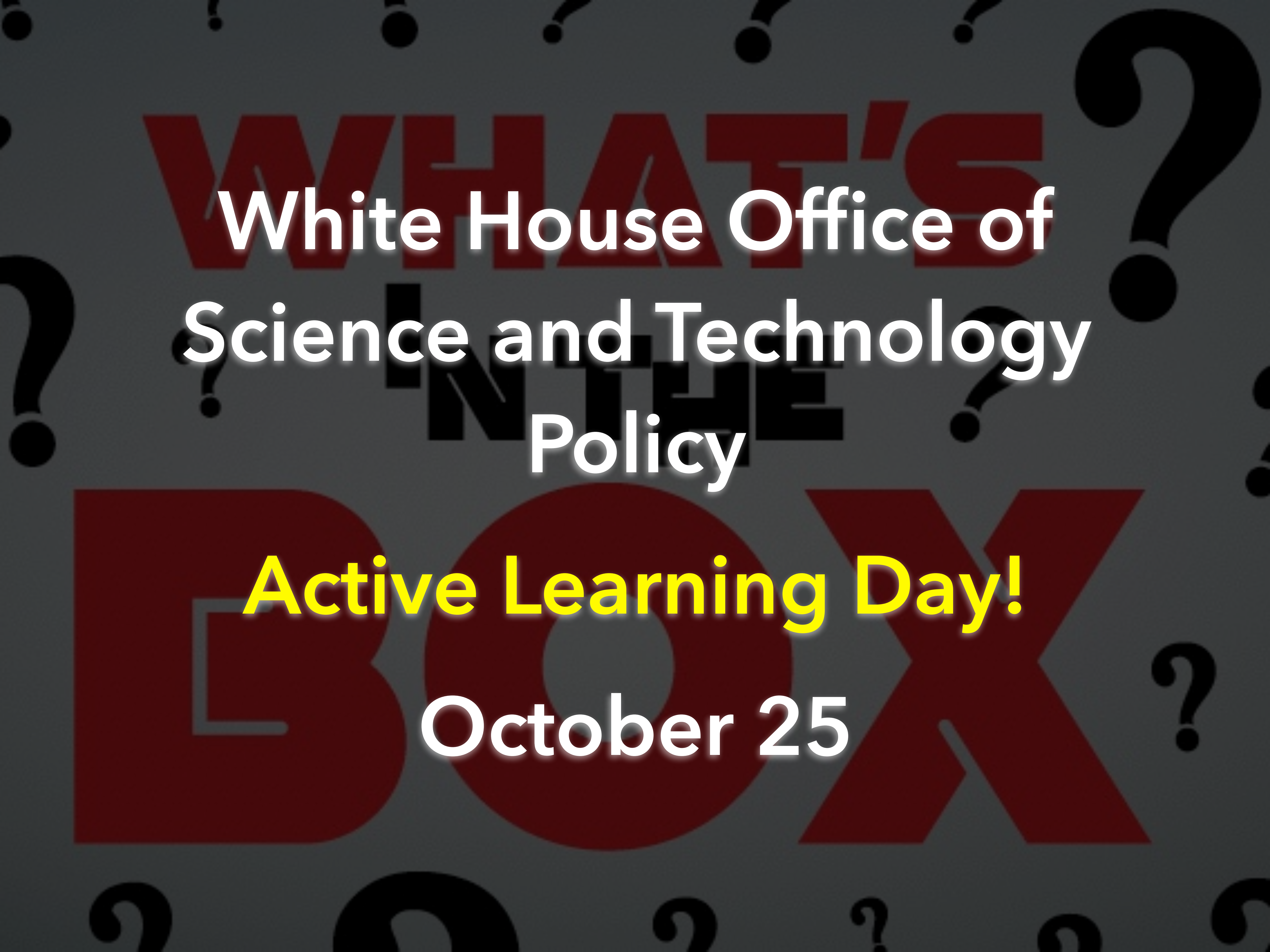
# Process of Science (POS)

# Process of Modeling (POM)



www.understandingscience.org

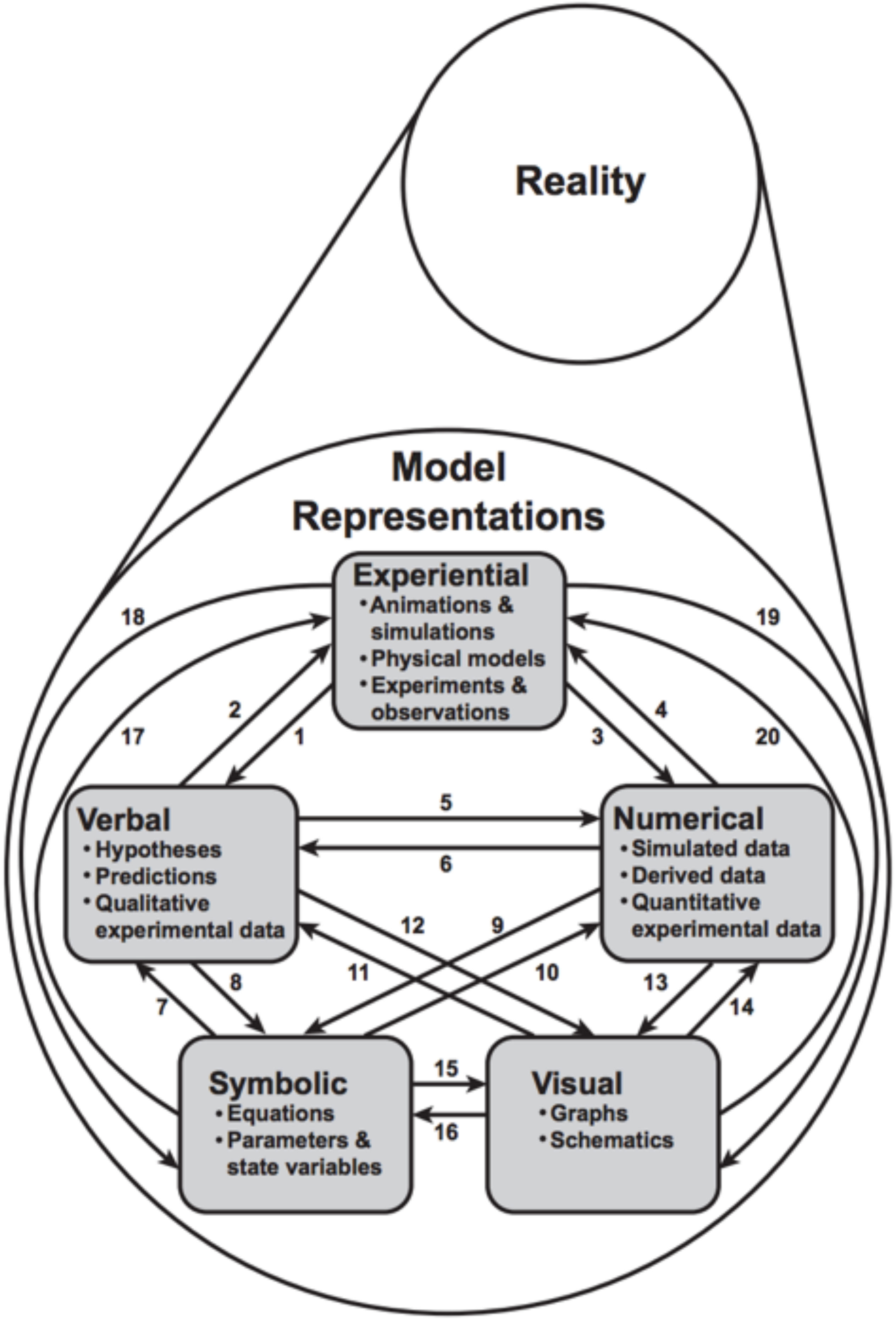
# WHAT'S IN THE BOX



# White House Office of Science and Technology Policy

## Active Learning Day!

October 25


Reality
Model Representations
Experiential
• Animations & simulations
• Physical models
• Experiments & observations
Verbal
• Hypotheses
• Predictions
• Qualitative experimental data
Numerical
• Simulated data
• Derived data
• Quantitative experimental data
Symbolic
• Equations
• Parameters & state variables
Visual
• Graphs
• Schematics
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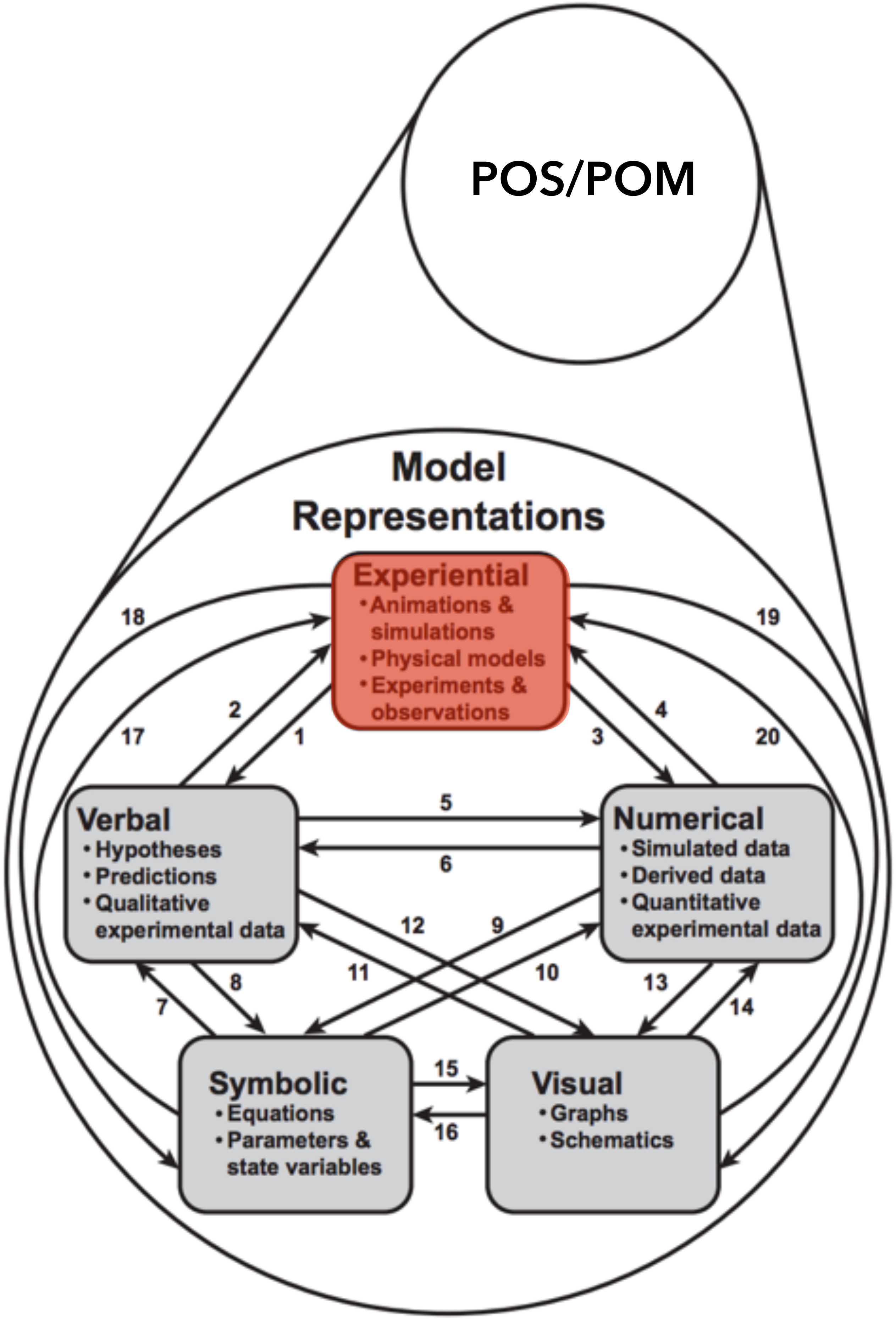

