QUANTITATIVE BIOLOGY ASSESSMENT

QUBES
TEACHING QUANTITATIVE BIO WORKING GROUP

HHMI/BIOQUEST/QUBES WORKSHOP
JUNE 19-24, 2016

ROBERT MAYES - GEORGIA SOUTHERN UNIVERSITY

JOSEPH DAUER – UNIVERSITY OF NEBRASKA

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QUBES WORKING GROUP
(MARCH 24-26, 2016)

- Quantitative Reasoning – determined focus to be on modeling
- Commissioned two papers
  - PRIMUS paper submitted
  - Quantitative Modeling Framework Paper under development
- Quantitative Reasoning Pilot Study – Joe Dauer and Robert Mayes

QUBES WORKING GROUP: Kristen Jenkins, Sam Donovan, Drew LaMar, Carrie Diaz Eaton, Melissa Aikens, Hannah Callender, Kam Dahlquist, Joe Dauer, Joe Redish, Robert Mayes, Gerg Goins, and John Jungck

SHORT HISTORY

- NSF: **Culturally Relevant Ecology, Learning Progressions, and Environmental Literacy** (DUE-0832173) – John Moore PI
  - Develop a learning progression for environmental science for grades 6-12. identified progress variables as biodiversity, carbon cycle, and water cycle.
  - QR played support role for LP: What barriers does QR raise for the development of an environmentally literate citizen?
  - Developed QR aspects of the environmental Science teaching experiments

QR Framework identification of mathematical skills/concepts that underpin 6-12 environmental science

Quantification Act

- Variable Identification
  - Object
  - Attribute
  - Measure
- Communication
  - Force-dynamic
  - Scientific discourse
  - Quantitative discourse
- Context
  - Avoids QR
  - Computation Driven
  - Situative view
- Variation
  - Causation
  - Correlation
  - Covariation

Quantitative Literacy

- Numeracy
  - Number Sense
  - Small/large Numbers
  - Scientific Notation
  - Logic
- Measurement
  - Accuracy
  - Precision
  - Estimation
  - Units
- Proportional Reasoning
  - Fraction
  - Ratio
  - Percent
  - Rates/Change
  - Proportions
  - Dimensional Analysis
- Basic Prob/Stats
  - Empirical Prob.
  - Counting
  - Central tendency

Quantitative Interpretation

- Representations
  - Tables
  - Graphs/diagrams
  - Equations
    - Linear
    - Quadratic
    - Power
    - Exponential
  - Statistical displays
  - Translation
- Science diagrams
  - Complex systems
- Statistics & Probability
  - Randomness
  - Evaluating Risks
  - Normal Distribution
  - Statistical Plots
  - Correlation
  - Causality
  - Z-scores
  - Confidence Intervals
- Logarithmic Scales

Quantitative Modeling

- Logic
- Problem Solving
  - Problem Formulation
- Modeling
  - Normal Distribution
  - Regression Model
    - linear
    - polynomial
    - power
    - exponential
    - logarithmic
  - Logistic Growth Model
  - Multivariate Model
  - Simulation Model
  - Scientific Diagram
  - Table & Graph Models
- Inference
  - Inference
  - Hypothesis Testing
  - Practical Significance

WHY A LEARNING PROGRESSION FOR QR?

- STEM literate citizens require QR to make data-based informed decisions
  - qualitative discourse vs. quantitative discourse
- Interdisciplinary nature of grand challenges in environment vs. codified abstract school sequences
- NGSS & CCSS-M call for modeling emphasis
- Learning progression informs long term development of QR and role in interdisciplinary STEM education

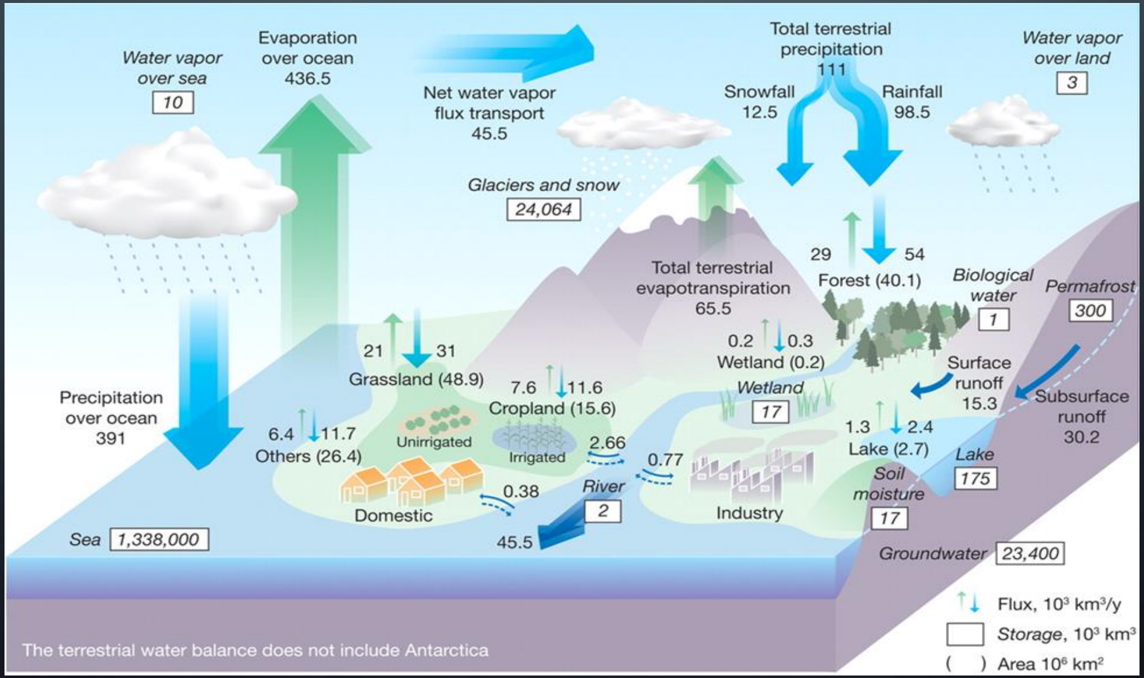
PATHWAYS QR TASK DEVELOPMENT

- QR learning progression within context of Environmental Science
  - Iterative research process where student data grounds learning progression
  - Hypothesized QR LP based on literature and prior research team QR project experience
- Qualitative Task Development: QR interviews developed that are driven by tasks embedded in real-world environmental science contexts
  - 3 science strands drive QR context:
    - QR Biodiversity, QR Carbon, QR Water
  - 4 reduced to 3 QR progress variables:
    - Quantitative Act, Quantitative Interpretation, Quantitative Modeling
  - 3 science scales:
    - macro scale, micro scale, landscape scale

THEORETICAL FRAMEWORK

- QR Definition (based on Delphi Study and literature)

  Quantitative reasoning is mathematics and statistics applied in real-life, authentic situations that impact an individual's life as a constructive, concerned, and reflective citizen. QR problems are context dependent, interdisciplinary, open-ended tasks that require critical thinking and the capacity to communicate a course of action.



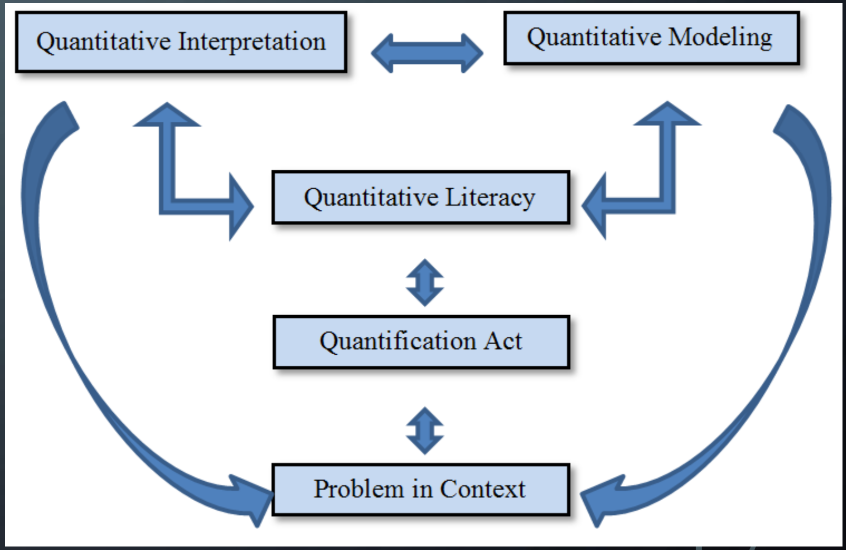
THEORETICAL FRAMEWORK

Quantification Act (QA): mathematical process of conceptualizing an object and an attribute of it so that the attribute has a unit measure, and the attribute's measure entails a proportional relationship (linear, bi-linear, or multi-linear) with its unit

Quantitative literacy (QL): use of fundamental mathematical concepts in sophisticated ways

Quantitative interpretation (QI): ability to use models to make predictions and discover trends, which is central to a person being a citizen scientist

Quantitative modeling (QM): ability to create representations to explain a phenomena



THEORETICAL FRAMEWORK

- Learning progressions are central to the theoretical framework
  - Duschl (2007) learning and curriculum designs should be organized around learning progressions as a means of supporting learners' development toward attaining the four proficiencies in science (know, use and interpret scientific explanations of the natural world; generate and evaluate scientific evidence and explanations; understand the nature and development of scientific knowledge; participate productively in scientific practices and discourse)
  - Corcoran, Mosher, & Rogat (2009) identified learning progressions as a promising model that can advance effective adaptive instruction teaching techniques and thereby change the norms of practice in schools

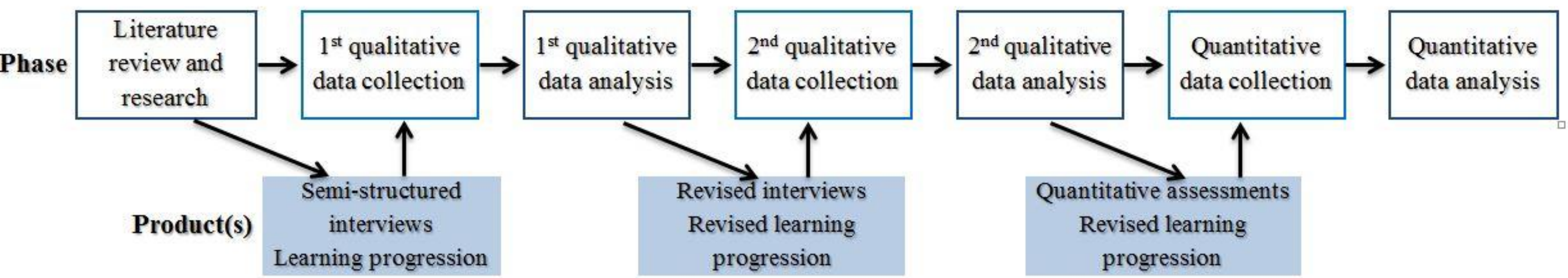
RESEARCH GOALS AND QUESTIONS

- Purpose: establish a learning progression for QR within the context of environmental science for middle and high school students
- Research questions.
  - Central research question: How do students develop QR in the context of environmental science across 6th–12th grade?
- Procedural questions :
  - What are the QR progress variables (dimensions of understanding, application, and practice) that support the development of an environmentally literate citizen?
  - What level of QR within the context of environmental science do students bring to the discourse at the sixth grade level?
  - What are the key QR conceptual stepping stones to moving from a novice to environmentally literate citizen? How do these inform a QR learning progression?

