Cultivating Quantitative Reasoning: Evaluating the impact of an instructor-led intervention on quantitative reasoning
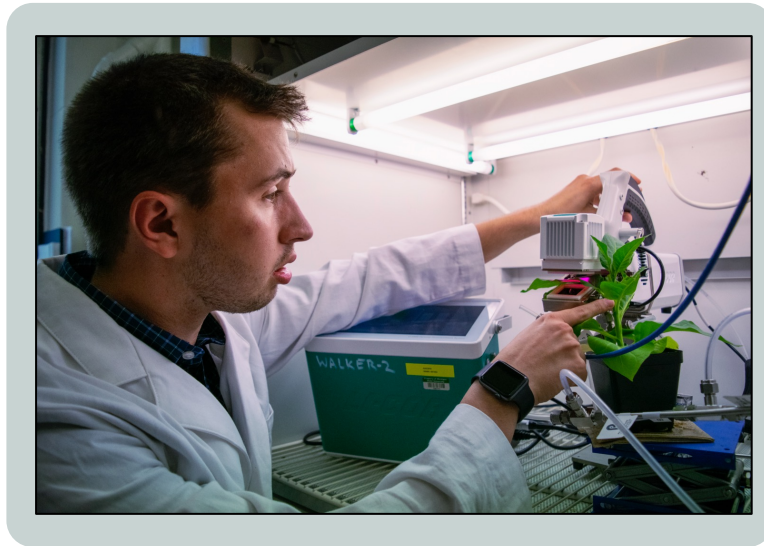
FAST fellow: Luke Gregory; Department of Plant Biology

**FAST mentor**: Berkley Walker; Department of Plant Biology

Approved IRB#: STUDY00010128 (Exempt 1)

Personal motivation: Beyond imparting knowledge, a personal goal of mine is to equip students with the higher-order skills to thrive in our data-rich and interconnected world

**Goal**: Instruct at a Comprehensive Public University (PUI)

Quantitative Reasoning

Interdisciplinary Thinking

Multicultural Teamwork
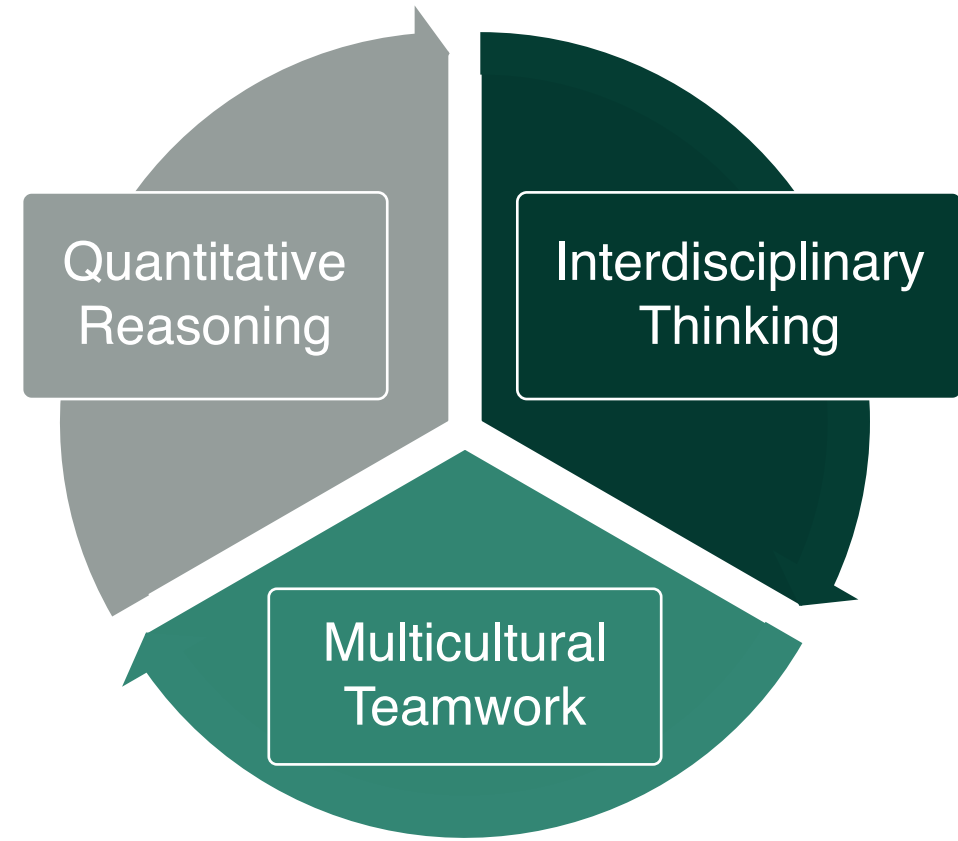
Quantitative Reasoning is …

… the ability to construct, comprehend, analyze, and interpret models to make informed decisions

What is a model?