POS/POM

Model Representations
Experiential
•Animations & simulations
•Physical models
•Experiments & observations
Verbal
•Hypotheses
•Predictions
•Qualitative experimental data
Numerical
•Simulated data
•Derived data
•Quantitative experimental data
Symbolic
•Equations
•Parameters & state variables
Visual
•Graphs
•Schematics
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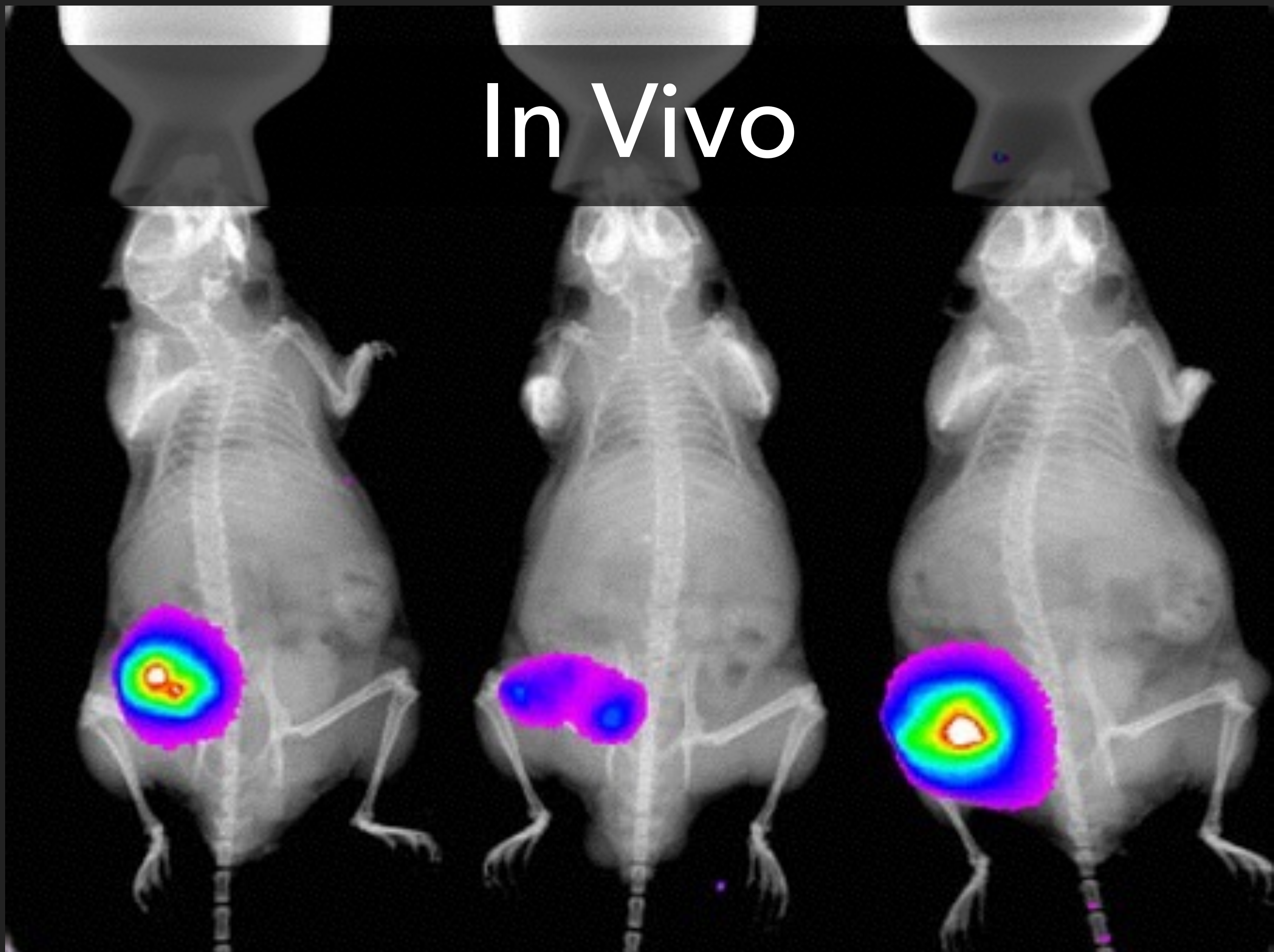
# In Vitro

In Vitro



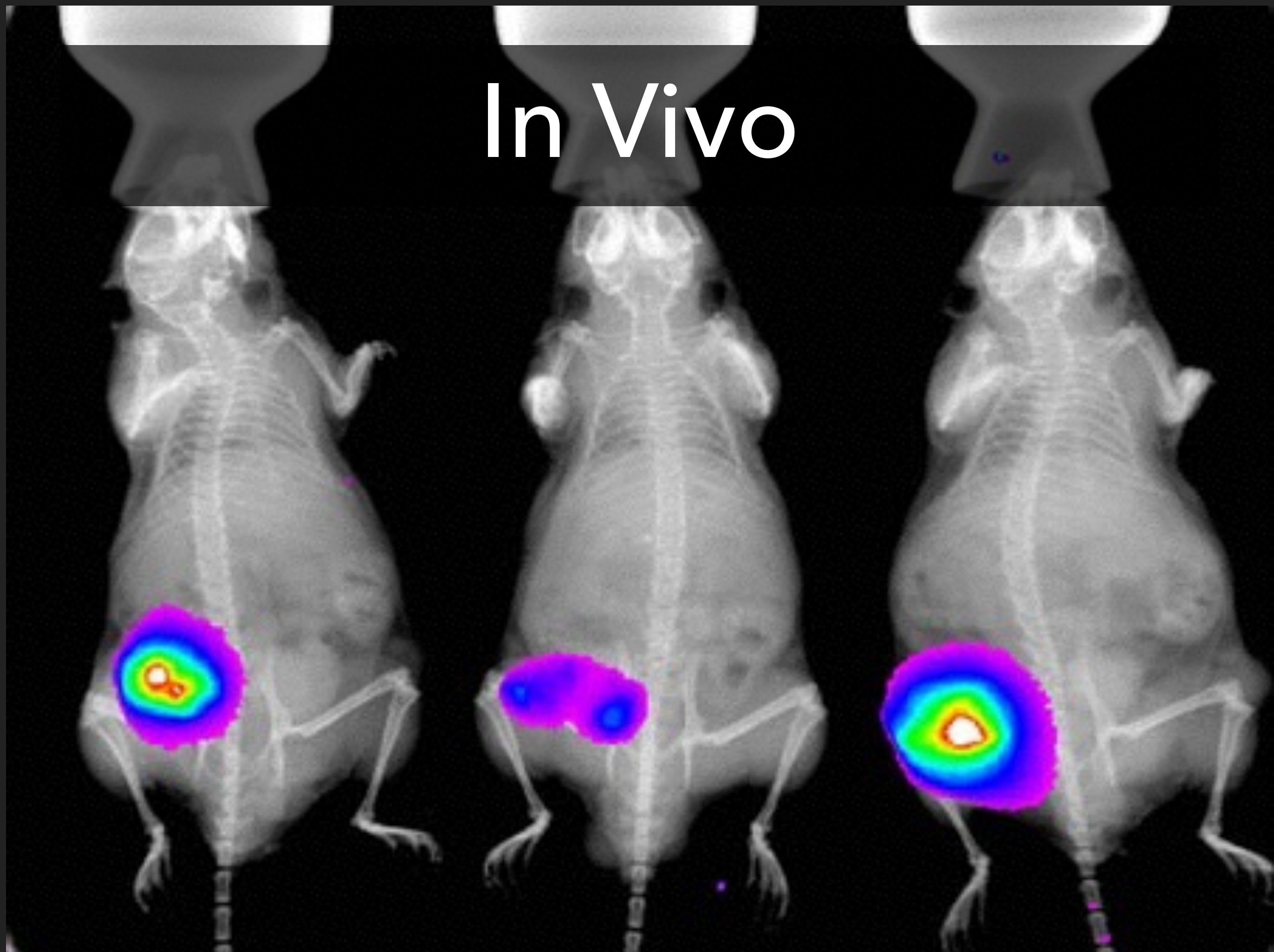
In Vivo

## In Silico/In Theoria

$$H = -\sum p(x) \log p(x)$$

## In Vitro

## In Vivo



# For mathematical and computational models:

In Silico/In Theoria

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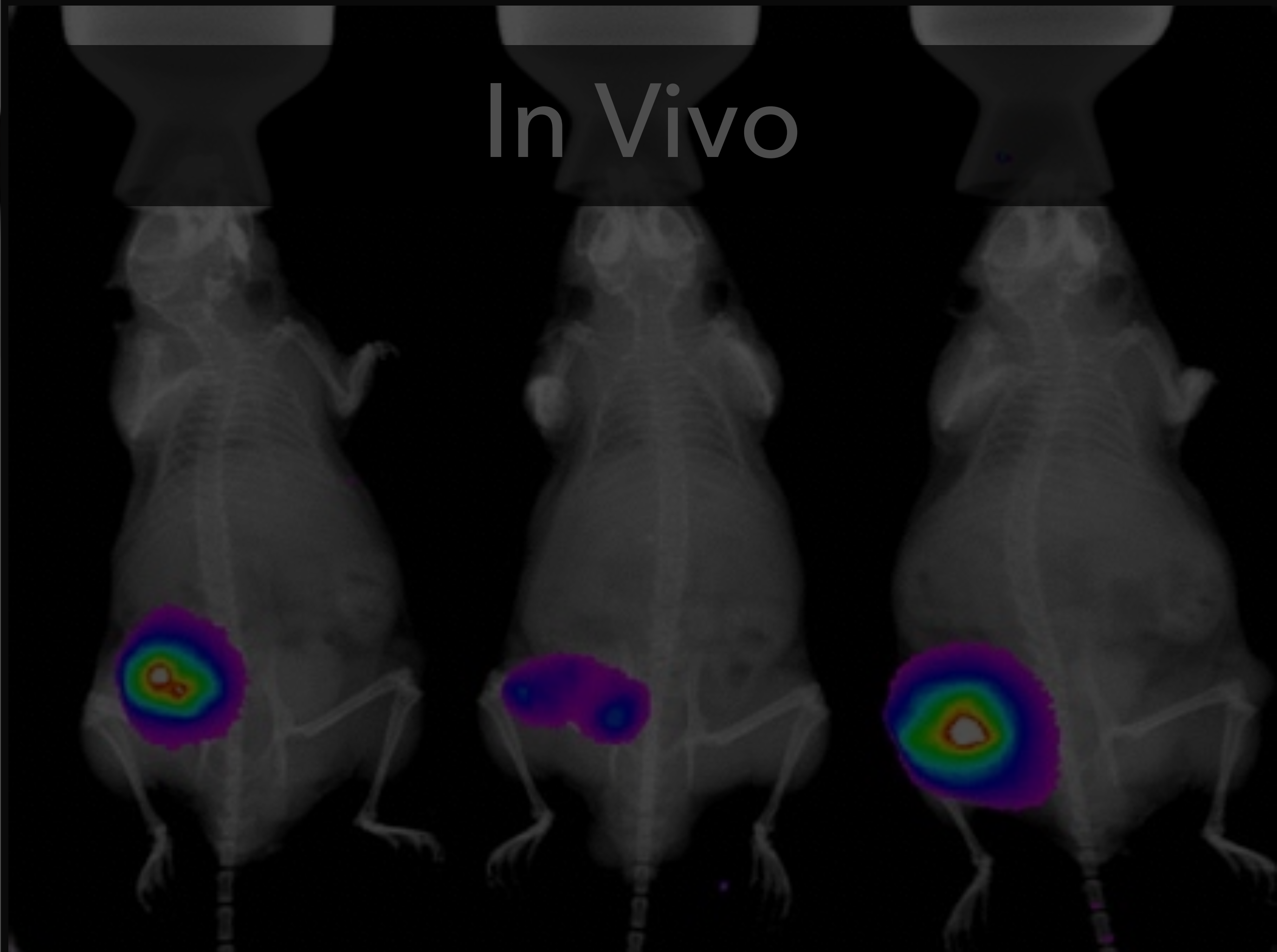
In Vitro