METHODS

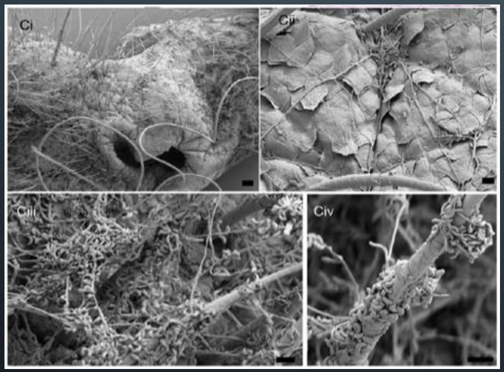
- Iterative research design
  - Creating learning progressions involves
    - Grounding the lower anchor
    - Identifying intermediate levels of understanding
    - Upper anchor based on expert views of what QR a scientifically literate citizen should know

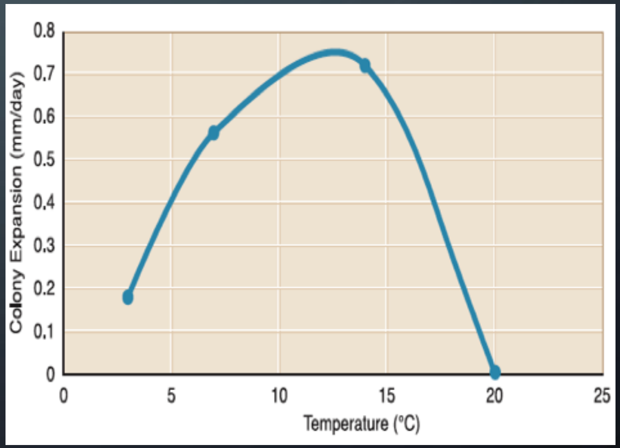
- Methods: First Iterative Cycle
  - 30-40 minute qualitative interviews (N=39 middle and high school students in STEM courses)
  - Grounded theory analysis, NVivo as tool
  - Descriptive statistics to determine trends across grade levels (6-12), science scales (Macro,Micro,Landscape), QR progress variables (QA, QI, QM) and QR process levels
- Revised LP and interviews, conducted second round of interviews (N=14) => Revision of LP and assessments



METHODS

- Second Iterative Cycle
  - Closed-form QR assessment items, 5-point Likert scale, 96 items total (24 per scale/8 per element)
  - Data collected in 3 states (N > 350)
  - Rasch model analysis conducted





PATHWAYS QI TASK DEVELOPMENT

- Quantitative Task Development: closed form QR assessment for science allowing survey of student learning trajectory for QR in science
  - Focus on Quantitative Interpretation (QI) progress variable of QR to support environmental literacy goal of Pathways
  - Quantitative Act (QA) incorporated as prerequisite to QI, but not focus of analysis
  - Tasks structured across 3 science strands, 3 scales, 4 levels of LP, and 4 elements of QI
  - Three versions: QI Biodiversity, QI Carbon, QI Water

PATHWAYS QI TASK

- Assessment Format
  - Qualtrics Online Survey
  - QA open response items: context passage with 3 questions
    - Identify quantitative objects within passage from a list
    - For selected object provide attributes
    - For selected object explain unit of measure
  - QI Lickert Scale Items with 5 options
    - Replicate for 3 scales: micro, macro, landscape
    - Across 4 QI elements: trend, translate, prediction, revision
    - Within each element 4 levels: novice to expert
    - Two questions per element per level
- 96 total Lickert scale items – 40% reversed

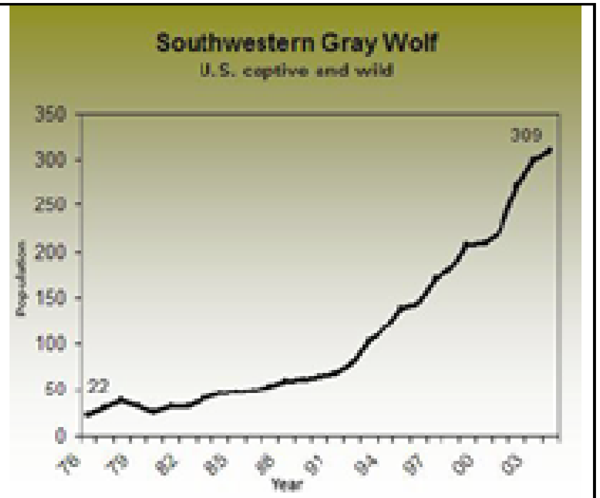
PATHWAYS QI TASK

Strand	Scale	Element	Level	Items
	Macro	TD-TS-PR-RV	LV 1-4	2 Items
Biodiversity	Micro	TD-TS-PR-RV	LV 1-4	2 items
	Landscape	TD-TS-PR-RV	LV 1-4	2 items
	Macro	TD-TS-PR-RV	LV 1-4	2 Items
Carbon	Micro	TD-TS-PR-RV	LV 1-4	2 items
	Landscape	TD-TS-PR-RV	LV 1-4	2 items
	Macro	TD-TS-PR-RV	LV 1-4	2 Items
Water	Micro	TD-TS-PR-RV	LV 1-4	2 items
	Landscape	TD-TS-PR-RV	LV 1-4	2 items

Exemplar: QI Biodiversity Assessment

Biodiversity Context - Macro Scale: The following is a table and graph of the Southwestern Gray Wolf, which is an endangered population.

Year	Number of Wolves
1976	22
1979	46
1982	30
1985	50
1988	54
1991	65
1994	103
1997	138
2000	212
2003	309



Prediction Element: Rate the statements below from very strongly disagree (1) to very strongly agree (5) on how well they match your understanding of predicting future events.

1.	Since the graph only provides information for up to 2005, one cannot make predictions of wolf population beyond the given data. **(Prediction 1b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
2.	I am not sure how one can make predictions for future events from either of the representations. **(Prediction 1b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
3.	The population is at 309 and increasing so there will be more wolves. **(Prediction 2b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
4.	Based on the wolf population trend one would predict the population remains at 309. **(Prediction 2b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
5.	As time passes the number of wolves is increasing, so there will be more wolves in 2013. **(Prediction 3b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
6.	Time and number of wolves are both increasing together, so before 1976 there were more than 20 wolves. **(Prediction 3b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
7.	One could extend the nonlinear trend of the data off the end of the graph, then estimate the year and number of wolves on the curve. **(Prediction 4b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree
8.	To predict the number of wolves in 2013 substitute 37 for year in the equation modeling the data, then solve for number of wolves. **(Prediction 4b)**	Very strongly disagree	1 2 3 4 5	Very strongly agree

RESULTS - INTERVIEWS

- Sample distribution across grades for overall QR, QA, QI, and QM

Table 1. QR by grade

Grade	Number of students	Total QR mean	QA mean	QI mean	QM mean
6	3	1.75	1.78	1.78	1.50
7	7	1.77	1.90	1.67	1.00
8	12	2.01	2.08	2.06	1.33
9	4	2.22	2.25	2.17	2.33
10	3	2.08	2.11	2.00	–
11	7	1.96	1.90	2.05	1.75
12	3	1.67	1.78	1.78	1.00
Cor[a]		0.076	0.012	0.294	0.026

[a]Correlation between grade level and QR processes.

RESULTS - INTERVIEWS

- 39 students ranked from level 1 (lower anchor-novice) to level 4 (upper anchor-expert)
- ANOVA on QR x Science Scale: no significant difference

Table 2. Overall learning progression rankings

Ranking	Macro-scale			Landscape scale			Micro/atomic scale			
QR level	QA	QI	QM	QA	QI	QM	QA	QI	QM	Total
1	5	9	7	6	5	3	7	9	0	51
2	28	27	6	28	24	2	26	26	0	167
3	6	3	1	5	10	0	6	4	0	35
4	0	0	0	0	0	0	0	0	0	0
NE/NA	0	0	25	0	0	34	0	0	39	98

QA, quantification act; QI, quantitative interpretation; QM, quantitative modeling.

RESULTS - INTERVIEWS

- Qualitative Interview Analysis
  - Trajectory issue: no consistent increase in learning progression levels across grade levels
  - Scaling issue: no consistent differences in QR use on the micro/atomic, macro and landscape-scale
  - Tool implementation issue: failed to select the appropriate mathematical or statistical tool from their toolbox, and even when the correct tool was selected they failed to use QR to apply the tool within the science context

RESULTS ASSESSMENT

- Rasch Analysis of Assessment
  - Analysis of items indicates which items were problematic (difficult item, poorly constructed item, miscoded item)
  - Analysis of persons allows removal of students not completing the assessment as intended (student answers are to predictable)
  - Analysis of persons x items allows improvement of instrument as well as results of students by scale (macro, micro, landscape scale), by strand (biodiversity, carbon, water) and by QI element (trend, translation, revise, predict)

RASCH ANALYSIS OF TASK

- Rasch Analysis conducted on data collected from pilot with 362 students in 3 states
- Assessment length concern: some students were fatigued and did not complete assessment with fidelity

Table 1: Rasch Iteration 2 – Number of Measured Persons

	Biodiversity	Carbon	Water
Rasch Iteration 1	122	114	126
Rasch Iteration 2	99	89	98

RASCH ANALYSIS OF TASK

- Item difficulty did not behave as expected
  - Item level difficulty mixed (Level 4 not hardest)
  - Reversed items more difficult
  - Overall person distribution higher than item distribution, indicating mismatch

Table 4: Expected Item Challenge Level by Empirical Performance Difficulty Level

Expected Item Challenge Level	Biodiversity Assessment				Carbon Assessment				Water Assessment			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Level 4	3	7	9	5	3	7	13	1	2	8	10	4
Level 3	5	3	6	10	8	4	10	2	3	9	9	3
Level 2	4	5	7	8	4	3	9	8	5	4	9	6
Level 1	11	6	4	3	6	7	5	6	7	6	6	5
TOTAL	23	21	26	26	21	21	37	17	17	27	34	18

RASCH RULER: QR BIODIVERSITY

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MEASURE
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EACH "X" IS 2. EACH "." IS 1.
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SCALE VARIABLE

Table 5: Scale by Empirical Performance Difficulty Level

Scale	Biodiversity Assessment				Carbon Assessment				Water Assessment			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Macro	13	4	7	8	10	7	11	4	9	9	8	6
Micro	5	8	9	10	9	8	10	5	6	8	14	4
Landscape	5	9	10	8	2	6	16	8	2	10	12	8
TOTAL	23	21	26	26	21	21	37	17	17	27	34	18

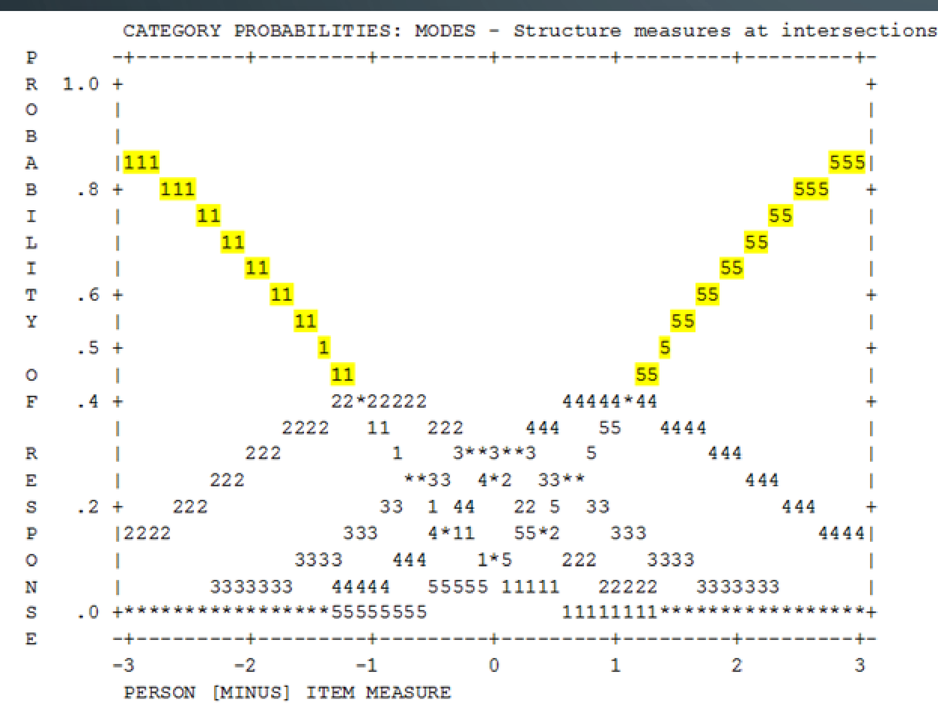
ELEMENTS VARIABLE

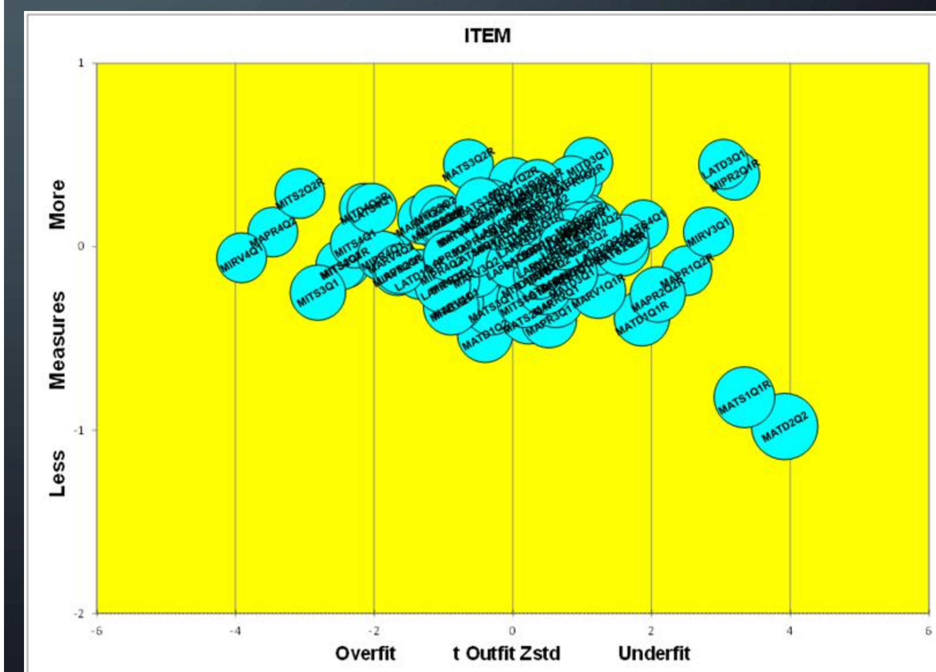
Table 6: Elements by Empirical Performance Difficulty Level