… a simplified representation of a real-world object and their mechanistic/functional relationship
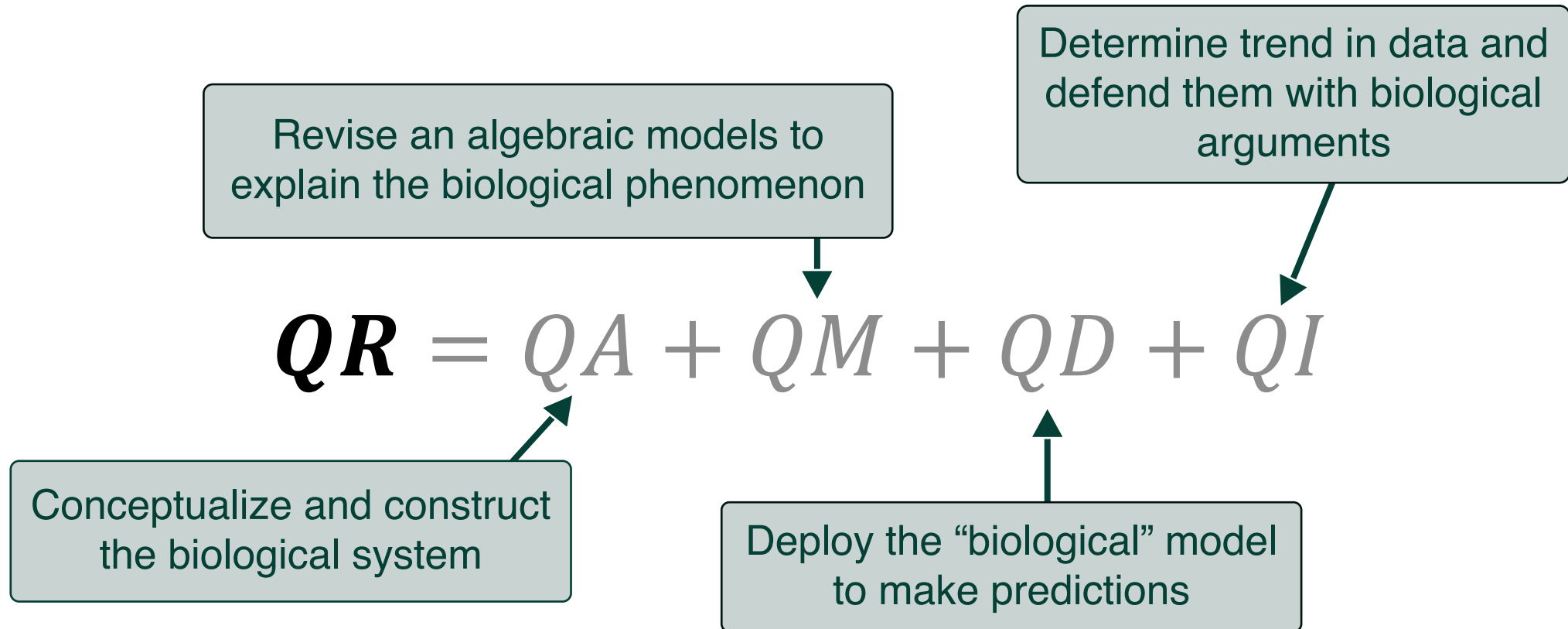
What is the purpose?