In Vivo



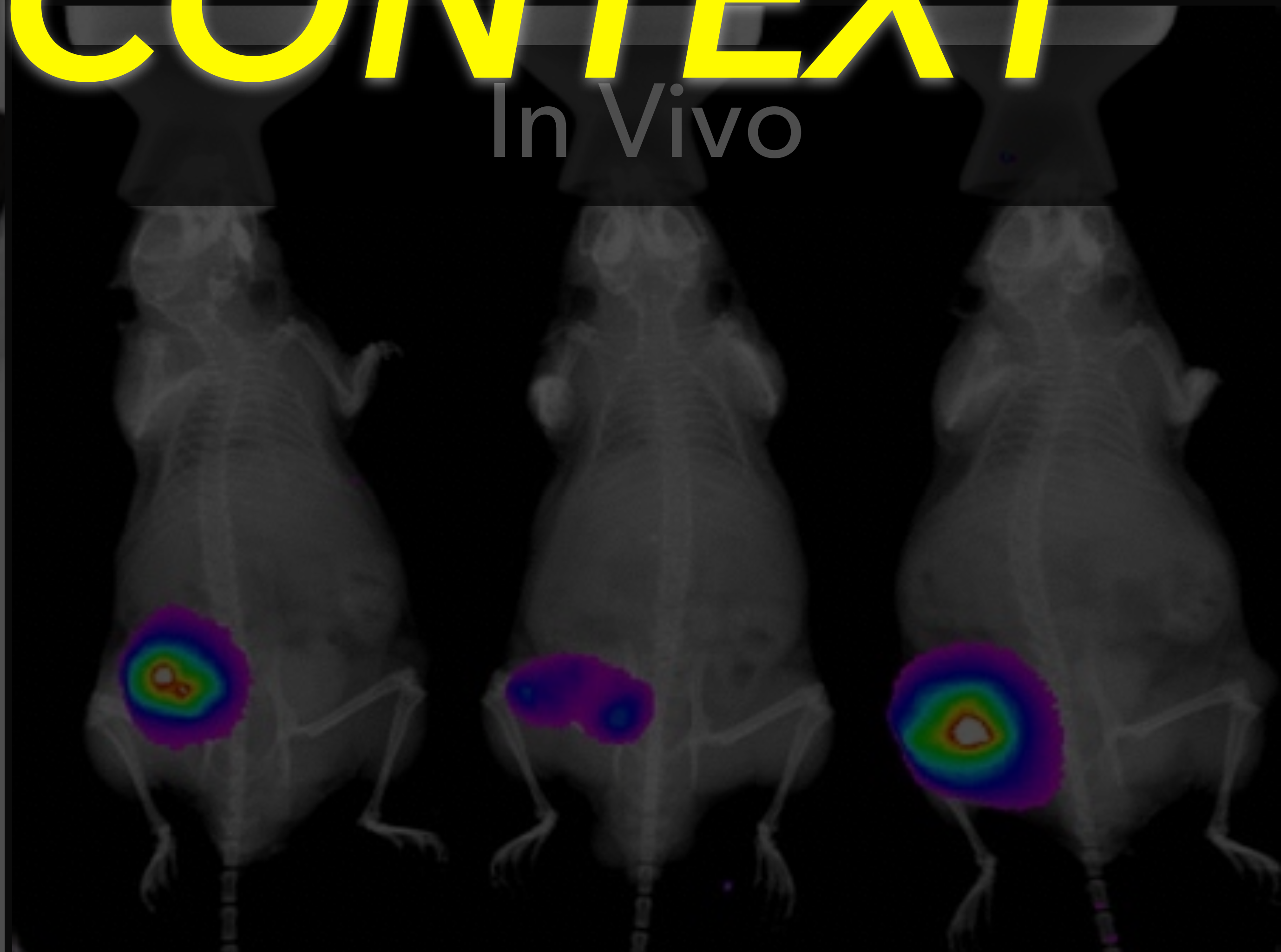
In Silico/In Theoria

In Vitro

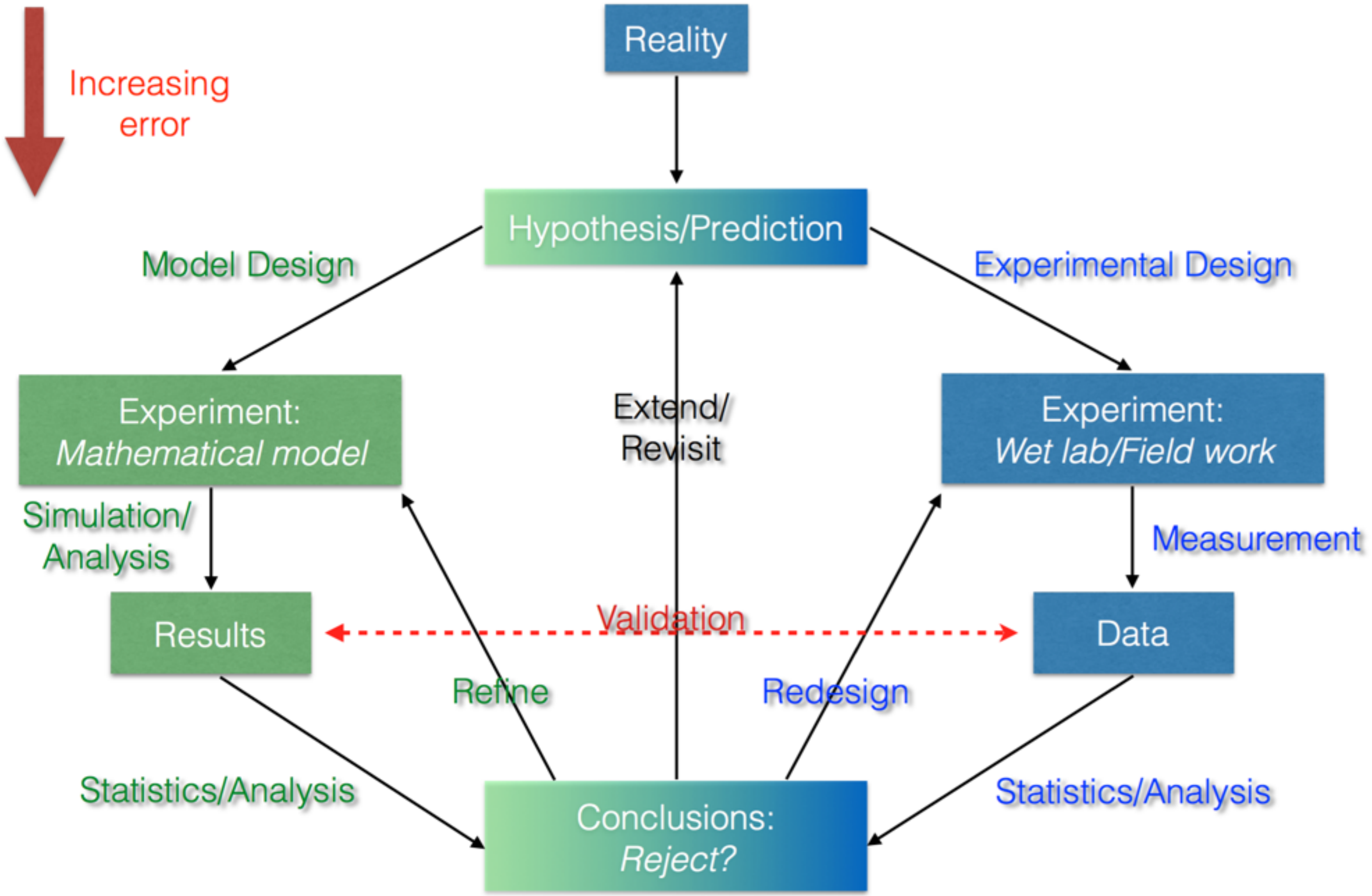
# For mathematical and computational models:

# PUT IT IN CONTEXT

In Vivo



$$H = -\sum p(x) \log p(x)$$


Increasing error
Reality
Hypothesis/Prediction
Model Design
Experimental Design
Experiment: *Mathematical model*
Extend/ Revisit
Experiment: *Wet lab/Field work*
Simulation/ Analysis
Measurement
Results
Validation
Data
Refine
Redesign
Statistics/Analysis
Conclusions: *Reject?*
Statistics/Analysis

# THE STRATEGIES OF MODELING IN BIOLOGY EDUCATION

Svoboda & Passmore 2011

# THE STRATEGIES OF MODELING IN BIOLOGY EDUCATION

> IN THE SCIENCE EDUCATION LITERATURE, MODELING HAS BEEN DISCUSSED IN A VARIETY OF WAYS, BUT OFTEN WITHOUT EXPLICIT REFERENCE TO THE DIVERSITY OF ROLES MODELS PLAY IN SCIENTIFIC PRACTICE.

Svoboda & Passmore 2011

# MODEL UTILITY

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**"WHY"**

Svoboda & Passmore 2011

# MODEL UTILITY IN BIOLOGY

Jay Odenbaugh

Richard Levins

o by Vishnu Hoff

# MODEL UTILITY IN BIOLOGY

- Simple, unrealistic models help scientists explore complex systems.

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- Models can be used to explore unknown possibilities.

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- Models can make accurate predictions.

Jay Odenbaugh

Richard Levins

# MODEL UTILITY IN BIOLOGY

- Simple, unrealistic models help scientists explore complex systems.
- Models can be used to explore unknown possibilities.
- Models can lead to the development of conceptual frameworks.
- Models can make accurate predictions.
- Models can generate causal explanations.