Element	Biodiversity Assessment				Carbon Assessment				Water Assessment			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Trend	8	2	3	11	9	1	11	3	7	5	7	5
Translation	7	5	6	6	2	6	12	4	5	6	9	4
Prediction	6	8	6	4	6	9	7	2	2	5	12	5
Revision	2	6	11	5	4	5	7	8	3	11	6	4
TOTAL	23	21	26	26	21	21	37	17	17	27	34	18

RASCH ANALYSIS OF TASK

- Lickert scale of 5 not distinct
  - Reduce scale to 4 levels
- Underfit, overfit, and misfit items and persons may indicate confounding of scale, element, and level

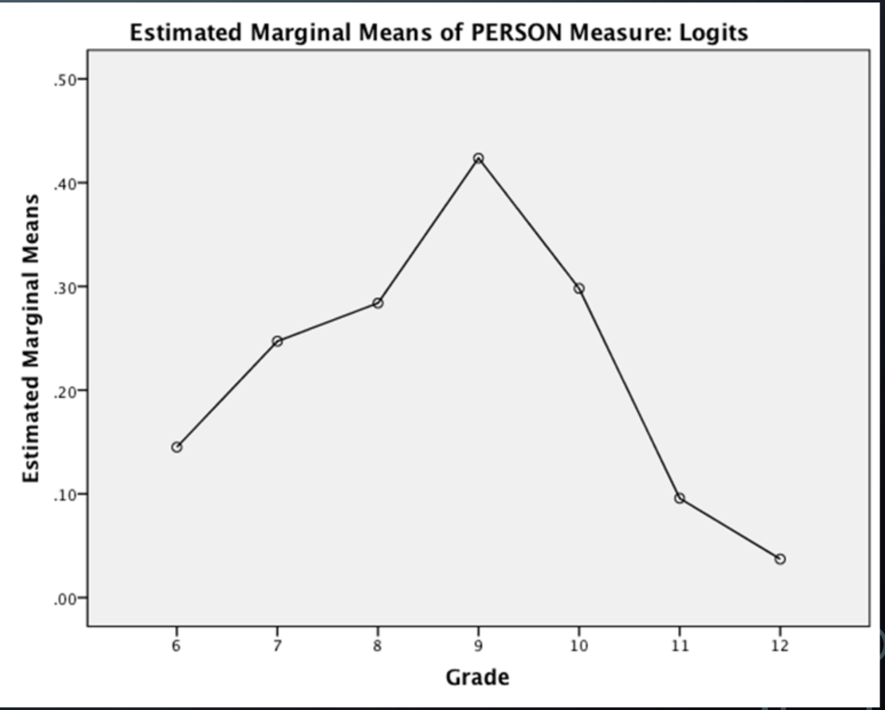




RASCH ANALYSIS OF TASK

- QR trajectory across grade for Rasch supported interview findings
  - QR scores increase from grade 6 to 8 or 9, then decrease from grade 9 to 12

Due to proximity of arithmetic methods and environmental science exposure with middle school grades?



DISCUSSION

- Implications for teaching
  - engage in real-world problem-based learning
  - require students to provide quantitative as well as qualitative support for their arguments
  - provide multiple quantitative representations (tables, graphs, equations, science models) within a science context and use QR to provide data-based informed decisions about critical issues that impact their place
  - engage in building their own models representing these issues, then test and refine those models

DISCUSSION

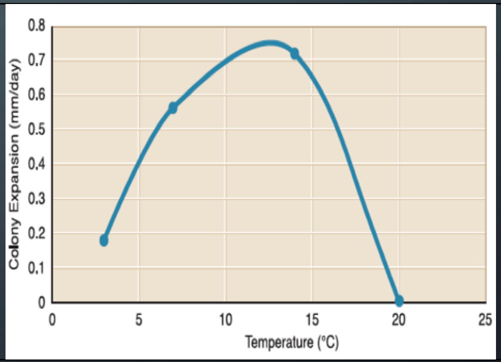
- QR Learning Progression
  - QA progress variable is the trigger for QR: student first quantifies an object within a context, allowing them to operate on that quantity using the arithmetic processes within quantitative literacy
    - Elements of QA: Variation, QL, Context, Variable
  - QI progress variable is the ability to interpret a model provided to the student
    - Elements of QI: Trends, Predictions, Translation, Revision
  - QM progress variable is creation of the model by the student
    - Elements of QM: Create model, Refine Model, Model Reasoning, Statistical
    - EXEMPLAR: Revised assessment given to small sample of students in Real STEM project Spring 2015

REVISED QI – MICRO SCALE

Version QI - **Micro Scale**

White Nose Syndrome (WNS) is currently found in cave hibernating bats, where 70-100% of bats in caves showing symptoms will die. A new fungus causing WNS is called *Geomyces destructans* (see picture of fungus). It is a cold tolerant fungus and species in this genus are found worldwide. Scientists believe that the fungus is transferred from cave to cave through human activity and natural bat movements. The table and graph below are representations of colony expansion of *Geomyces destructans* (millimeters per day) and temperature.

Temp.	Expan.		Temp.	Expan.
3	0.175		12	0.75
4	0.3		13	0.74
5	0.41		14	0.71
6	0.5		15	0.65
7	0.55		16	0.55
8	0.61		17	0.42
9	0.66		18	0.28
10	0.7		19	0.15
11	0.71		20	0



TREND QUESTIONS

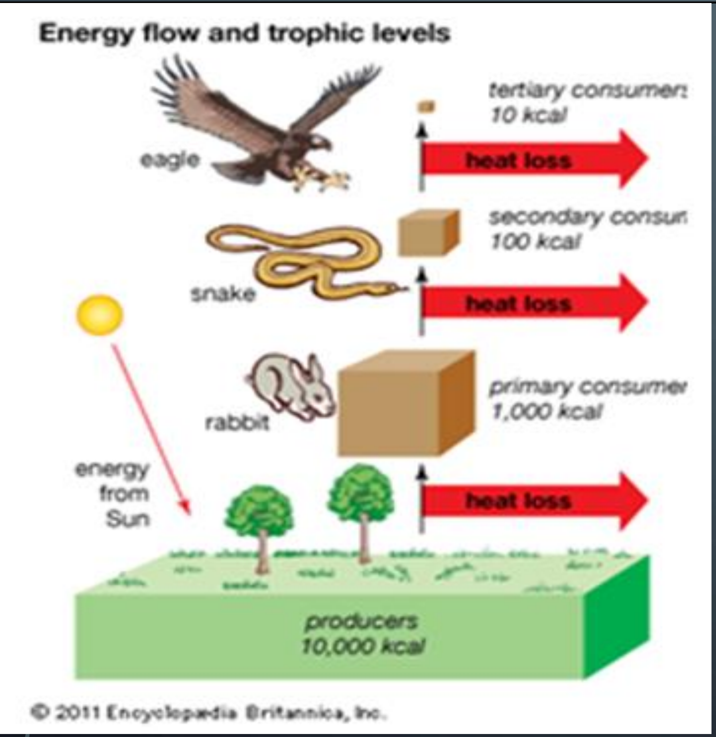
A. Rate the statements below from very strongly disagree (1) to very strongly agree (4) on how well they match your interpretation of the trend depicted in the graph and table. **(QI Trends 1a-4a)**

1.	Table and graphs provide specific values, but trends cannot be determined from this table or graph. **(Trend 1a)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**
2.	The colony expands at first. **(Trend 2a)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**
3.	Between the temperatures of 15 degrees and 20 degrees Celsius the colony expansion is decreasing at a rate that is constant or linear. **(Trend 3a)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**
4.	After 15 degrees Celsius the trend is linear with a slope of -0.13 which indicates every 1 degree Celsius drop in temperature the colony expansion slows 0.13 millimeters. **(Trend 4a)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**

REVISED QI - LANDSCAPE

Version QI - **Landscape Scale**

Plants and animals depend on each other for the survival of their species. Use the box model of energy flow within the food chain to answer the following questions.



Box Model

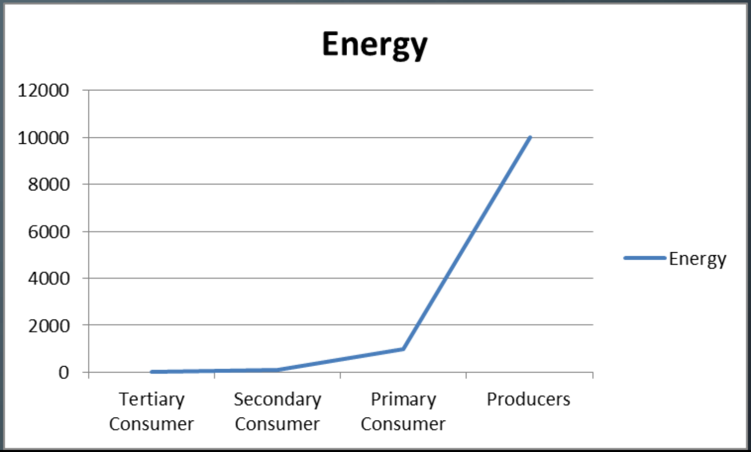
Trophic Level	Energy
Tertiary Consumer Level 3	10 kcal
Secondary Consumer Level 2	100 kcal
Primary Consumer Level 1	1,000 kcal
Producers Level 0	10,000 kcal

B. Below are different possible representations of the data table on model of energy flow. Rate the statements below from very strongly disagree (1) to very strongly agree (4) on how well they match your understanding of the representations. **(QI Translation 1b-4b)**

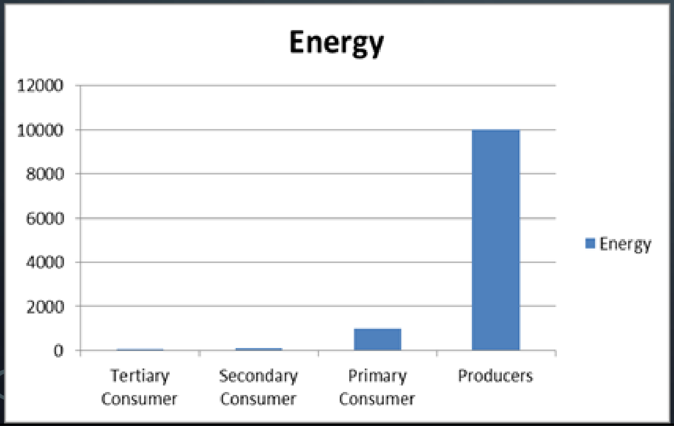
1. Data Table

Trophic Level	Energy
Tertiary Consumer Level 3	10 kcal
Secondary Consumer Level 2	100 kcal
Primary Consumer Level 1	1,000 kcal
Producers Level 0	10,000 kcal

2. Connected Scatter Plot



3. Statistical Display – Bar Chart



4. Equation Models

Linear: $y = -3087x + 7408$
Quadratic: $y = 2227x^2 - 9770x + 9636$
Power: $y = 1156\,x^{-4.1}$
Exponential: $y = 10000 \cdot 0.1^x$

TRANSLATION QUESTIONS

1.	There can only be one correct representation for the data, so the bar chart and connected scatter plot are representations of two different ecosystems. **(Translation 1b)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**
2.	I can select any of the representations, but would not use two different representations because you cannot translate between them. **(Translation 2b)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**
3.	The representations are of energy flow in different systems, such as a mountain ecosystem versus a desert ecosystem. **(Translation 3b)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**
4.	The exponential model provides estimates for values between trophic levels, which is not of use since we are only interested in the specific values at the trophic levels. **(Translation 4b)**	**Very strongly disagree**	**1 2 3 4**	**Very strongly agree**

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 4 (Upper Anchor)	**4a** Variation: reasons about covariation of 2 or more variables; comparing, contrasting, relating variables in the context of problem **4b** Quantitative Literacy: reasons with quantities to explain relationships between variables; proportional reasoning, numerical reasoning; extend to algebraic and higher math reasoning (MAA) **4c** Context: situative view of QR within a community of practice (Shavelson); solves ill-defined problems in socio-political contexts using ad-hoc methods; informal reasoning within science context (Steen & Madison; Sadler & Zeidler) **4d** Variable: mental construct for object within context including both attributes and measure (Thompson); capacity to communicate quantitative account of solution, decision, course of action within context	**4a** Trends: determine multiple types of trends including linear, power, and exponential trends; recognize and provide quantitative explanations of trends in model representation within context of problem **4b** Predictions: makes predictions using covariation and provides a quantitative account which is applied within context of problem **4c** Translation: translates between models; challenges quantitative variation between models as estimates or due to measurement error; identifies best model representing a context **4d** Revision: revise models theoretically without data, evaluate competing models for possible combination (Schwarz)	**4a** Create Model: ability to create a model representing a context and apply it within context; use variety of quantitative methods to construct model including least squares, linearization, normal distribution, logarithmic, logistic growth, multivariate, simulation models **4b** Refine Model: extend model to new situation; test and refine a model for internal consistency and coherence to evaluate scientific evidence, explanations, and results; (Duschl) **4c** Model Reasoning: construct and use models spontaneously to assist own thinking, predict behavior in real-world, generate new questions about phenomena (Schwarz) **4d** Statistical: conduct statistical inference to test hypothesis (Duschl)