… we construct models for the purpose of understanding and to making predictions about real world phenomenon
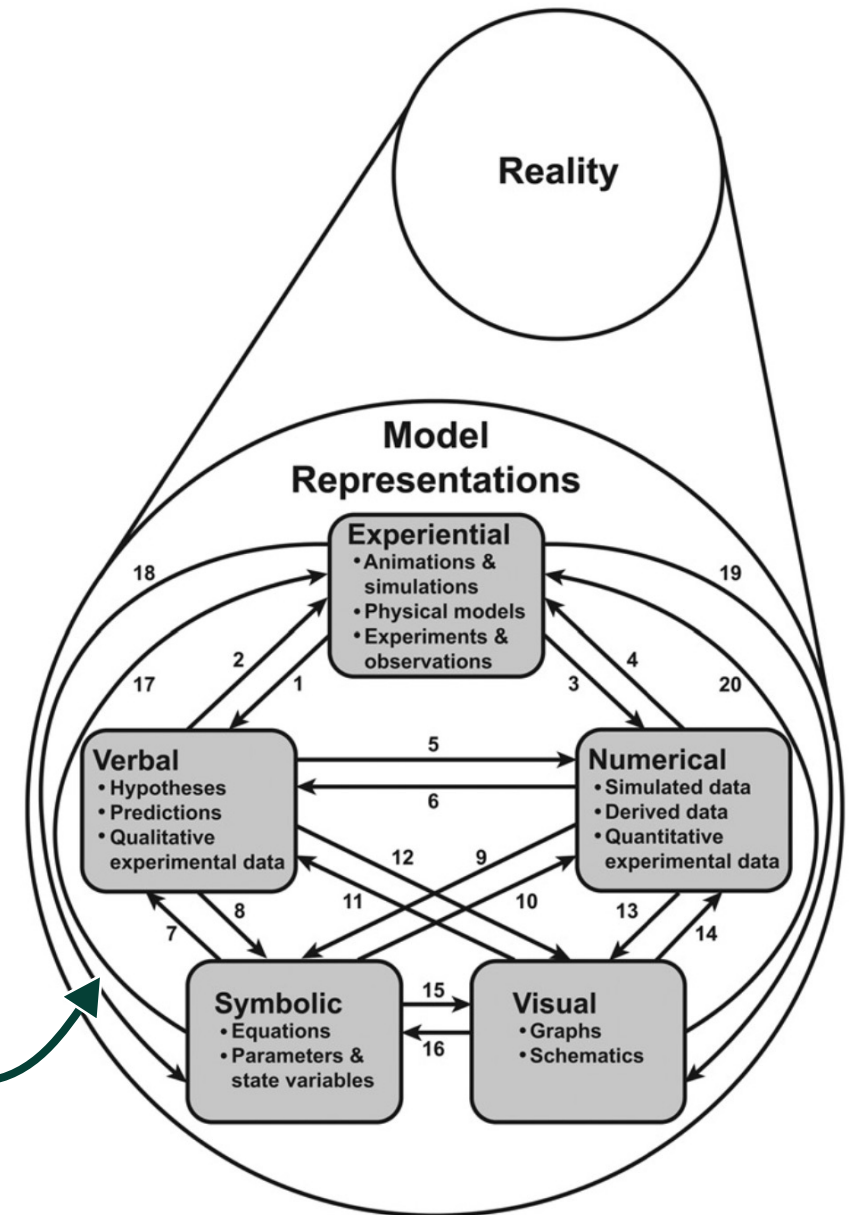

Figure 1 from Eaton D.C. *et al.*, 2019   3

Students should have the ability to generate *"**defensible explanations**"* to describe biological phenomenon using quantitative reasoning (QR)

$$\boldsymbol{QR} = QA + QM + QD + QI$$

Dauer *et al.*, 2021; Mayes *et al.*, 2014

Students should have the ability to generate *"**defensible explanations**"* to describe biological phenomenon using quantitative reasoning (QR)

Revise an algebraic models to explain the biological phenomenon

Determine trend in data and defend them with biological arguments

$$QR = QA + QM + QD + QI$$

Conceptualize and construct the biological system

Deploy the "biological" model to make predictions

Observation as a TA for undergraduate plant physiology (*PLB415*) in the spring semester 2023