Jay Odenbaugh

Richard Levins

o by Vishnu Hoff

# TOWARDS BETTER MODELLING AND DECISION SUPPORT: DOCUMENTING MODEL DEVELOPMENT, TESTING, AND ANALYSIS USING TRACE

Grimm et al. 2014

# TOWARDS BETTER MODELLING AND DECISION SUPPORT: DOCUMENTING MODEL DEVELOPMENT, TESTING, AND ANALYSIS USING TRACE

> WE RE-DEFINE TRACE AS A TOOL FOR PLANNING, PERFORMING, AND DOCUMENTING GOOD MODELLING PRACTICE.

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**PROCESS OF MODELING**

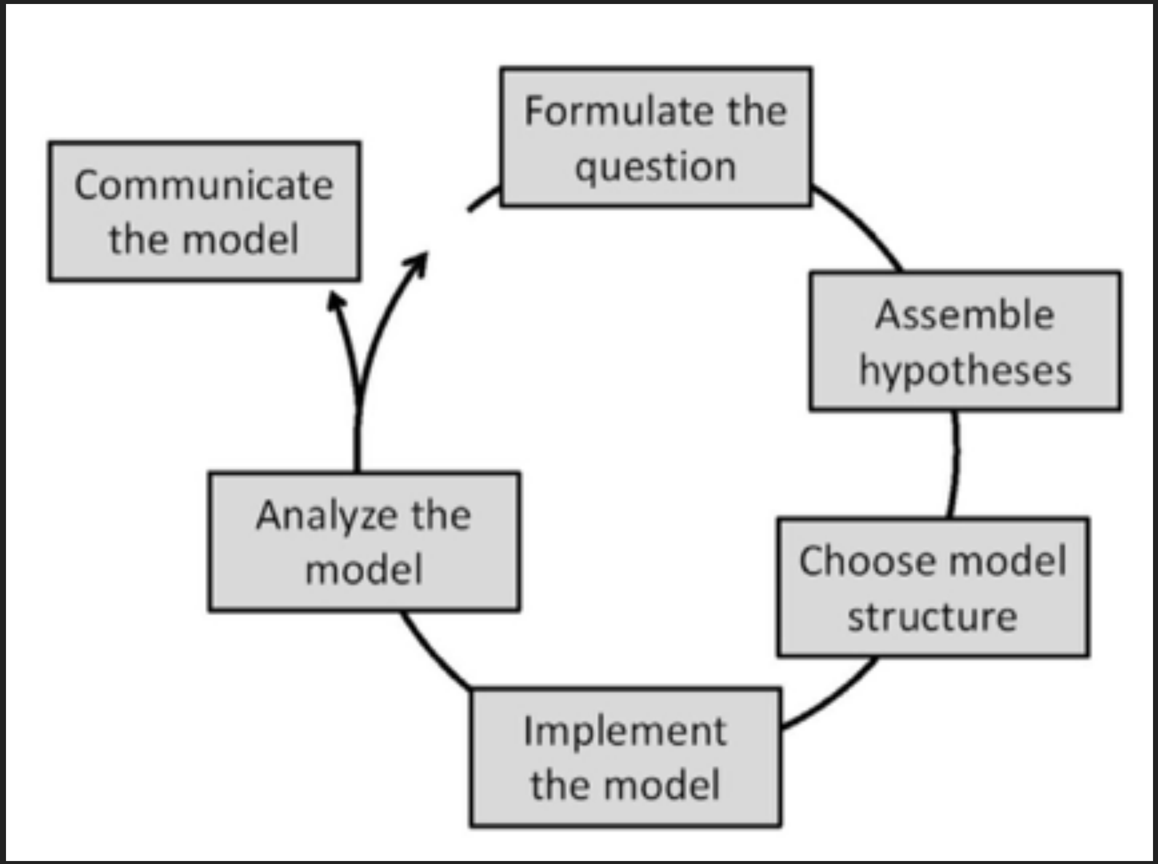
Grimm et al. 2014

WE RE-DEFINE TRACE AS A TOOL FOR PLANNING, PERFORMING, AND DOCUMENTING GOOD MODELLING PRACTICE.

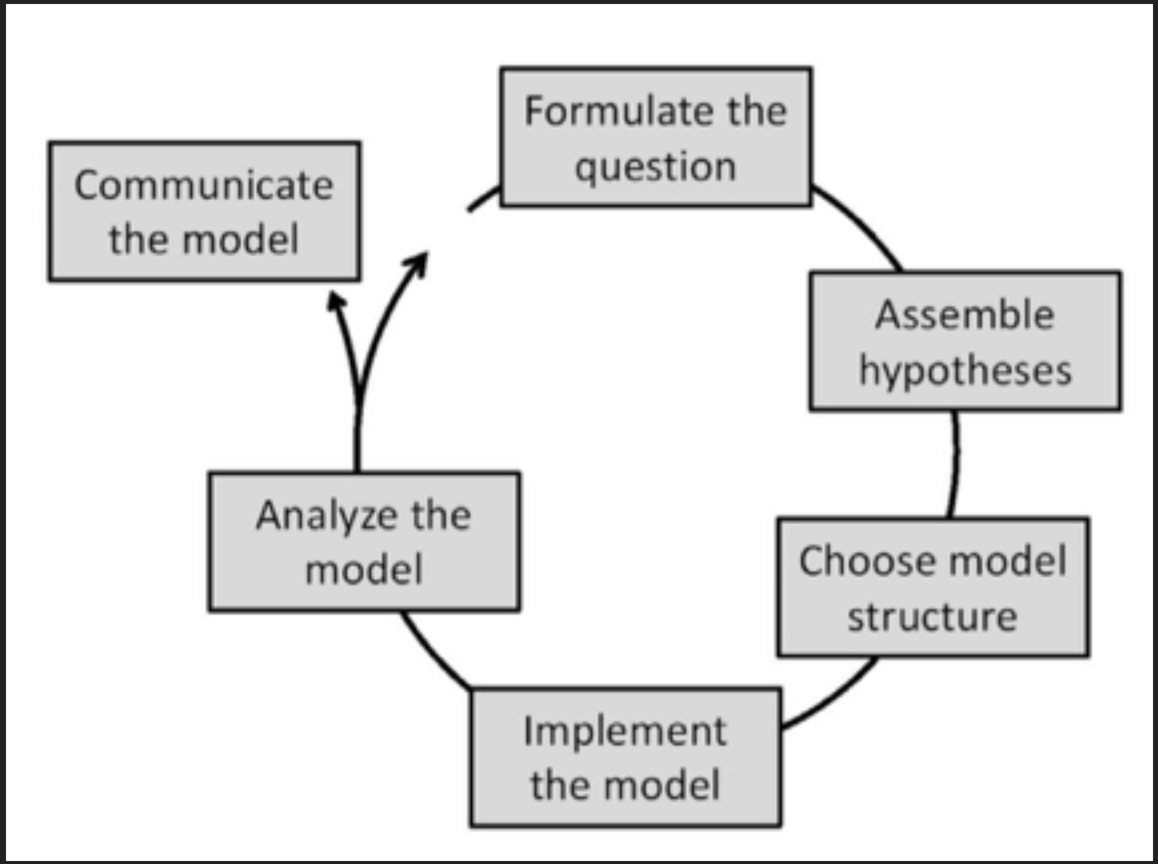
**“WHAT”**

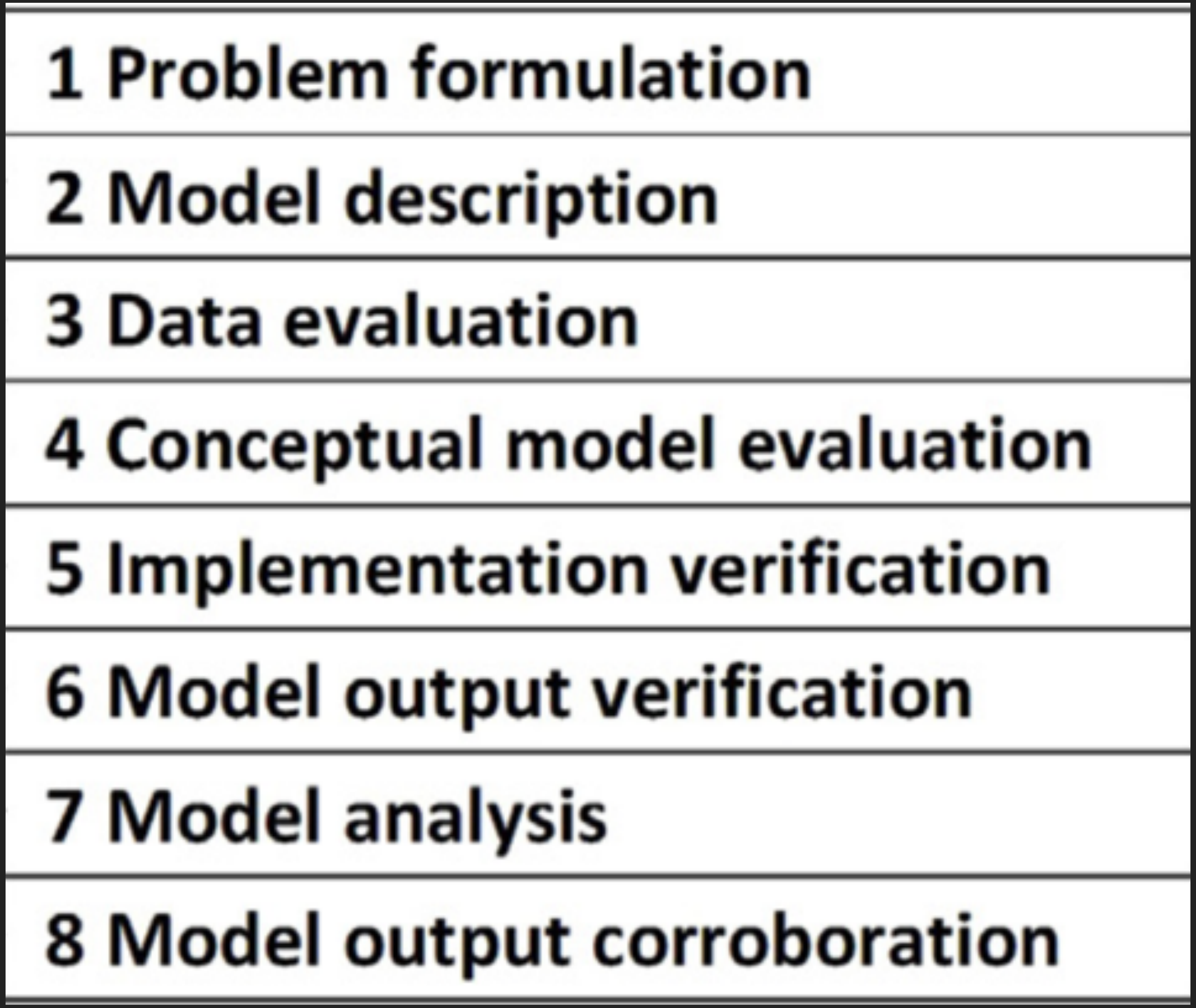
Grimm et al. 2014

# PROCESS FRAMEWORK



# PROCESS FRAMEWORK




1 Problem formulation
2 Model description
3 Data evaluation
4 Conceptual model evaluation
5 Implementation verification
6 Model output verification
7 Model analysis
8 Model output corroboration

# DEVELOPING A LEARNING PROGRESSION FOR SCIENTIFIC MODELING

Schwarz et al. 2009

## DEVELOPING A LEARNING PROGRESSION FOR SCIENTIFIC MODELING

> WE DEFINE SCIENTIFIC MODELING AS INCLUDING THE ELEMENTS OF THE PRACTICE (CONSTRUCTING, USING, EVALUATING, AND REVISING SCIENTIFIC MODELS) AND THE METAKNOWLEDGE THAT GUIDES AND MOTIVATES THE PRACTICE (E.G., UNDERSTANDING THE NATURE AND PURPOSE OF MODELS).