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 3	**3a** Variation: recognizes correlation between two variables without assuming causation, but provides a qualitative or isolated case account; lacks covariation **3b** Quantitative Literacy: manipulates quantities to discover relationships; applies measure, numeracy, proportions, descriptive statistics **3c** Context: display confidence with and cultural appreciation of mathematics within context; practical computation skills within context (Steen); lacks situative view **3d** Variable: object within context is conceptualized so that the object has attributes, but weak measure (Thompson); capacity to communicate qualitative account of solution, decision, course of action within context, but weak quantitative account	**3a** Trends: recognize difference between linear vs. curvilinear growth; discuss both variables, providing a quantitative account **3b** Predictions: makes predictions based on two variables, but relies on qualitative account; uses correlation but not covariation. **3c** Translation: attempts to translate between models but struggles with comparison of quantitative elements; questions quantitative differences between models but provides erroneous qualitative accounts for differences **3d** Revision: revise model to better fit evidence and improve explanatory power (Schwarz)	**3a** Create Model: create models for covariation situations that lack quantitative accounts; struggle to apply model within context or provide quantitative account **3b** Refine Model: extend model based on supposition about data; do not fully verify fit to new situation **3c** Model Reasoning: construct and use multiple models to explain phenomena, view models as tools supporting thinking, consider alternatives in constructing models (Schwarz) **3d** Statistical: use descriptive statistics for central tendency and variation; make informal comparisons to address hypothesis

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 2	**2a** Variation: sees dependence in relationship between two variables, provides only a qualitative account; lacks correlation, erroneously assumes causation **2b** Quantitative Literacy: poor arithmetic ability interferes with manipulation of variables; struggle to compare or operate with variables **2c** Context: lack confidence with or cultural appreciation of math within context; practical computation skills are not related to context **2d** Variable: object within context is identified, but not fully conceptualized with attributes that are measurable; fails to communicate solution, decision, course of action within context; qualitative account without quantitative elements (Thompson)	**2a** Trends: identify and explain single case in model; recognize increasing/ decreasing trends but rely on qualitative account or change in only one variable **2b** Predictions: makes predictions for models based on only one variable, provides only qualitative arguments supporting prediction **2c** Translation: indicate preference for one model over another but do not translate between models ; acknowledge quantitative differences in models but do not compare **2d** Revision: revise model based on authority rather than evidence, modify to improve clarity not explanatory power (Schwarz)	**2a** Create Model: constructs a table or data plot to organize two dimensional data ;create visual models to represent single variable data, such as statistical displays (pie charts, histograms) **2b** Refine Model: extends a given model to account for dynamic change in model parameters; provides only a qualitative account **2c** Model Reasoning: construct and use model to explain phenomena, means of communication rather than support for own thinking (Schwarz) **2d** Statistical: calculates descriptive statistics for central tendency and variation but does not use to make informal comparisons to address hypothesis

Achievement Level	QR Progress Variable		
	Quantification Act	**Quantitative Interpretation**	**Quantitative Modeling**
Level 1 (Lower Anchor)	**1a** Variation: does not compare variables; works with only one variable when discussing trends, **1b** Quantitative Literacy: fails to manipulate and calculate with variables to answer questions of change, discover patterns, and draw conclusions; **1c** Context: does not relate quantities to context or exhibit computational skills **1d** Variable, fail to relate model to context by identifying objects no attempt to conceptualize attributes that are measurable; discourse is force-dynamic; avoids quantitative account, provides weak qualitative account	**1a** Trends: do not identify trends in models **1b** Predictions: avoids making predictions from models **1c** Translation: fail to acknowledge two models can represent the same context **1d** Revision: view models as fixed, test to see if good or bad replicas of phenomena (Schwarz)	**1a** Create Model: does not view science as model building and refining so does not attempt to construct models **1b** Refine Model: accepts authority of model, does not see as needing refinement **1c** Model Reasoning: construct and use models that are literal illustrations, model demonstrates for others not tool to generate new knowledge (Schwarz) **1d** Statistical: does not use statistics; no calculation of even descriptive statistics

Pathways QR Research Team:

Robert Mayes – Georgia Southern University

Jennifer Harris Forrester – University of Wyoming

Jennifer Schuttlefield Christus – University of Wisconsin Oshkosh

Franziska Peterson – University of Wyoming

Rachel Bonilla – Georgia Southern University

Nissa Yestness – Colorado State University

QUBES RESEARCH (MAYES AND DAUER)

- Revise Pathways Project QI survey for undergraduate biology.
- Pilot short survey – incorporate into Spring 2016 Final in two University of Nebraska Biology courses
  - Population Dynamics – Dr. Drew Tyre (N = 32)
  - Introductory Biology – Dr. Joe Dauer (N = 89)

QUBES RESEARCH SURVEY DEVELOPMENT

- QI to QM focus, not QL: want modeling focus, but difficult with closed-form questions
- QA limited, but good QI and QM requires this as first step – included a question on QA
- QI items revised from Likert to multiple choice – move from combined belief-ability to ability
- QM assessed around existing projects – included Likert and open response questions around projects embedded in their class. Want to assess impact of QR innovations

QUBES RESEARCH SURVEY DEVELOPMENT

- Reviewed some existing QR Biology Measures
  - So much to measure and so little time – need to make choices
- BioSquare Modeling Assessment
  - QA focus in 10 of 29 items
  - QI trend focus in 18 of 29 items, some translation, one prediction
  - Great variety in model representations
  - QM 8 items that elicit aspects of modeling

QUBES RESEARCH SURVEY DEVELOPMENT

- Reviewed existing QR Biology Measures
  - So much to measure and so little time – need to make choices
- UBC Population Dynamics Inventory
  - QA focus in 15 of 17 items, implicit in all 17 items
  - QI is strong with 14 of 17 graphic representations, 3 table representations, 2 algebraic representations (lines of best fit)
  - QI primarily trend – 16 0f 17, 3 involved translation, and 3 involved prediction, none required revision
  - QM not directly measured, but 10 questions do require selecting a model from a given set of items, could engage students in creating model of own then comparing

QUBES SURVEY

- QA –
- Variable
- Measure
- Attribute

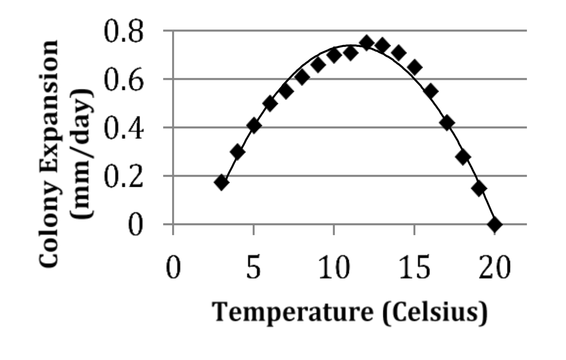
White Nose Syndrome (WNS) is currently found in cave hibernating bats, where 70-100% of bats in caves showing symptoms will die. A new fungus causing WNS is called *Geomyces destructans.* It is a cold tolerant fungus. Scientists believe that the fungus is transferred from cave to cave through human activity and natural bat movements.

The fungus population grows temporally (once in a cave, its abundance increases) and spatially (reaching new caves).

1. A scientist interested in modeling the growth of this fungus would focus on (QA Variable-Variation):
   a. Variation of bat deaths over time in years
   b. Variation of time in days over cold tolerant fungus species
   c. Variation of fungus growth in millimeters over time in days
   d. Amount of area covered by the fungus on a given day
   e. Variation in fungus growth in millimeters to temperature in celsius

The table and graph below are representations of colony expansion of *Geomyces destructans* (millimeters per day) and temperature.

Temp (°C)	Expansion (mm/day)		Temp (°C)	Expansion (mm/day)
3	0.175		12	0.75
4	0.3		13	0.74
5	0.41		14	0.71
6	0.5		15	0.65
7	0.55		16	0.55
8	0.61		17	0.42
9	0.66		18	0.28
10	0.7		19	0.15
11	0.71		20	0



QUBES SURVEY

- QI –
- Trends

2. What trends in fungus growth can be determined from the table and graph?
   a. No trend can be determined
   b. Colony grows to 0.75 mm and then declines in size
   c. As temperature increases from 12 Celsius to 19 Celsius the colony expansion is linear
   d. Colony expansion increases to 0.75 mm/day up through 12 Celsius, then slows in growth
   e. Colony expands by increasing rates through 12 Celsius, then decreases in size between 12 and 20 Celsius.

QUBES SURVEY

- QI –
- Translation

3. The quadratic model for the rate of colony expansion c by time t is $c = -0.009t^2 + 0.201t - 0.379$. At 10 degrees Celsius the quadratic model gives a rate of colony expansion of 0.731 mm/day. The scientists notice a discrepancy between this value and that in the data table. How do you explain the discrepancy?

a. The table and quadratic model represent different caves
b. The table provides the exact value so quadratic model is wrong
c. The quadratic model is a better reflection of actual changes, so there was an error in gathering the data
d. The table and quadratic model represent different times when data were collected
e. The quadratic model provides an estimate to the data in the table and difference is due to this estimate

QUBES SURVEY

- QI –
- Predict

4. Predict the colony expansion for a temperature of 22 degrees Celsius.
   a. Data was only collected for 0 to 20 degrees, so you cannot make a prediction
   b. The temperature is getting warmer
   c. The colony expansion was decreasing after 12 Celsius so likely will continue to decrease but can determine how much
   d. After 12 Celsius as temperature increases the colony size decreases to 0
   e. After 17 Celsius as temperature increases the colony expansion decreases by a rate of about -0.15 per degree, so the colony would be contracting at -0.30 per degree.

QUBES SURVEY

- QI –
- Revise

5. Biologists determined that in some regions of the country, colony expansion is much faster than the observed data in this study. The equation for the curve in the current study is $y = -0.0091x^2 + 0.2014x - 0.3791$. For the faster fungal growth rates

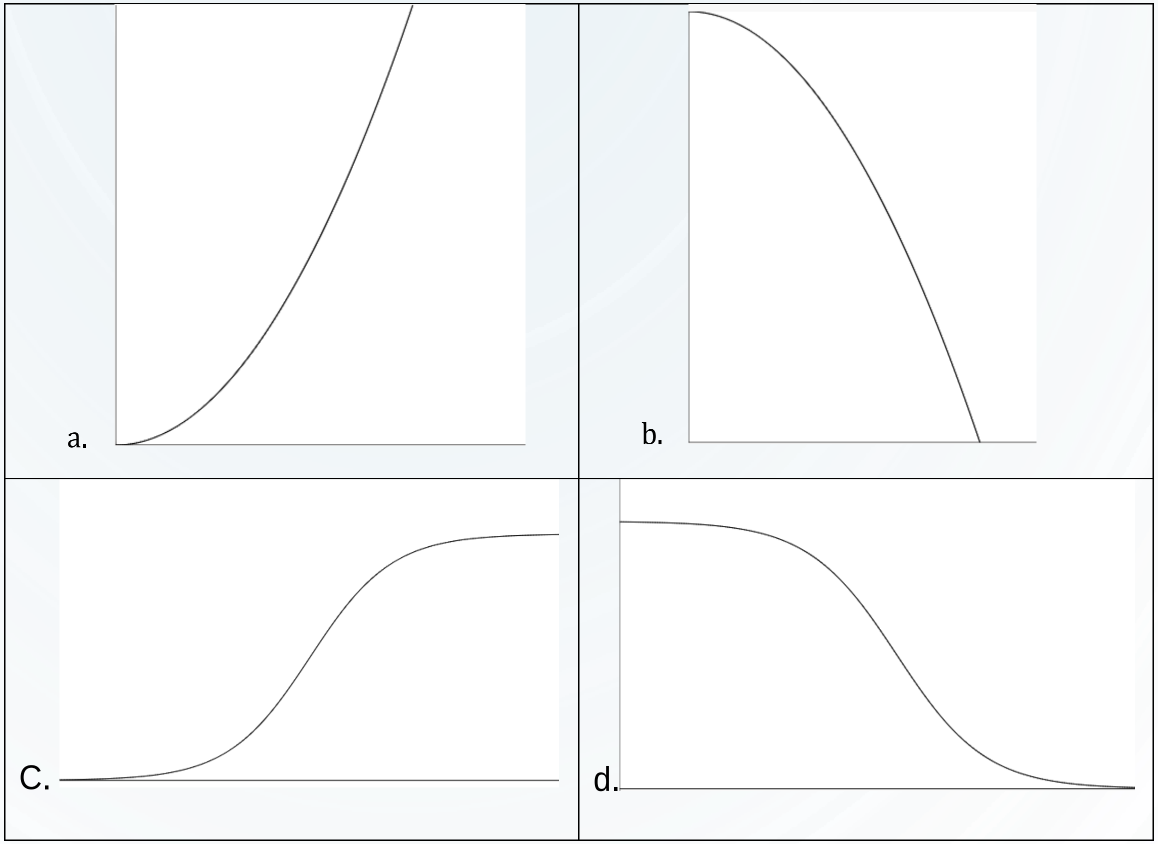
a. The constant value of -0.379 would be larger
b. The linear coefficient of 0.2014 would be smaller
c. The linear coefficient of 0.2014 would be larger
d. The quadratic coefficient of -0.0091 would change to be positive
e. The quadratic coefficient of -0.0091 would be larger

QUBES SURVEY

- QM –
- Algebraic "Best-fit" Model

6. White Nose Syndrome (WNS) is currently found in cave hibernating bats, where 70-100% of bats in caves showing symptoms will die. A new fungus causing WNS is called *Geomyces destructans.* It is a cold tolerant fungus. Scientists believe that the fungus is transferred from cave to cave through human activity and natural bat movements.