Water Relations in Potato Tuber

Tuber Cell Ψ:
− 591 kPa
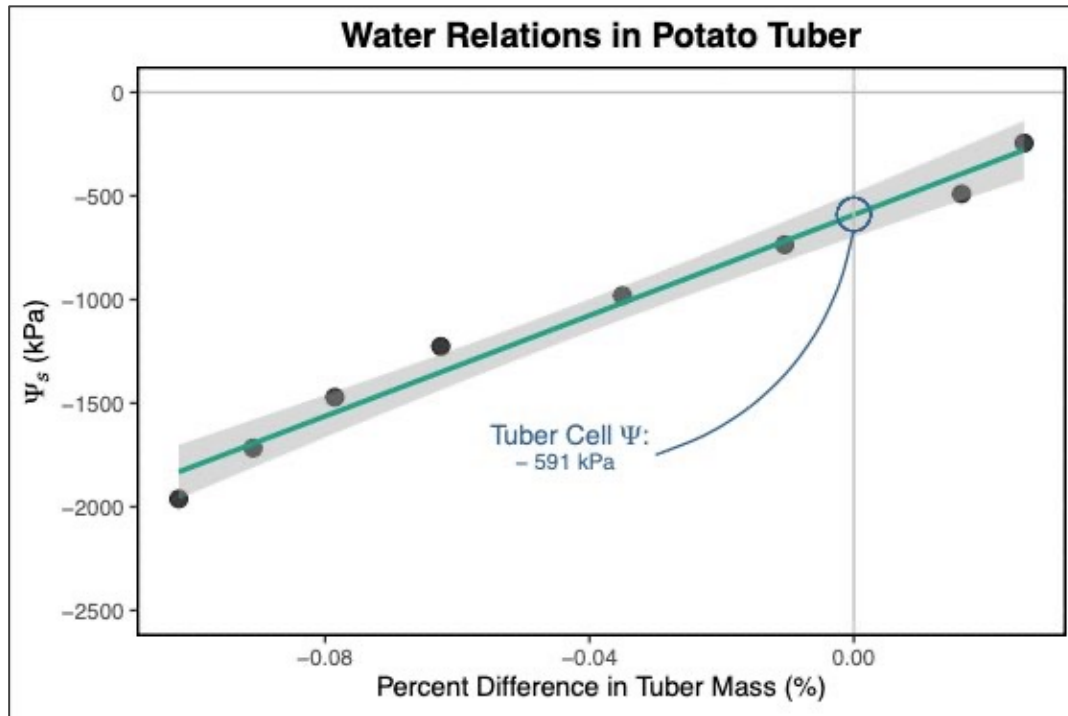
- ○ I noticed a tremendous challenge when students are asked to think/solve quantitative biological questions

Motivation:

Students' limitations could be due to a lack of one or more of the following QR elements

Teaching-as-Research: *Question*

How does an instructor-led quantitative reasoning intervention impact the quantitative reasoning ability and confidence of upper-level Plant Physiology students?

Teaching-as-Research: **Question**

How does an instructor-led quantitative reasoning intervention impact the quantitative reasoning ability and confidence of upper-level Plant Physiology students?

Obj. 1

Characterize students' quantitative reasoning ability and confidence to assess improvements in quantitative reasoning ability and/or confidence

$$\boldsymbol{QR} = QA + QM + QD + QI$$

Teaching-as-Research: *Question*

How does an instructor-led quantitative reasoning intervention impact the quantitative reasoning ability and confidence of upper-level Plant Physiology students?

Obj. 1

Characterize students' quantitative reasoning ability and confidence to assess improvements in quantitative reasoning ability and/or confidence

Obj. 2

**Analyze** and **Evaluate** specific challenges in quantitative reasoning and identify common areas of struggle

$$QA, QM, QD, QI$$

*Teaching-as-Research: **Question***

How does an instructor-led quantitative reasoning intervention impact the quantitative reasoning ability and confidence of upper-level Plant Physiology students?

Obj. 1
Characterize students' quantitative reasoning ability and confidence to assess improvements in quantitative reasoning ability and/or confidence

Obj. 2
Analyze and **Evaluate** specific challenges in quantitative reasoning and identify common areas of struggle

Obj. 3
Synthesize evidence on the status of quantitative reasoning and develop future instructional materials in PLB415

Assessing Student Learning: I designed three quantitative reasoning exercises to capture both ability and confidence data

QA

QM

QD

QI
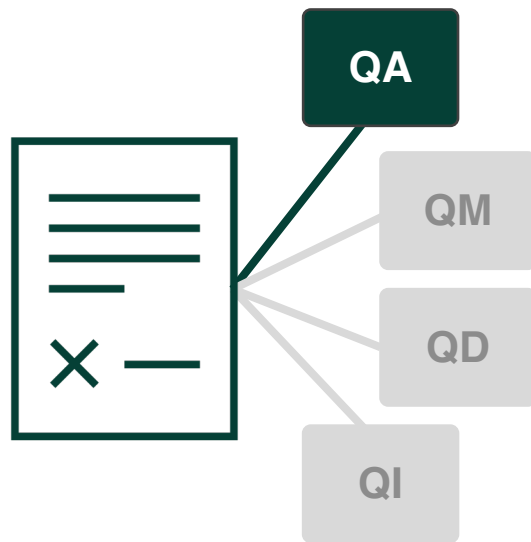
Ability

Can you construct a diagram of a cross section of a leaf and illustrate the journey of water molecule from the mid-vein (i.e., xylem tissue) of the leaf to the atmosphere?