Schwarz et al. 2009

# LEARNING PROGRESSION FOR POM

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**"HOW"**

Schwarz et al. 2009

# METRICS OF UNDERSTANDING IN POM

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- What is a model (in terms of use; measures depth)?

# METRICS OF UNDERSTANDING IN POM

- What is a model (in terms of use; measures depth)?
- What does modeling include (as a process; measures breadth)?

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- What is a model (in terms of use; measures depth)?
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- Where does evidence come from (measures foundation)?

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- What is a model (in terms of use; measures depth)?
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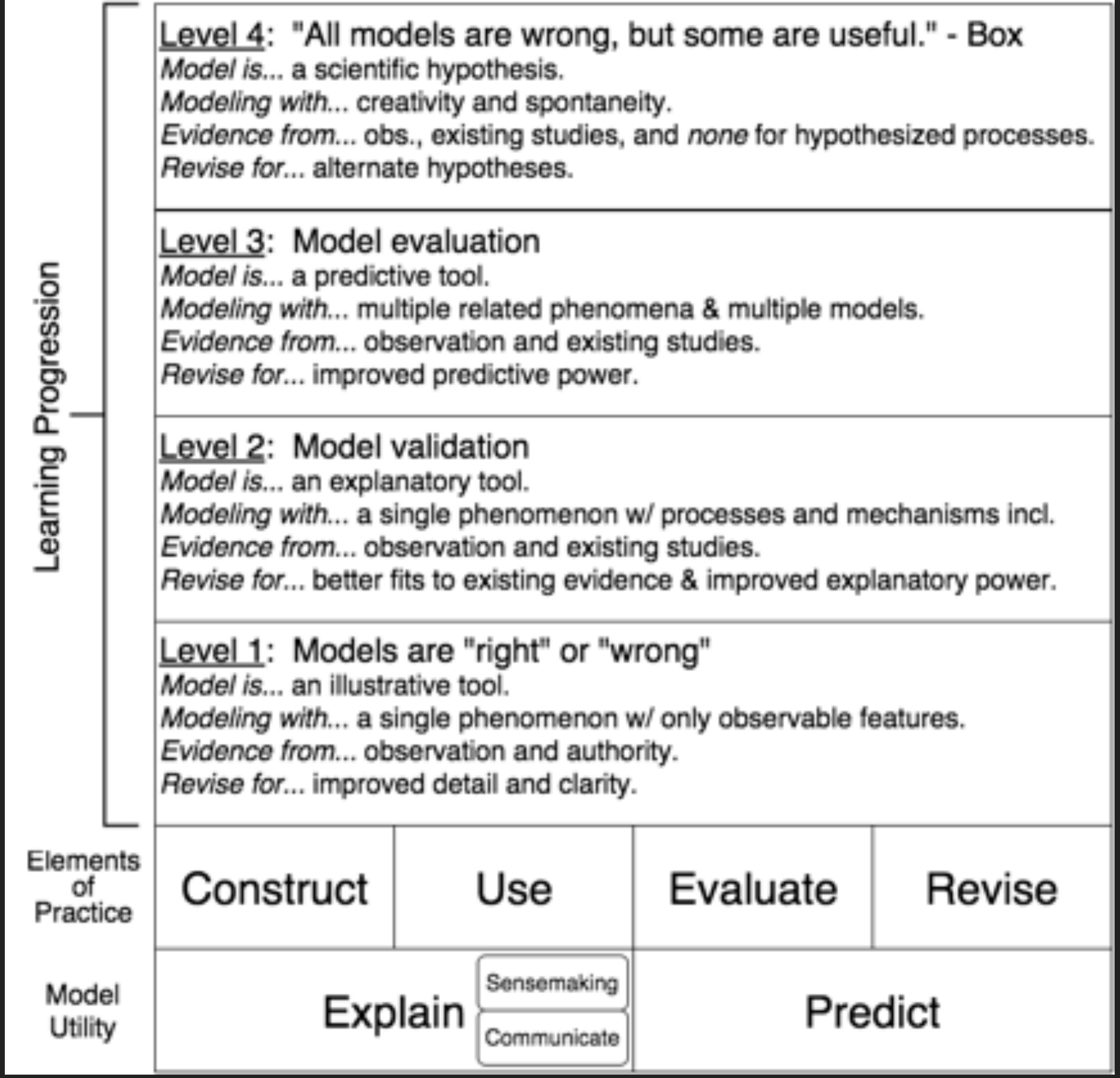

Level 4: "All models are wrong, but some are useful." - Box
*Model is...* a scientific hypothesis.
*Modeling with...* creativity and spontaneity.
*Evidence from...* obs., existing studies, and *none* for hypothesized processes.
*Revise for...* alternate hypotheses.

Level 3: Model evaluation
*Model is...* a predictive tool.
*Modeling with...* multiple related phenomena & multiple models.
*Evidence from...* observation and existing studies.
*Revise for...* improved predictive power.

Level 2: Model validation
*Model is...* an explanatory tool.
*Modeling with...* a single phenomenon w/ processes and mechanisms incl.
*Evidence from...* observation and existing studies.
*Revise for...* better fits to existing evidence & improved explanatory power.

Level 1: Models are "right" or "wrong"
*Model is...* an illustrative tool.
*Modeling with...* a single phenomenon w/ only observable features.
*Evidence from...* observation and authority.
*Revise for...* improved detail and clarity.

| | | | | |
|---|---|---|---|---|
| Elements of Practice | Construct | Use | Evaluate | Revise |
| Model Utility | Explain | Sensemaking<br>Communicate | Predict | |

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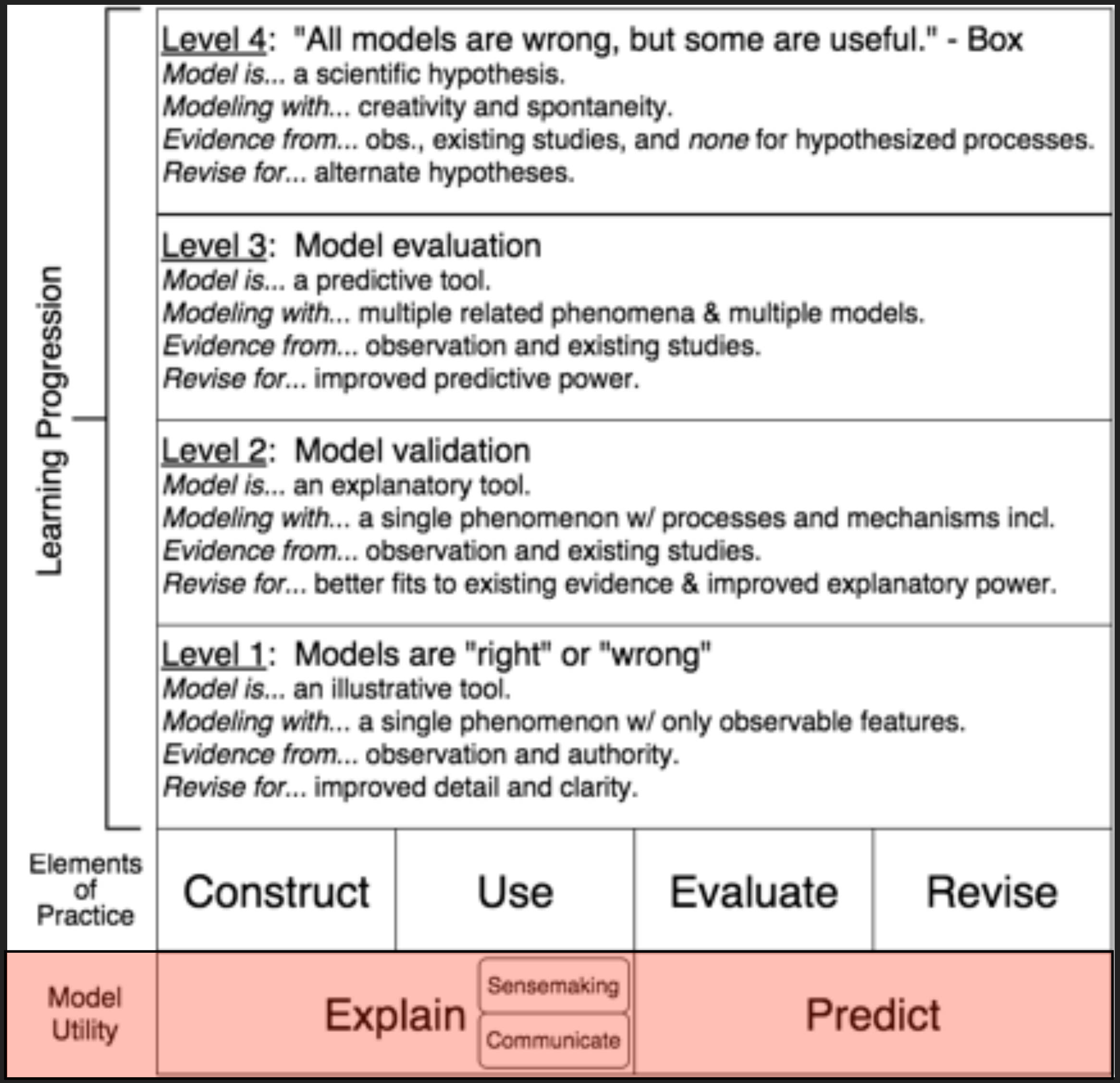