The fungus population grows temporally (once in a cave, its abundance increases) and spatially (reaching new caves). If the cave temperature is relatively constant at 12 degrees Celsius, which graph below best models how the bat population would change over time?



QUBES SURVEY

- QM –
- Likert Items
- Confidence level
- 7 questions with sub-questions

Relative to your class project, rate your level of confidence for each question below. If a question is not relevant to your class project, select N/A.

7. Working from verbal descriptions of the problem, I was able to determine the variables needed for the model, identifying both characteristics of the variables that assisted in seeing how they were related and measures for the variables.

N/A	Very Strongly Disagree			Very Strongly Agree
	1	2	3	4

7a. Select one of the variables from your model and provide information on important characteristics and measure

7b. Provide a brief explanation of the covariation of 2 variables in your model (covariation is how the variables change with respect to one another, it allows you to compare, contrast, and build relationships between the variables).

QUBES SURVEY – MODELING PROJECT OPEN QUESTIONS

8. I developed a hypothesis that my model tested.

9. I was comfortable using statistics in development and testing of model in the following ways.

   a. Use descriptive statistics to determine center and spread.
   b. Make informal comparisons using descriptive statistics to support arguments that there was a potential change or difference related to a hypothesis.
   c. Conduct a formal statistical test to determine significance of a hypothesis.
   d. Provide the hypothesis you tested and a brief discussion of any statistical analysis you conducted.

QUBES SURVEY – MODELING PROJECT OPEN QUESTIONS

10. I was comfortable creating a model, reasoning with the model, and refining the model in the following ways.

   a. I was able to create a model representing the problem
   b. I was able to reason with the model to improve my understanding of the problem, predict behavior in the real-world, and generate new questions.
   c. I refined my model to extend it to a new situation, to improve consistency and coherence of explanations and results.
   d. Provide your model and briefly discuss how you applied the model to the problem you were studying

QUBES SURVEY – MODELING PROJECT OPEN QUESTIONS

11. I was able to make a prediction (biological or mathematical) from an equation.

12. I was able to determine trends in the data and defend them using biological and mathematical arguments.

13. I translated between more than one model of the problem, identifying the best model to use or exploring differences in the models.

QUBES QR SURVEY PILOT FINDINGS

Question	Drew	Joe
Q1 QA Variable	34%	NA
Q2 QI Trends	63%	53%
Q3 QI Translation	91%	NA
Q4 QI Prediction	38%	43%
Q5 QI Revise	22%	na
Q6 QI-QM Model	44%	61%

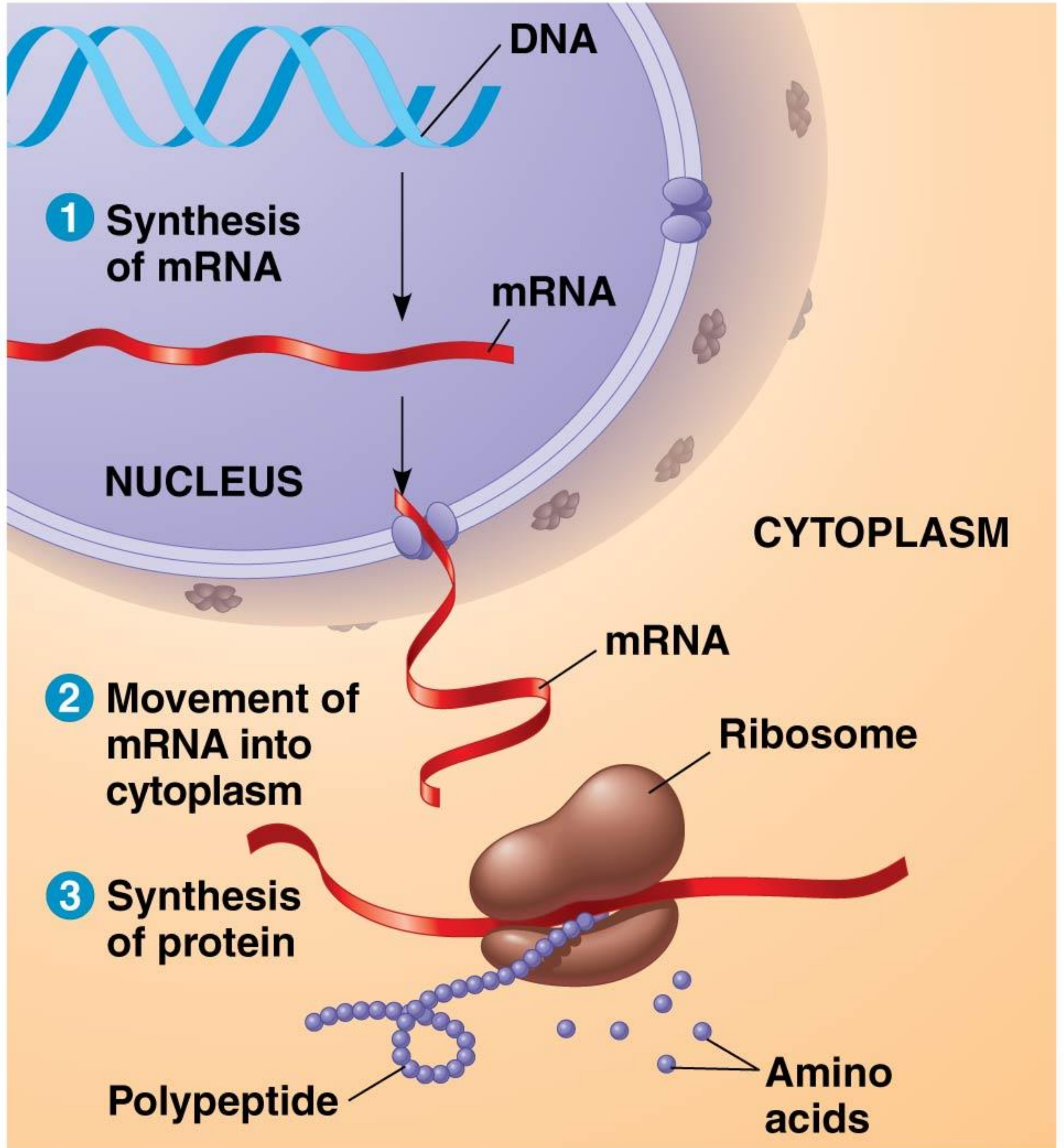
QUBES QR SURVEY PILOT FINDINGS

	Q7	Q8	Q9a	Q9b	Q9c	Q10a	Q10b	Q10C	Q11	Q12	Q13
QR Area	QA	QM Hypot	QL StatsD	QMS Comp	QMS StatsT	QM Create	QM Reasn	QI Refine	QI Predct	QI Trend	QI Trans
Trend	+	0	+	+	-	+	+	0	+	+	0

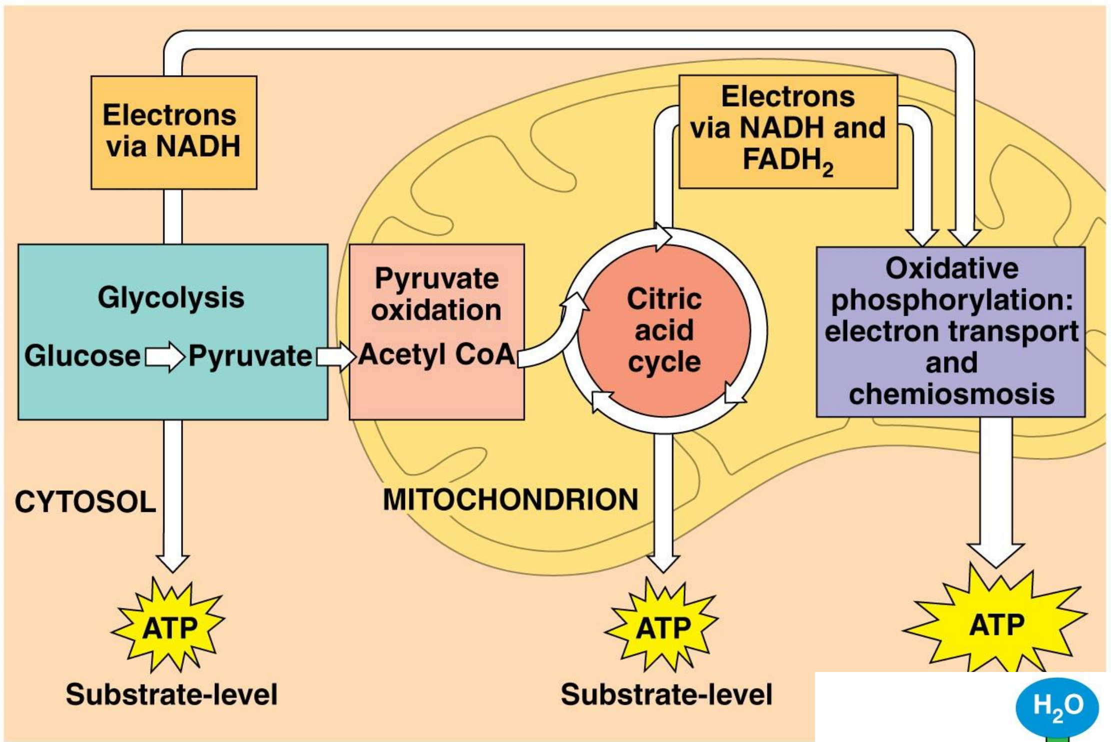
NOTE: N = 15, trend refers to skew in distribution not significance

JOE'S MODELING PROBLEMS

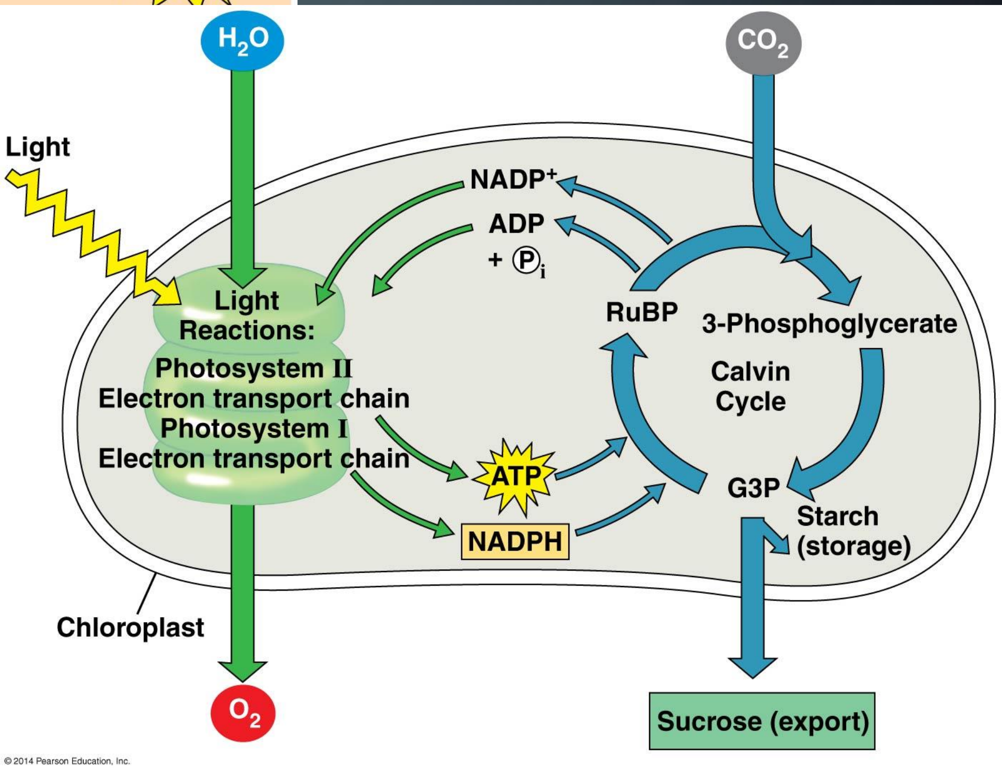
- White-nose syndrome in bats was context used in pilot
- Considering other modeling problems used by Joe in his classes as context for next version of survey