Strongly disagree	Disagree
1	2

Agree	Strongly Agree
3	4
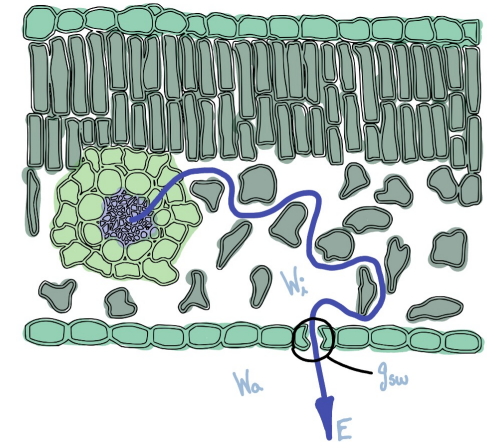
Confidence

I have the biological cognition to develop a conceptual diagram for plant physiology processes?

Assessing Student Learning: I designed three quantitative reasoning exercises to capture both ability and confidence data
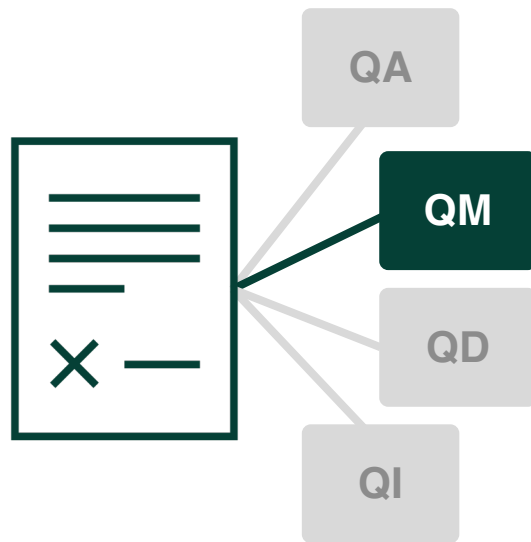
Ability

Using your diagram, can you substitute the terms in Fick law to better represent water diffusion in a leaf?

$$J = g(X_1 - X_2)$$

$$E = g_{sw}(W_i - W_a)$$

Confidence

Strongly disagree	Disagree
1	2

Agree	Strongly Agree
3	4

I am capable of reasoning with mathematical models and can identify/substitute the relevant variables needed to represent plant physiological processes?

QA

QM

QD

QI

Assessing Student Learning: I designed three quantitative reasoning exercises to capture both ability and confidence data

Ability

QA

QM

QD

QI

Using the model you developed, solve for the transpiration rate (E) and plot the temperature response of transpiration in the space below?

Species	Temperature	W_i	W_a	g_{sw}
Encelia farinosa	10	7.5	0.71	0.18
Encelia farinosa	20	7.5	1.16	0.20
Encelia farinosa	30	7.5	2.08	0.24
Encelia farinosa	40	7.5	2.89	0.28
Solidago altissima	10	7.5	0.71	0.24
Solidago altissima	20	7.5	1.16	0.27
Solidago altissima	30	7.5	2.08	0.33
Solidago altissima	40	7.5	2.89	0.42

Confidence

Strongly disagree	Disagree
1	2

Agree	Strongly Agree
3	4

I can deploy mathematical models to answer plant physiological questions?

Assessing Student Learning: I designed three quantitative reasoning exercises to capture both ability and confidence data

QA

QM

QD

QI
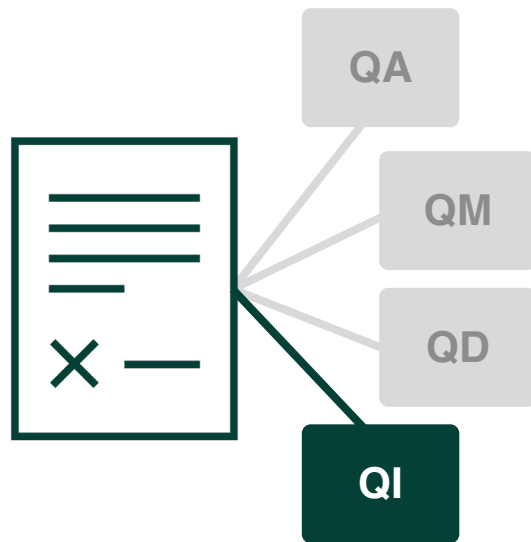
Ability

Based on the transpiration rate these species, can you infer any strategy they have adapted based on their growth environment?