Learning Progression

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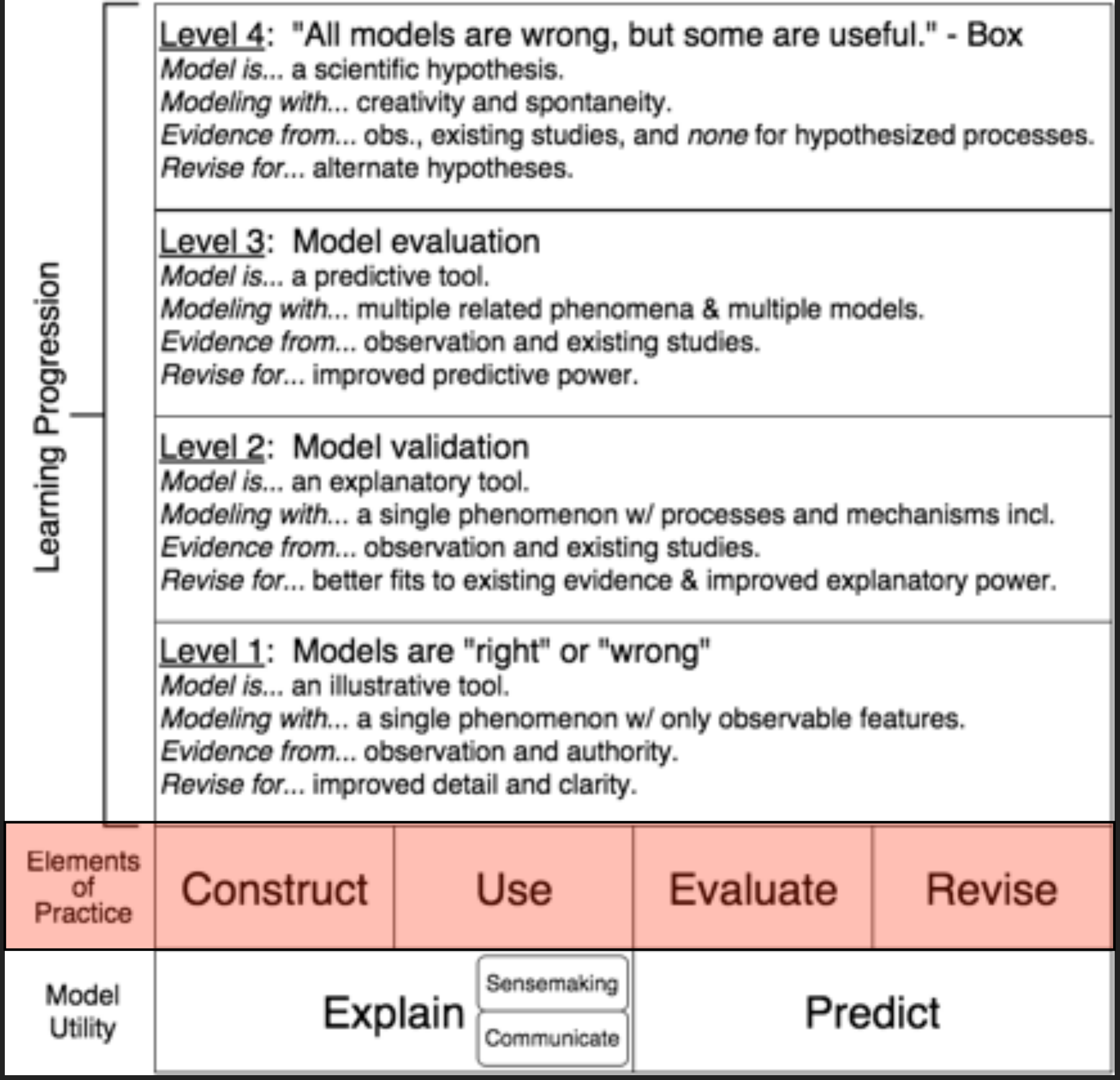

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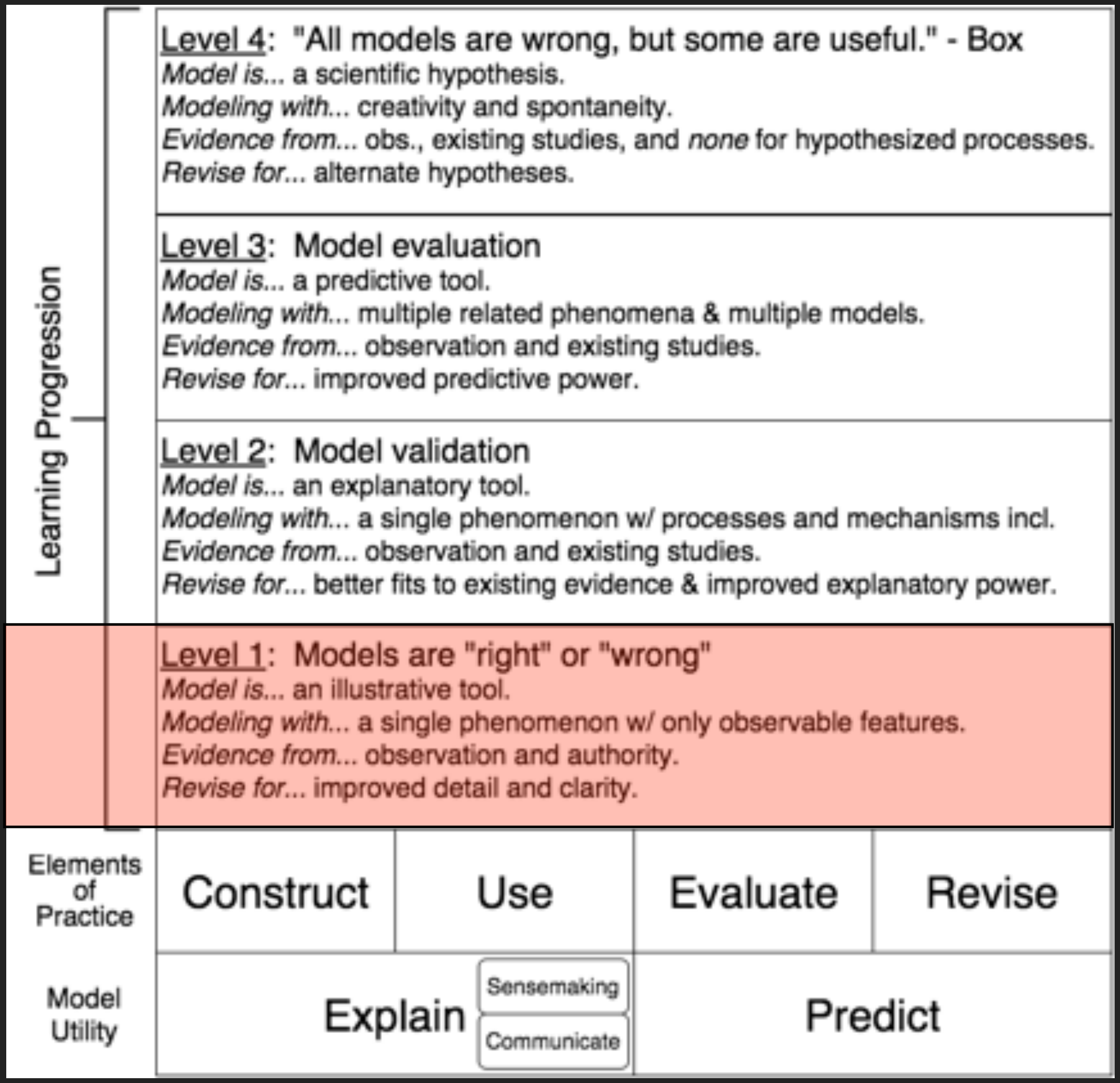
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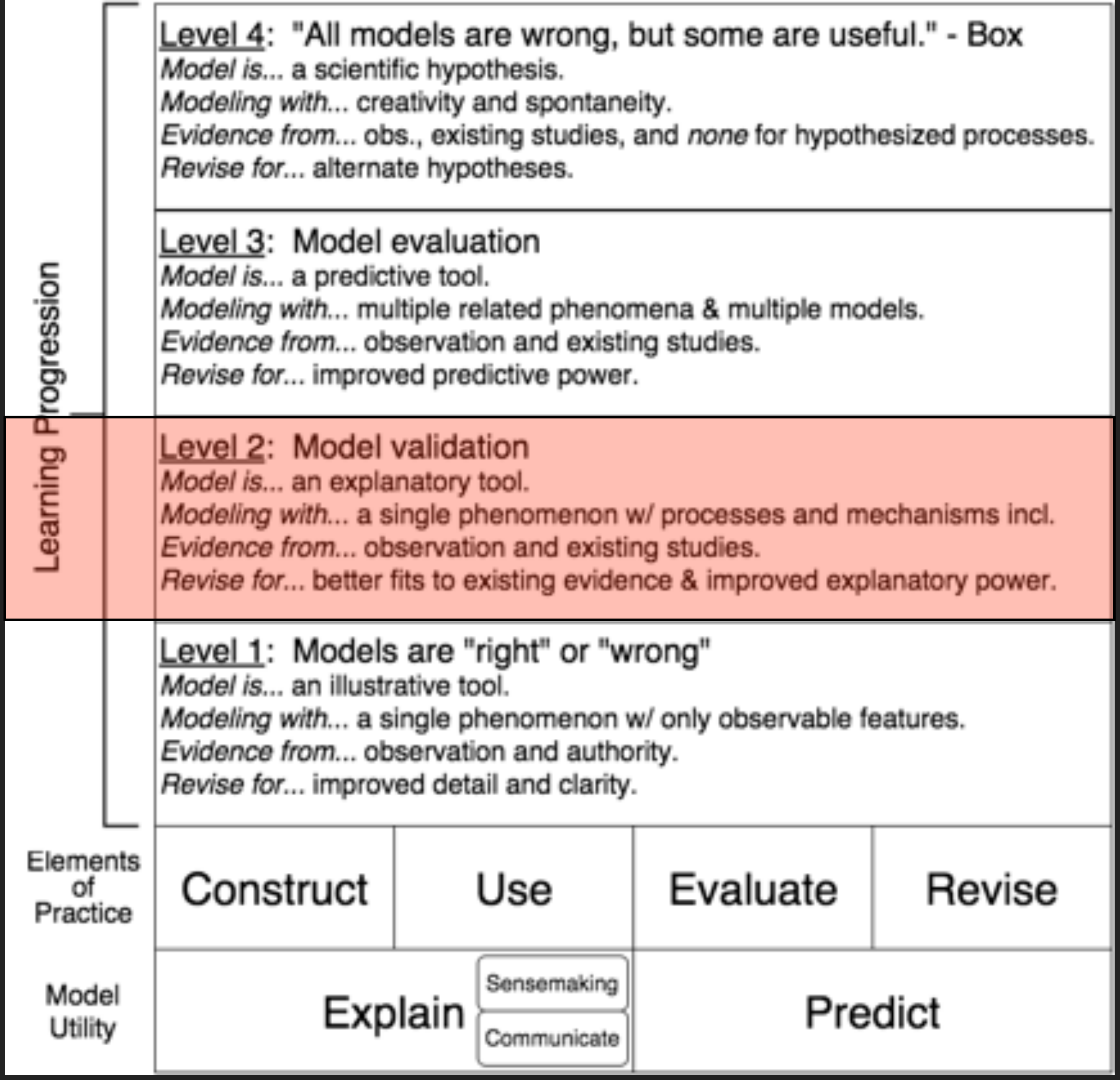
- Where does evidence come from (measures foundation)?
- How malleable are models (measures creativity)?



Learning Progression

Level 4: "All models are wrong, but some are useful." - Box
*Model is...* a scientific hypothesis.
*Modeling with...* creativity and spontaneity.
*Evidence from...* obs., existing studies, and *none* for hypothesized processes.
*Revise for...* alternate hypotheses.