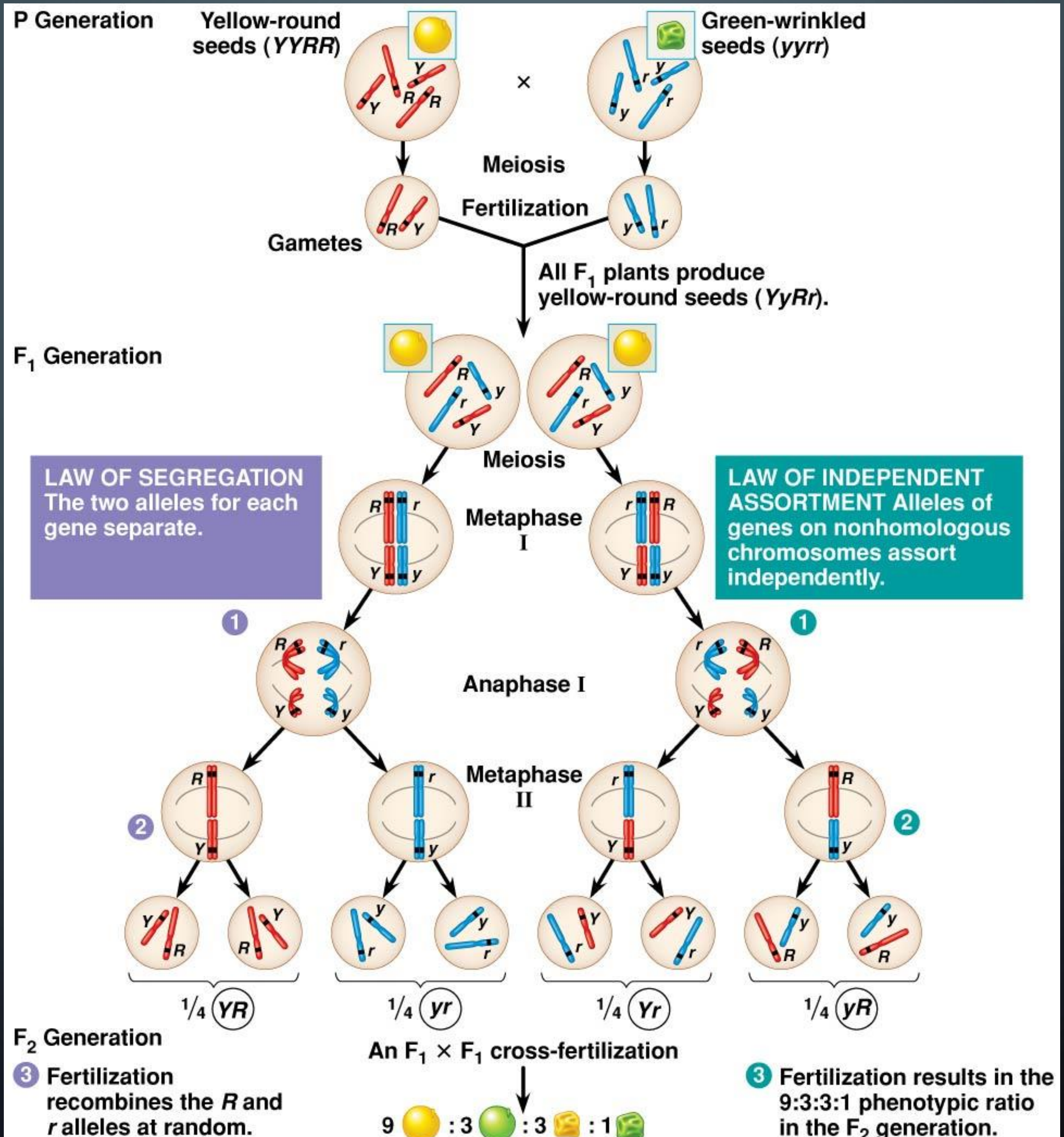
DNA
1 Synthesis of mRNA
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm
Ribosome
3 Synthesis of protein
Polypeptide
Amino acids



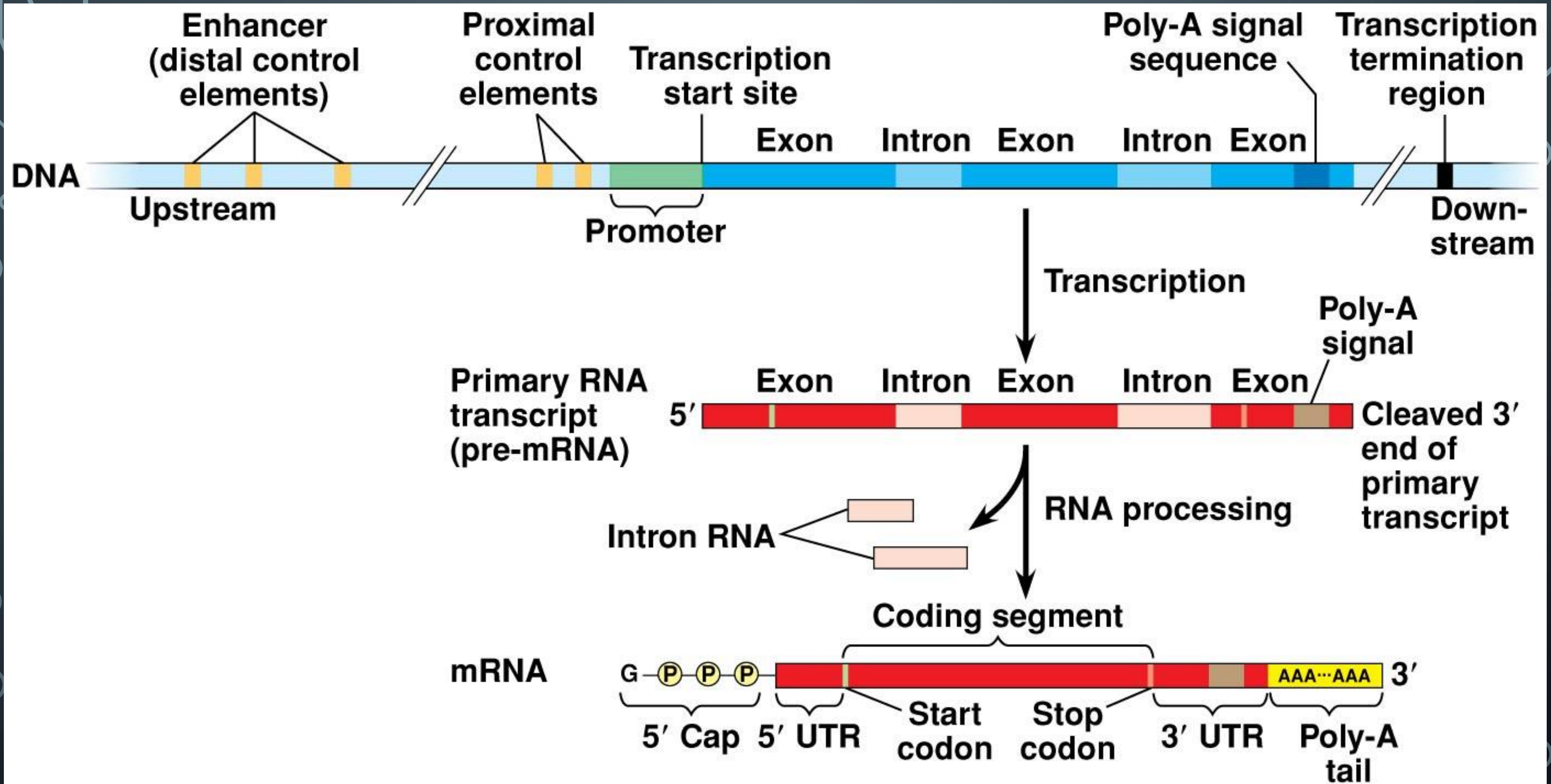
Electrons via NADH
Electrons via NADH and $FADH_2$
Glycolysis
Glucose
Pyruvate
Pyruvate oxidation
Acetyl CoA
Citric acid cycle
Oxidative phosphorylation: electron transport and chemiosmosis
CYTOSOL
MITOCHONDRION
ATP
ATP
ATP
Substrate-level
Substrate-level