Strongly disagree	Disagree
1	2

Agree	Strongly Agree
3	4
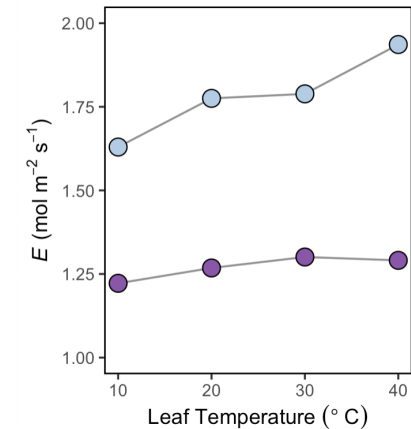
Confidence

I can determine trends in data and defend those trends using biological arguments?

Project Timeline: I administered three assessments during the first half of the seminar to get initial-, during-, and after- intervention data
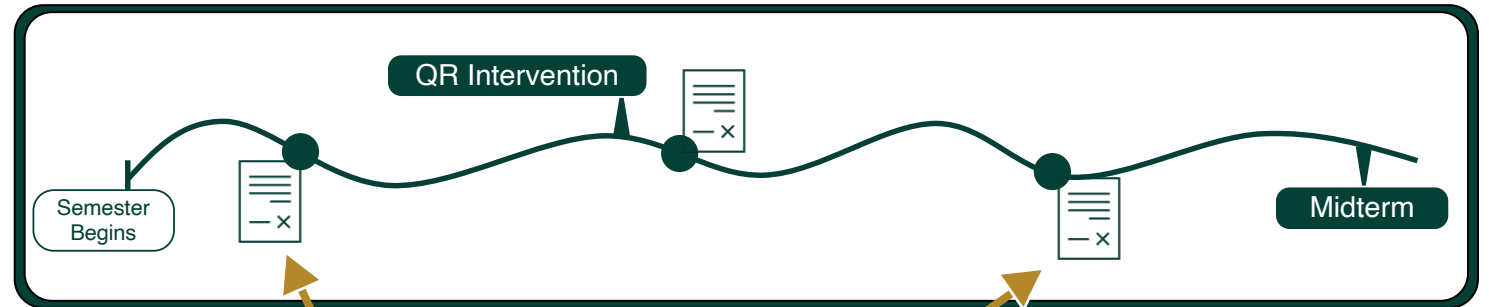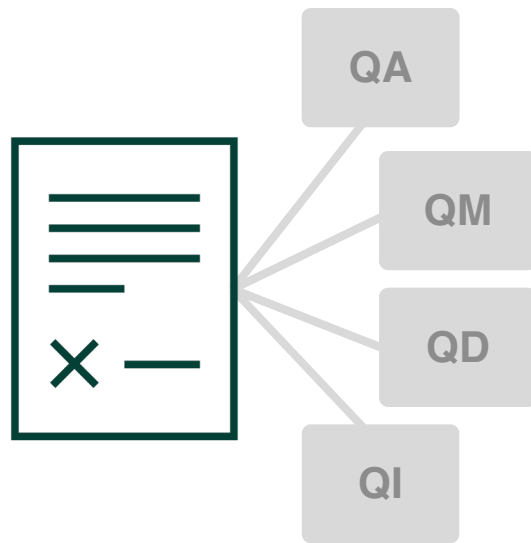
We have a 22.1% improvement in quantitative reasoning ability after the intervention, without increase in confidence
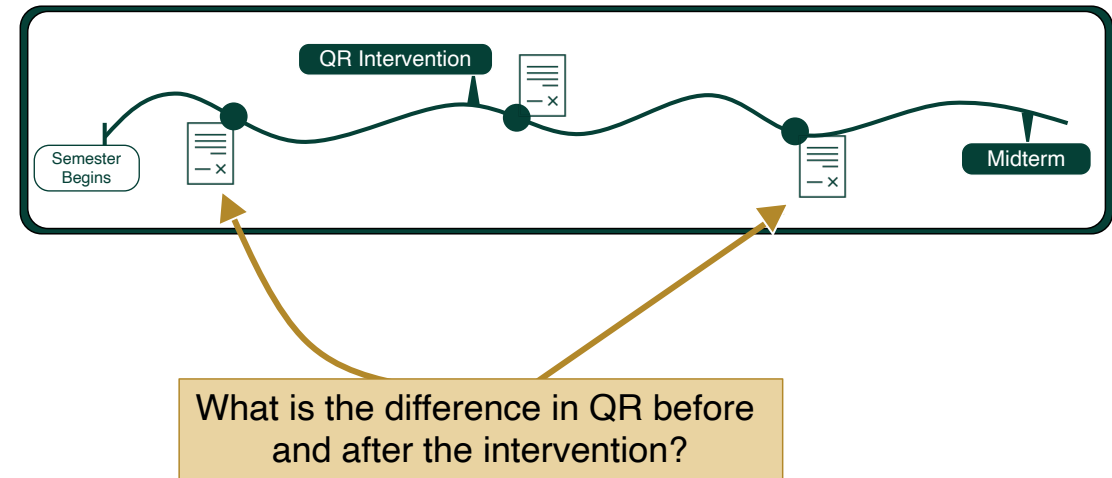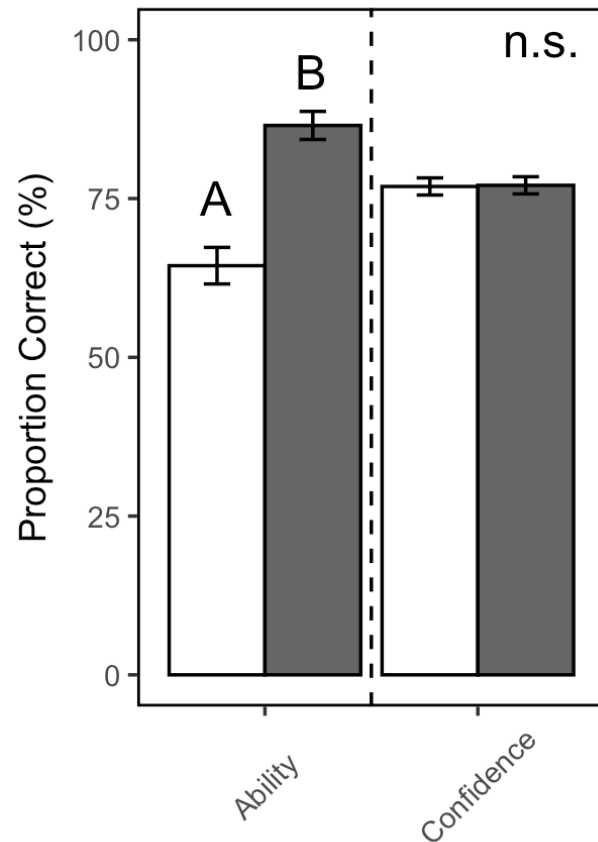