Level 3: Model evaluation
*Model is...* a predictive tool.
*Modeling with...* multiple related phenomena & multiple models.
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Level 2: Model validation
*Model is...* an explanatory tool.
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Level 1: Models are "right" or "wrong"
*Model is...* an illustrative tool.
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| | | | | |
|---|---|---|---|---|
| Elements of Practice | Construct | Use | Evaluate | Revise |
| Model Utility | Explain | Sensemaking<br>Communicate | Predict | |

# METRICS OF UNDERSTANDING IN POM

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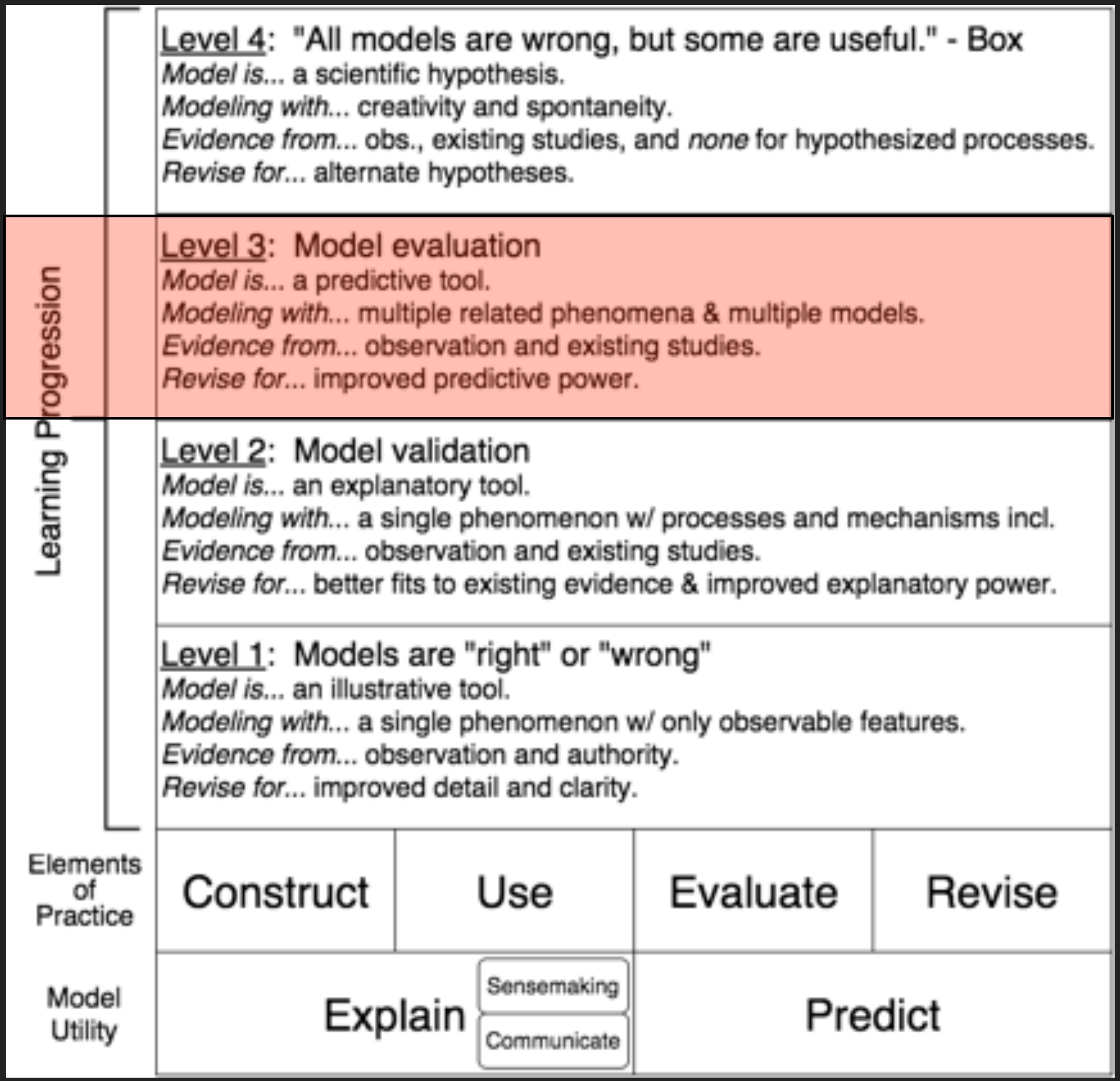

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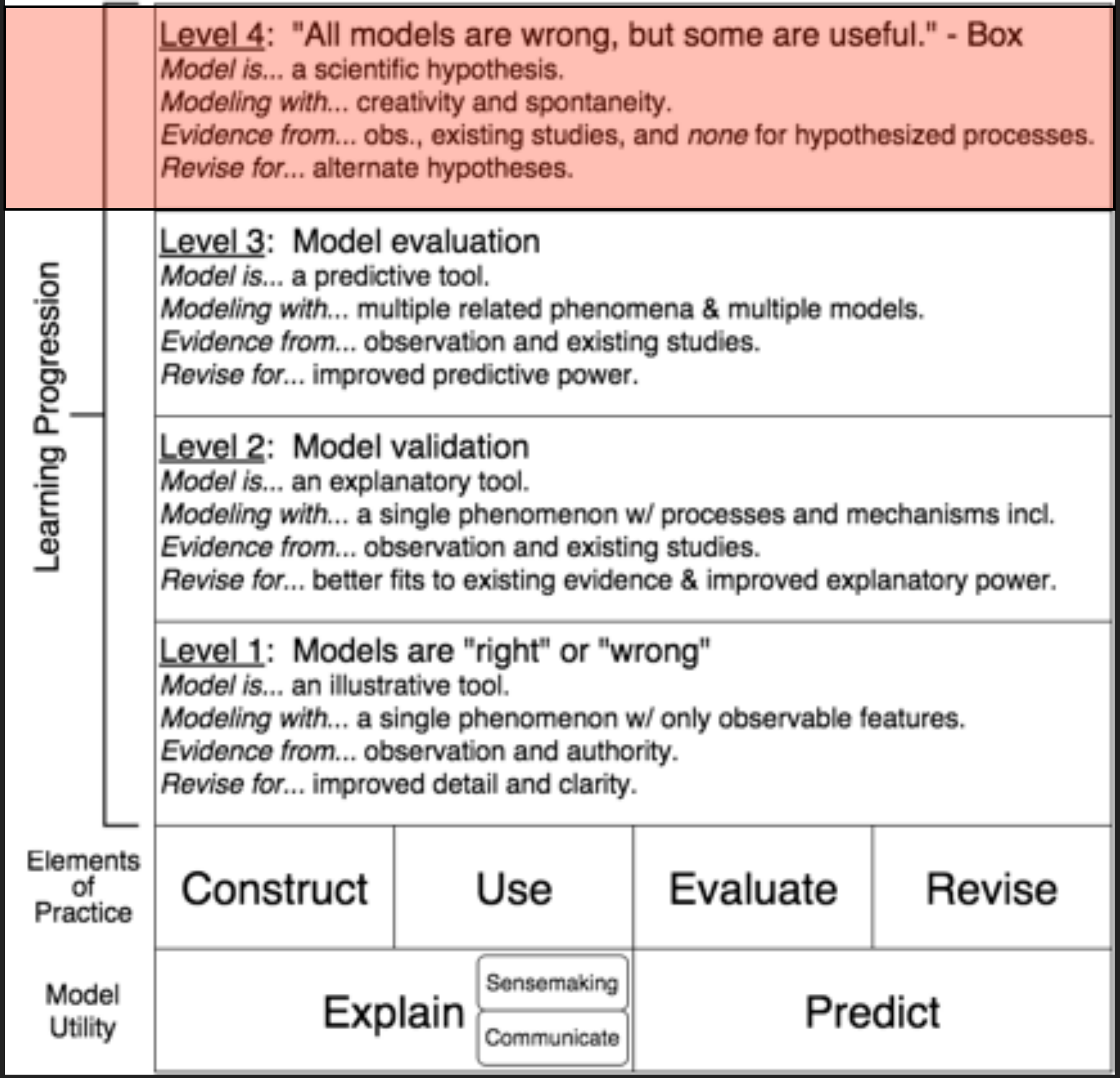

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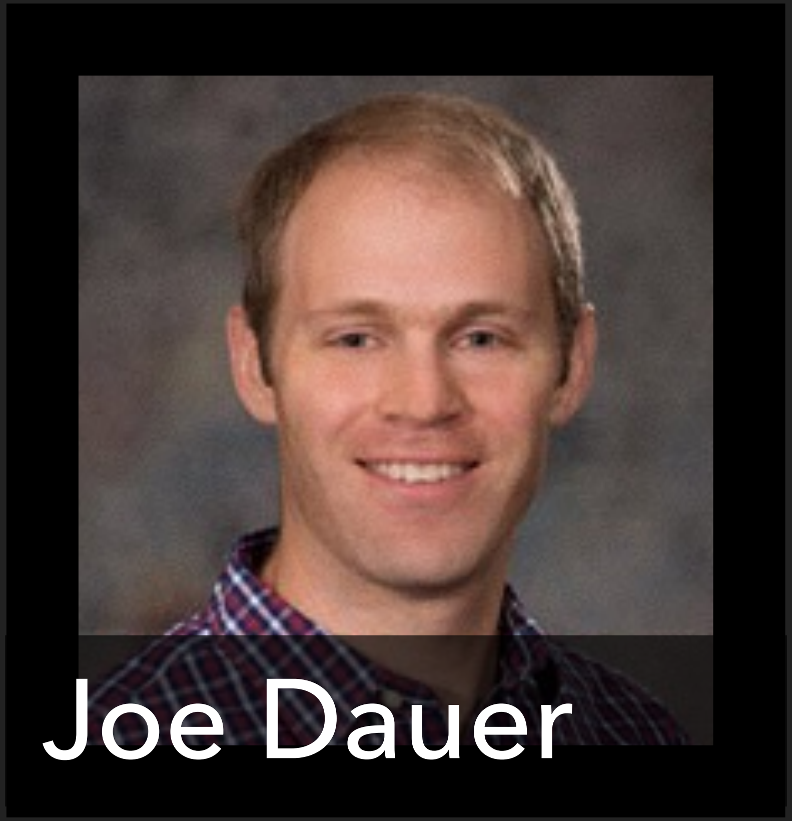
- Article aimed at undergraduate biology educators on framework

CBE
Life
Sciences
Education

# WHAT'S NEXT?

- Article aimed at undergraduate biology educators on framework
- Develop assessments for mathematical modeling in undergraduate biology curriculum



Joe Dauer

Bob Mayes

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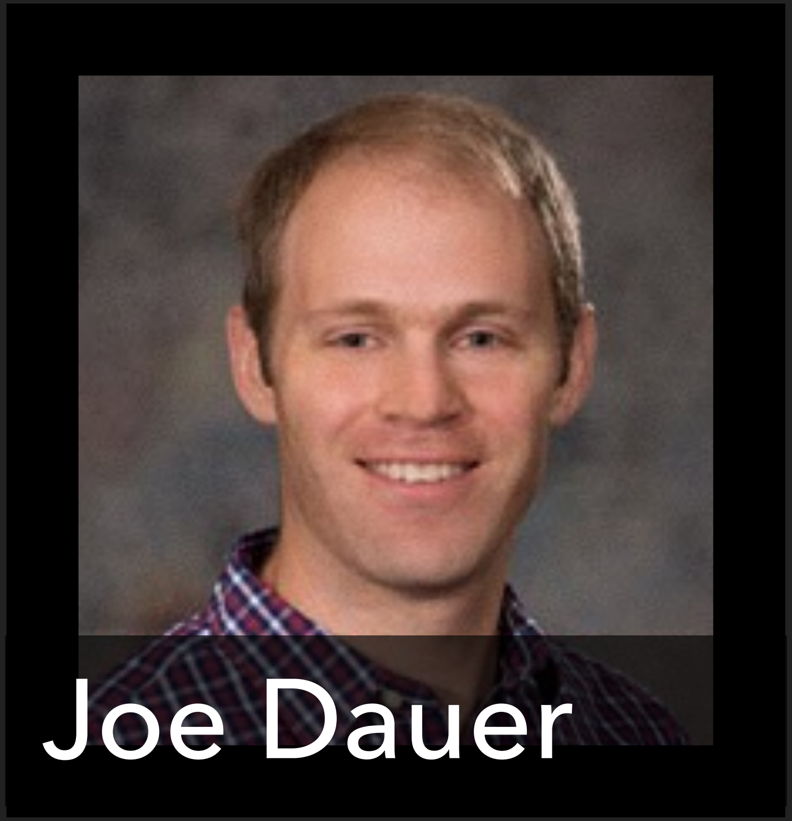