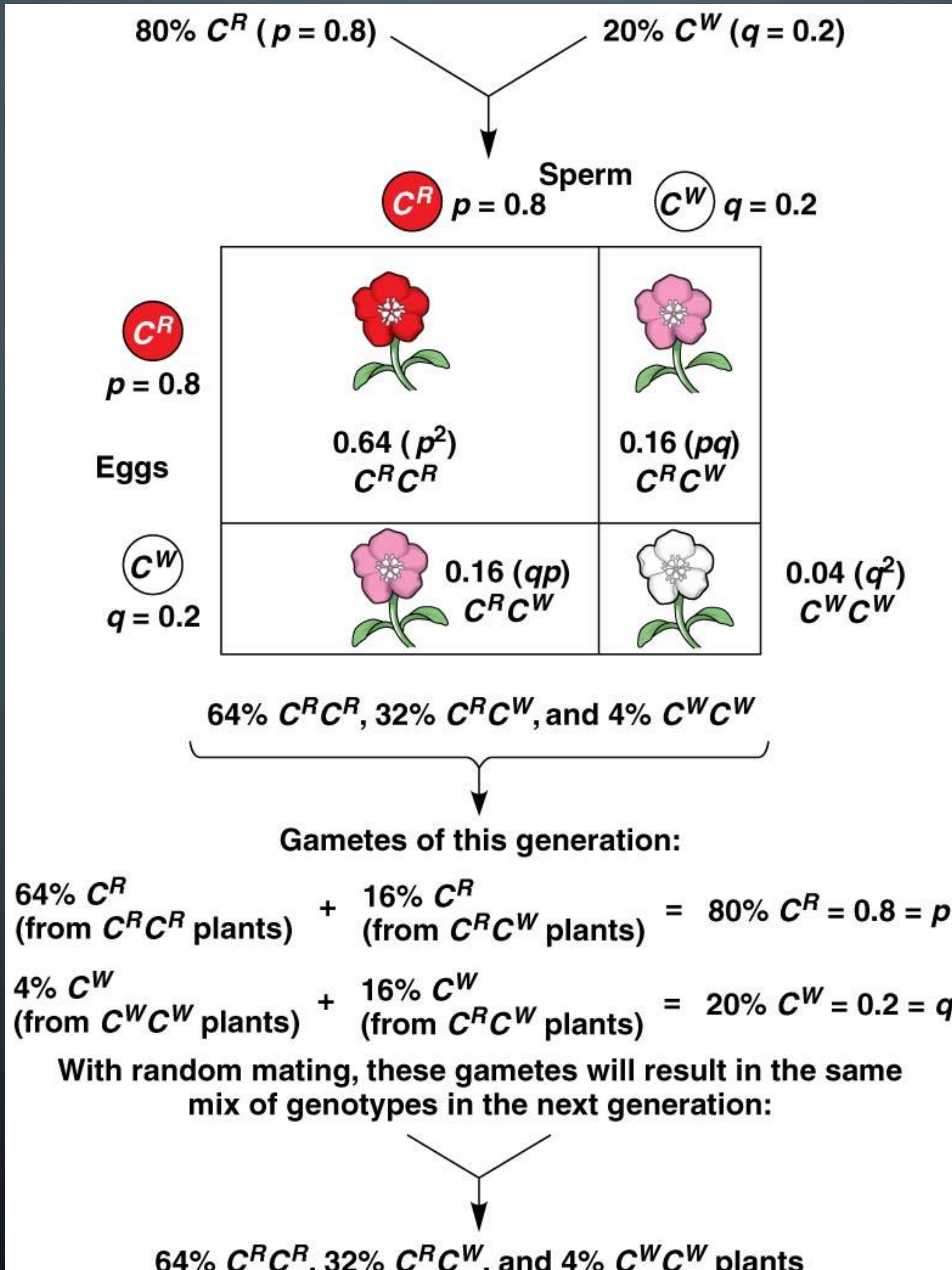


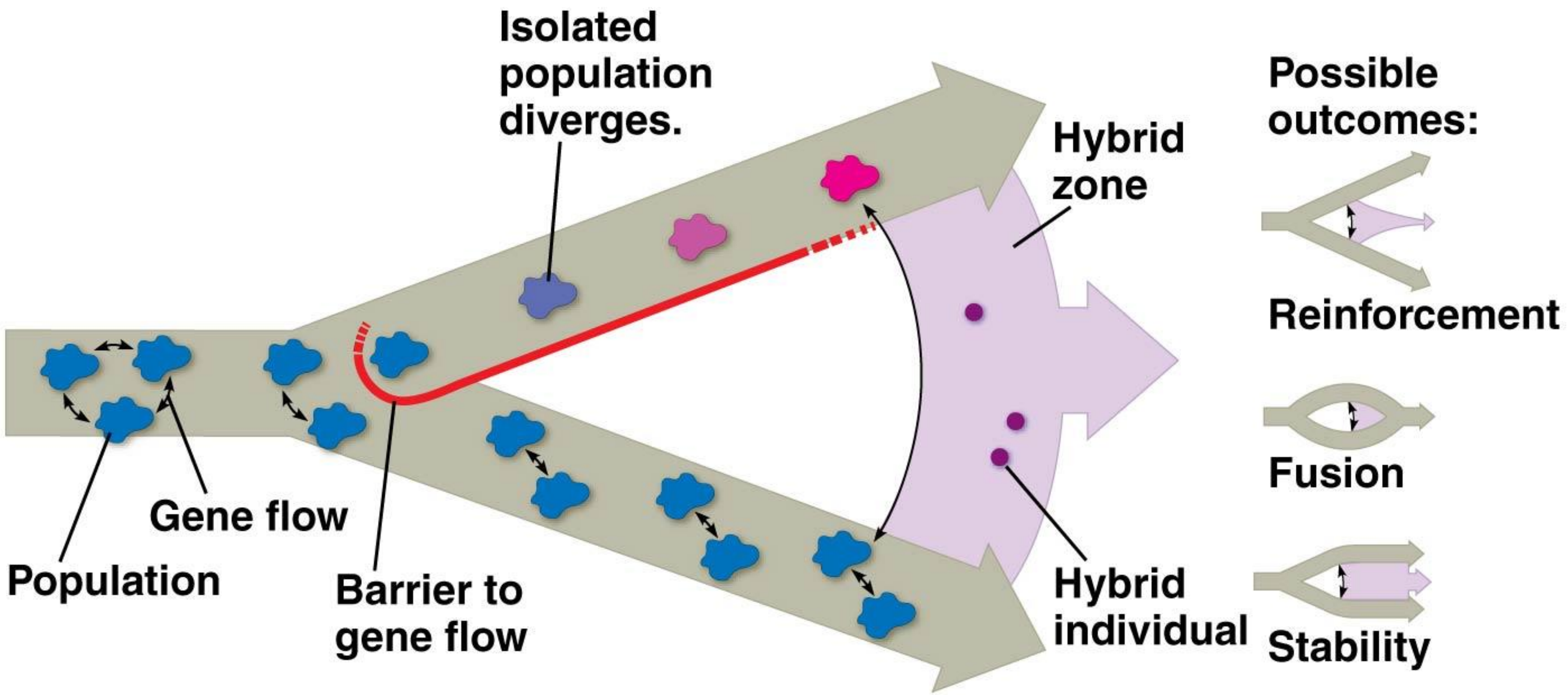
H_2O
CO_2
Light
$NADP^+$
ADP
+ P_i
Light Reactions:
Photosystem II
Electron transport chain
Photosystem I
Electron transport chain
RuBP
3-Phosphoglycerate
Calvin Cycle
ATP
NADPH
G3P
Starch (storage)
Chloroplast
O_2
Sucrose (export)



P Generation
Yellow-round seeds (YYRR)
Green-wrinkled seeds (yyrr)
×
Meiosis
Fertilization
Gametes
All F1 plants produce yellow-round seeds (YyRr).
F1 Generation
Meiosis
LAW OF SEGREGATION The two alleles for each gene separate.
LAW OF INDEPENDENT ASSORTMENT Alleles of genes on nonhomologous chromosomes assort independently.
Metaphase I
1
Anaphase I
Metaphase II
2
1/4 YR
1/4 yr
1/4 Yr
1/4 yR
F2 Generation
3 Fertilization recombines the R and r alleles at random.
An F1 × F1 cross-fertilization
9 : 3 : 3 : 1
3 Fertilization results in the 9:3:3:1 phenotypic ratio in the F2 generation.


Enhancer (distal control elements)
Proximal control elements
Transcription start site
Poly-A signal sequence
Transcription termination region
Exon
Intron
Exon
Intron
Exon
DNA
Upstream
Promoter
Down-stream
Transcription
Poly-A signal
Primary RNA transcript (pre-mRNA)
5′
Exon
Intron
Exon
Intron
Exon
Cleaved 3′ end of primary transcript
Intron RNA
RNA processing
Coding segment
mRNA
G P P P
AAA···AAA
3′
5′ Cap
5′ UTR
Start codon
Stop codon
3′ UTR
Poly-A tail


80% C^R (p = 0.8)
20% C^W (q = 0.2)
Sperm
C^R p = 0.8
C^W q = 0.2
Eggs
C^R p = 0.8
C^W q = 0.2
0.64 (p^2) C^RC^R
0.16 (pq) C^RC^W
0.16 (qp) C^RC^W
0.04 (q^2) C^WC^W
64% C^RC^R, 32% C^RC^W, and 4% C^WC^W
Gametes of this generation:
64% C^R (from C^RC^R plants) + 16% C^R (from C^RC^W plants) = 80% C^R = 0.8 = p
4% C^W (from C^WC^W plants) + 16% C^W (from C^RC^W plants) = 20% C^W = 0.2 = q
With random mating, these gametes will result in the same mix of genotypes in the next generation:
64% C^RC^R, 32% C^RC^W, and 4% C^WC^W plants



Isolated population diverges.
Hybrid zone
Possible outcomes:
Reinforcement
Fusion
Stability
Gene flow
Population
Barrier to gene flow
Hybrid individual

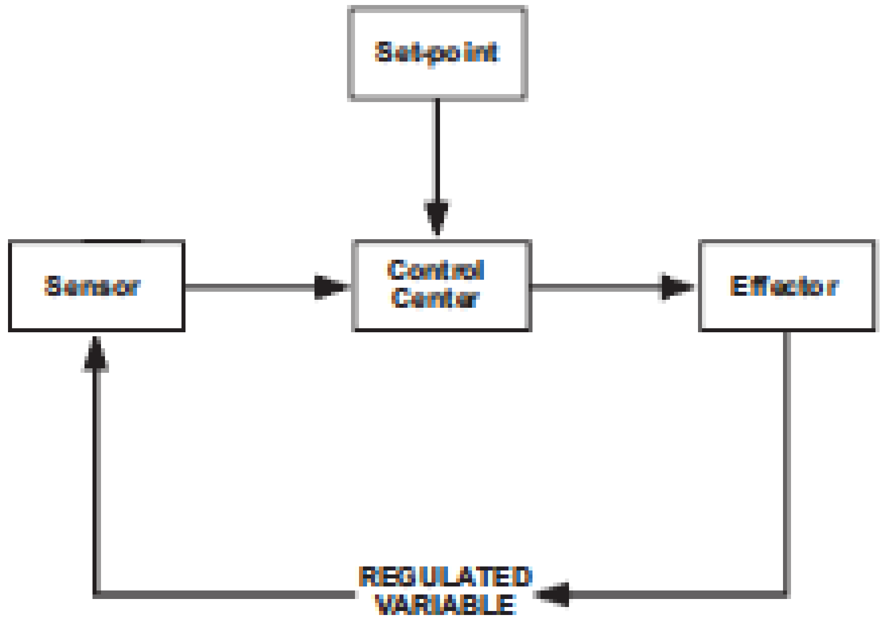
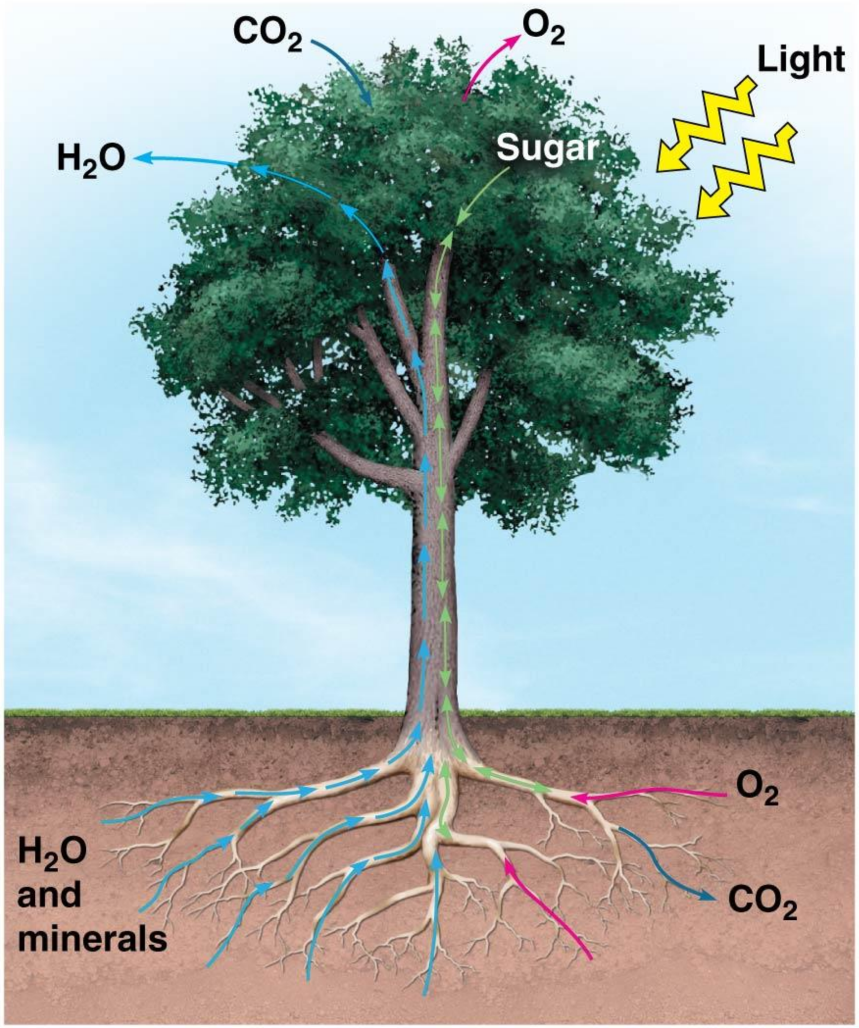
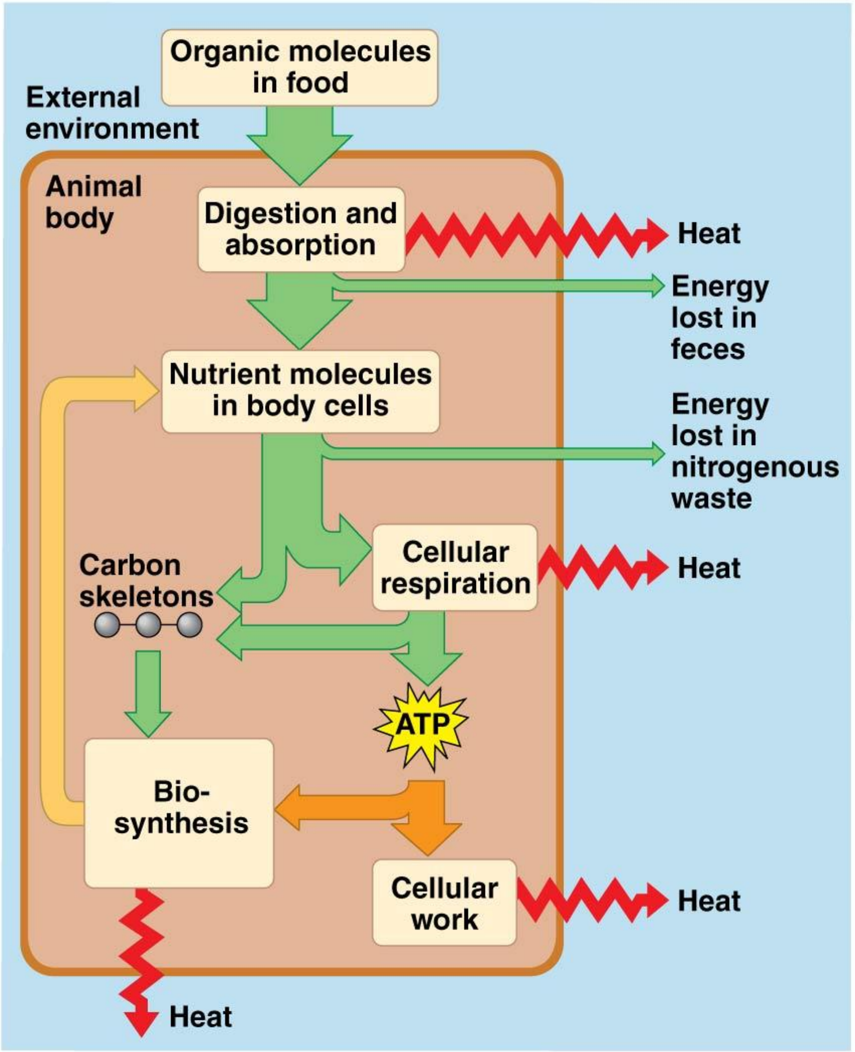