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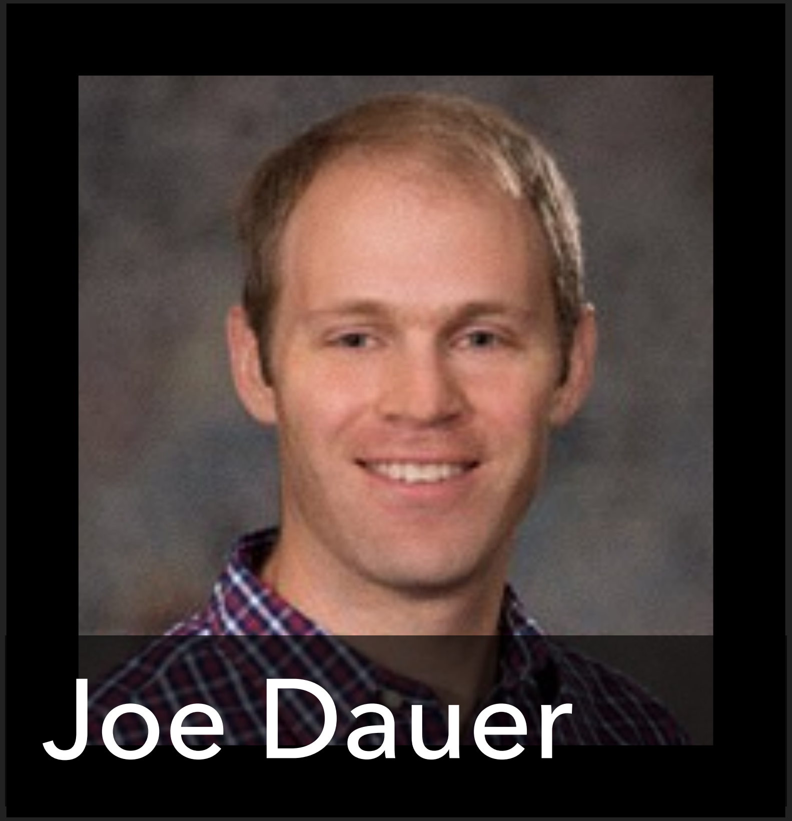
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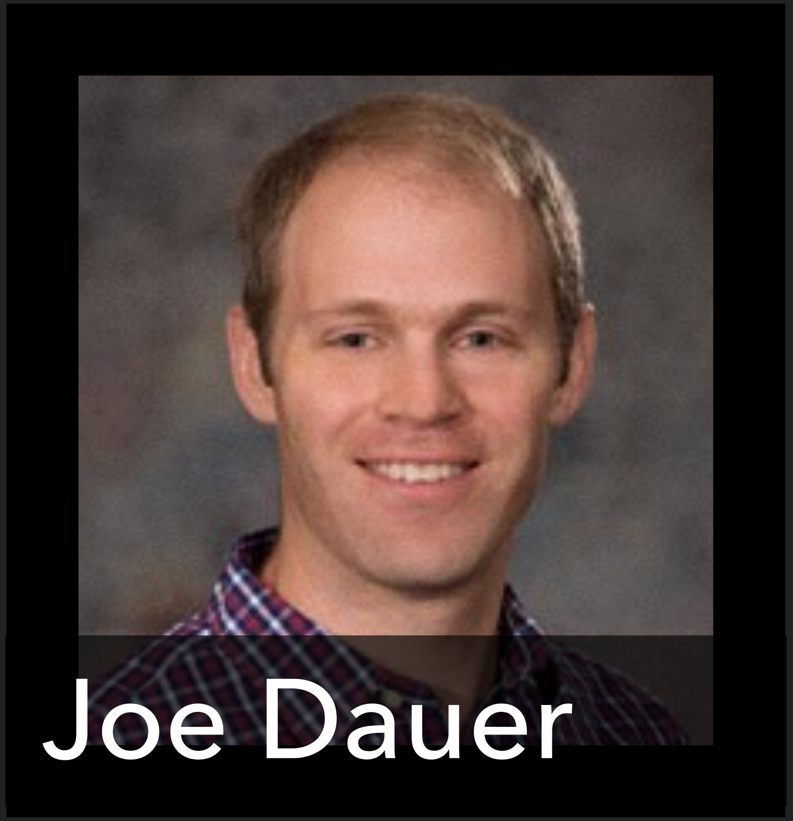
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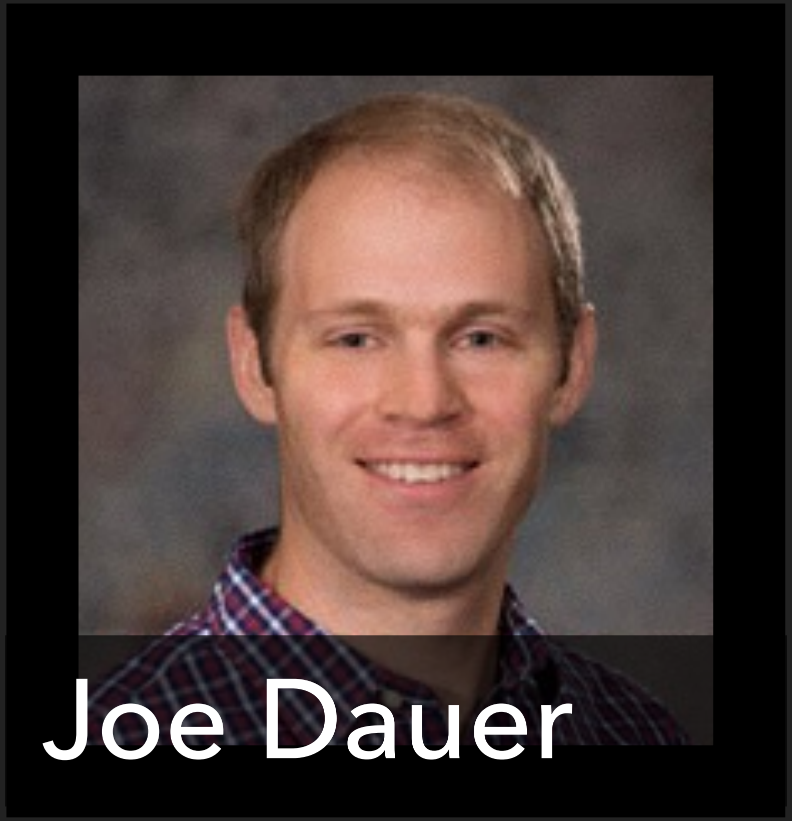

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# WHAT'S NEXT?

GAIMME

GUIDELINES FOR ASSESSMENT & INSTRUCTION
IN MATHEMATICAL MODELING EDUCATION

CONSORTIUM FOR MATHEMATICS AND
ITS APPLICATIONS (COMAP)

SOCIETY FOR INDUSTRIAL AND
APPLIED MATHEMATICS (SIAM)

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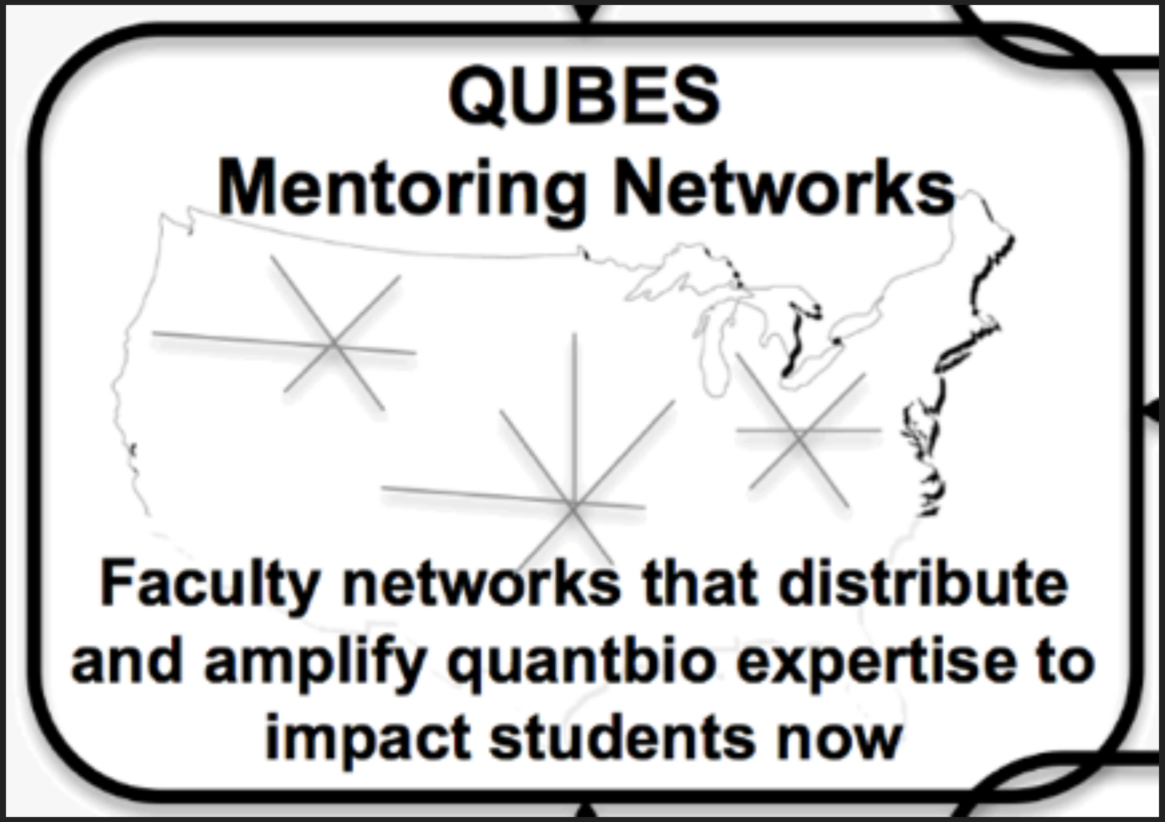
# WHAT'S NEXT?

QUBES

The Power of Biology × Math × Community



QUBES

Mentoring Networks

Faculty networks that distribute and amplify quantbio expertise to impact students now

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- Utilize QUBES community for professional development and dissemination

# NIMBIOS WORKING GROUP:  UNPACKING THE BLACK BOX

https://qubeshub.org/groups/nimbios_wg_teachingquantbio

- Kristin Jenkins
- Carrie Diaz Eaton
- Kam Dahlquist
- Hannah Callander
- Melissa Aikens
- Joseph Dauer
- Robert Mayes
- Ben Fitzpatrick
- Richard Schugart
- Joe Redish
- John Jungck
- Sam Donovan
- Gledd Ledder

**QUESTIONS?**