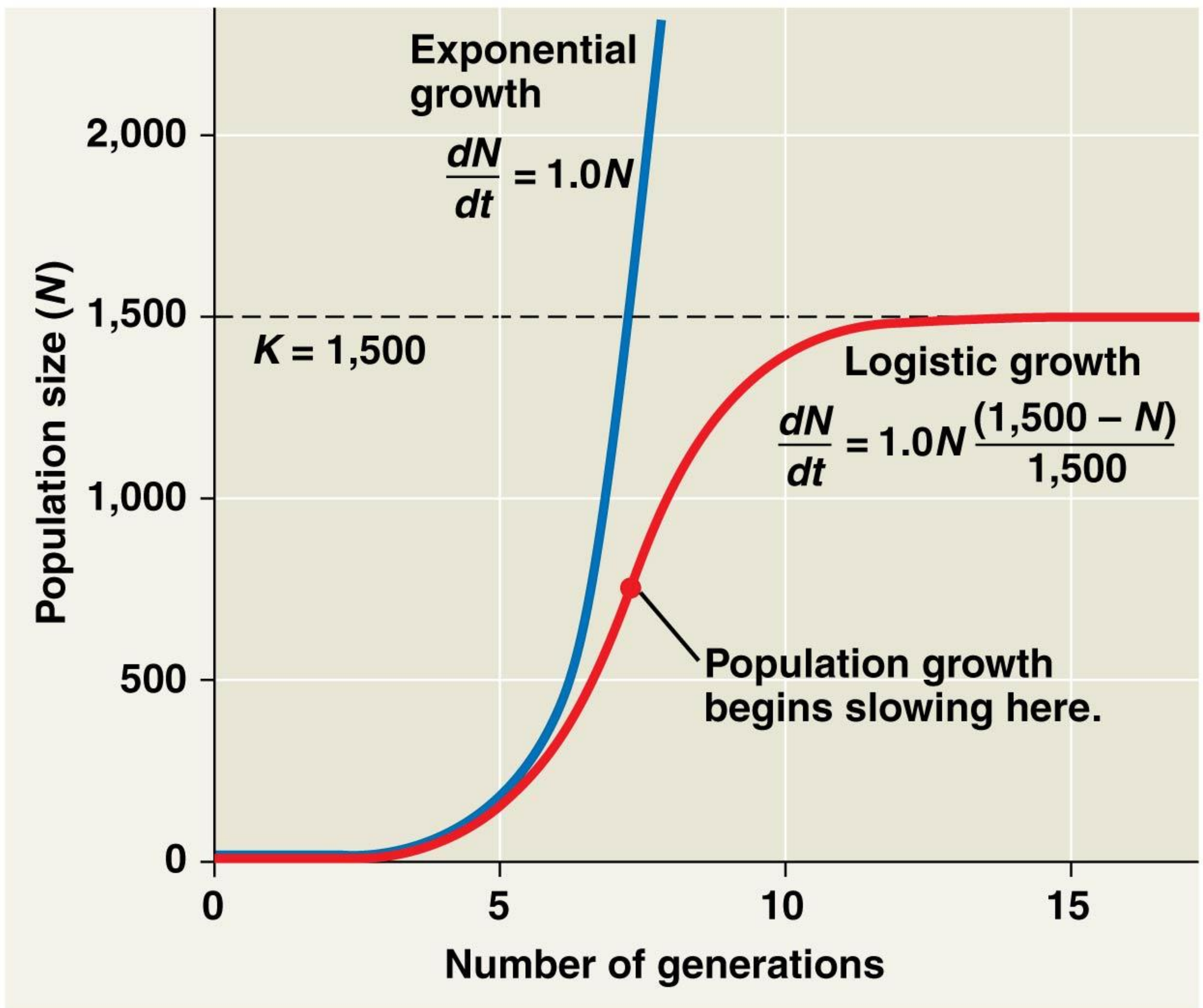
Fig. 2. Simplified representation of a homeostatic regulatory system. Several components shown in Fig. 1 are combined in this representation. The reader should refer to Table 1 to find correspondence between components of physiologically significant homeostatic regulatory systems and this simplified representation. For example, chemosensors in the carotid bodies and aortic body are "sensors," the brain stem is the "control center," and the diaphragm and other respiratory muscles are "effectors" in the homeostatic regulatory system for arterial P_{O_2}.

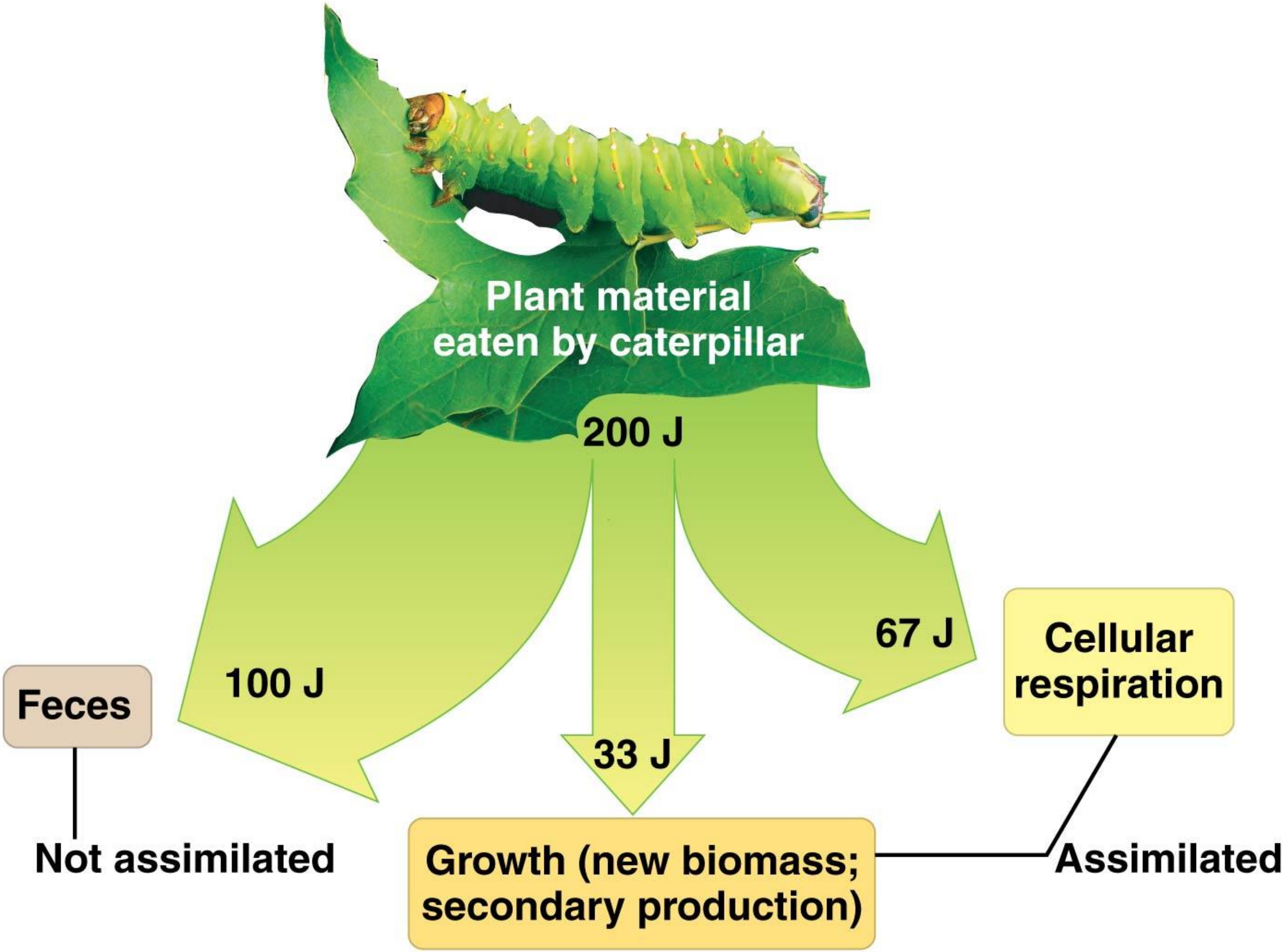


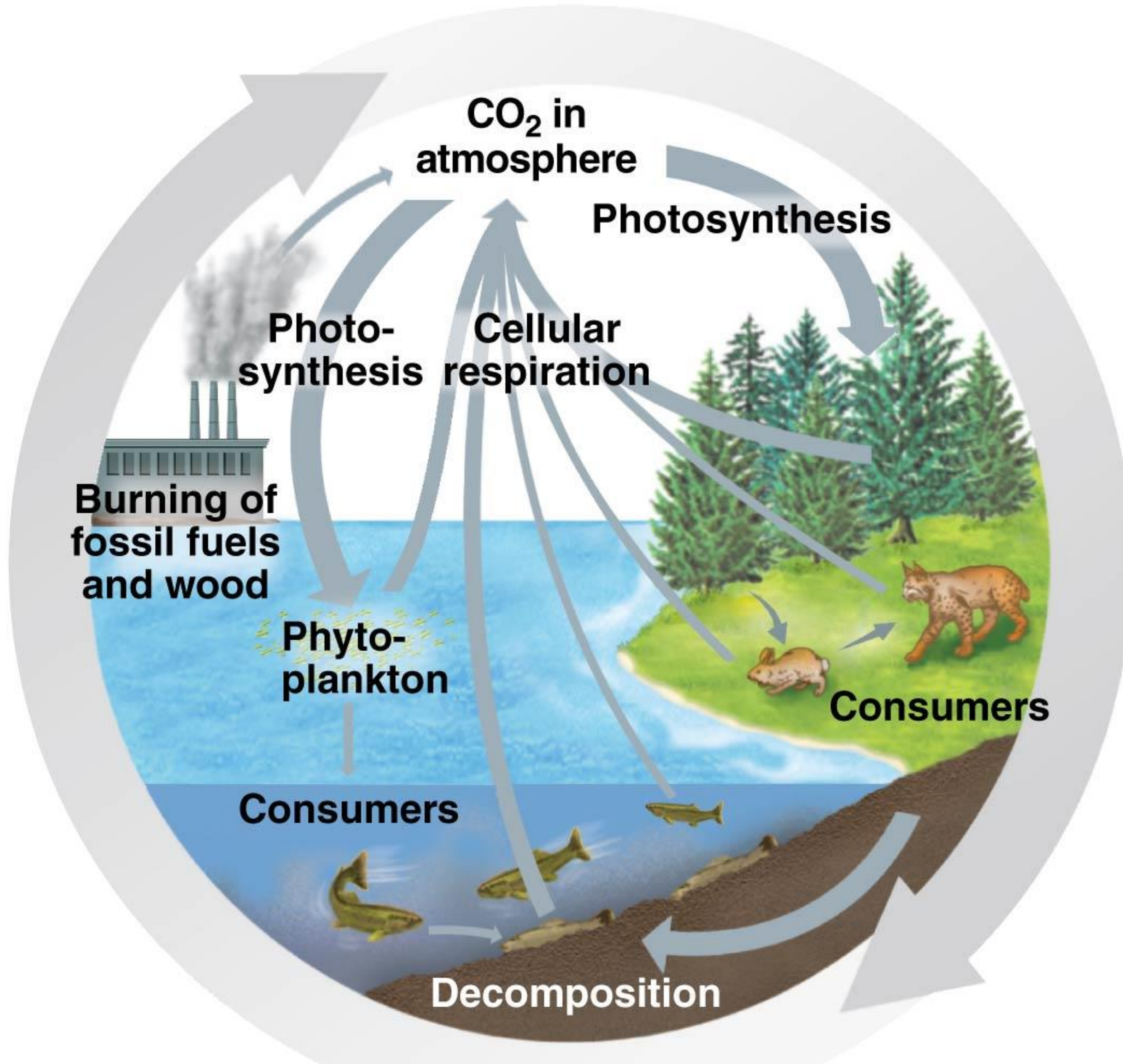
CO_2
O_2
Light
H_2O
Sugar
O_2
H_2O and minerals
CO_2



Organic molecules in food
External environment
Animal body
Digestion and absorption
Heat
Energy lost in feces
Nutrient molecules in body cells
Energy lost in nitrogenous waste
Carbon skeletons
Cellular respiration
Heat
ATP
Bio-synthesis
Cellular work
Heat
Heat


Exponential growth
$\frac{dN}{dt} = 1.0N$
2,000
1,500
1,000
500
0
Population size (N)
K = 1,500
Logistic growth
$\frac{dN}{dt} = 1.0N \frac{(1,500 - N)}{1,500}$
Population growth begins slowing here.
0
5
10
15
Number of generations


Plant material eaten by caterpillar
200 J
100 J
Feces
33 J
67 J
Cellular respiration
Not assimilated
Growth (new biomass; secondary production)
Assimilated



The carbon cycle

QUBES QR SURVEY
FALL 2016-SPRING 2017

- We invite you to join our team
- Provide feedback on items
- Create and share items
- Implement survey in your course as part of national study

THANK YOU

ROBERT MAYES
RMAYES@GEORGIASOUTHERN.EDU

INSTITUTE *for* INTERDISCIPLINARY **STEM** EDUCATION
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