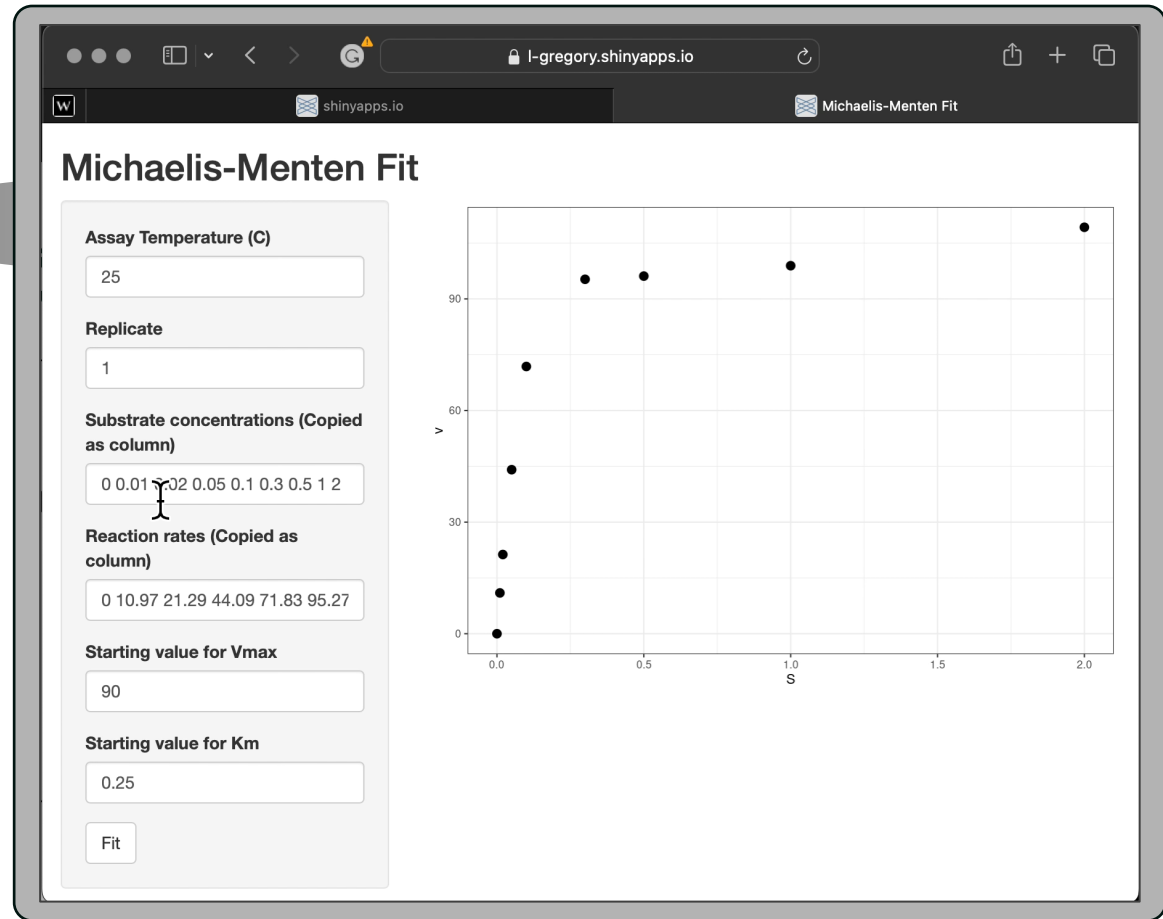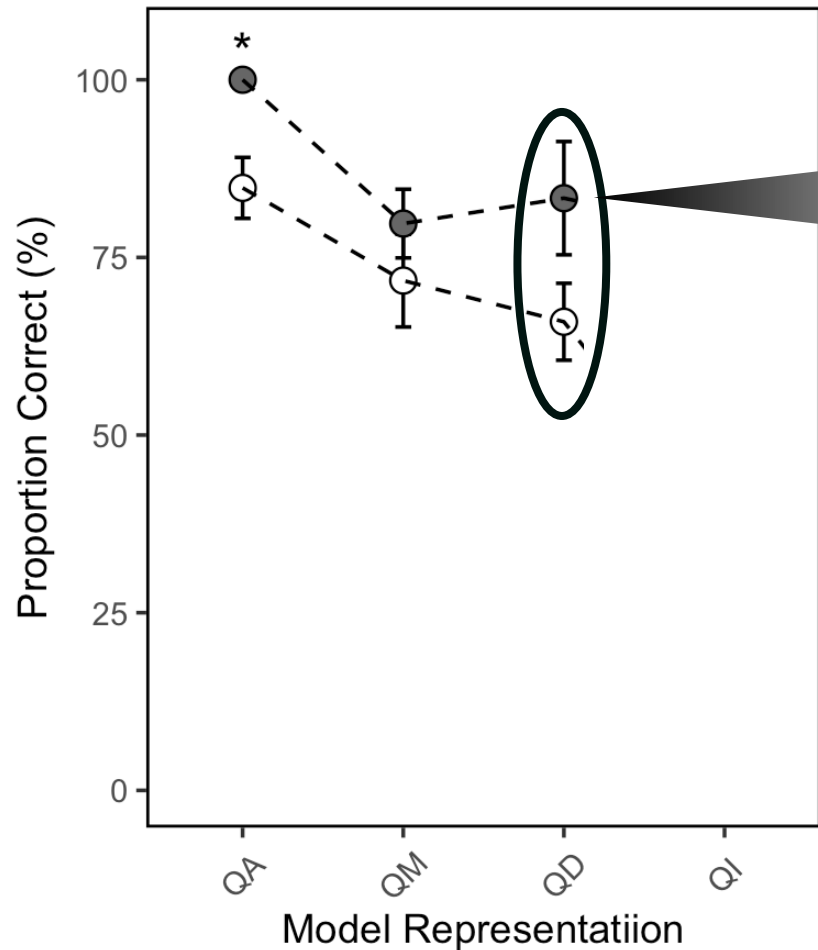
$$QR = QA + QM + QD + QI$$

Skills in quantitative act significantly increase by 15.2% after the instructor-led intervention

**Analyze** and **Evaluate** specific challenges in quantitative reasoning and identify common areas of struggle
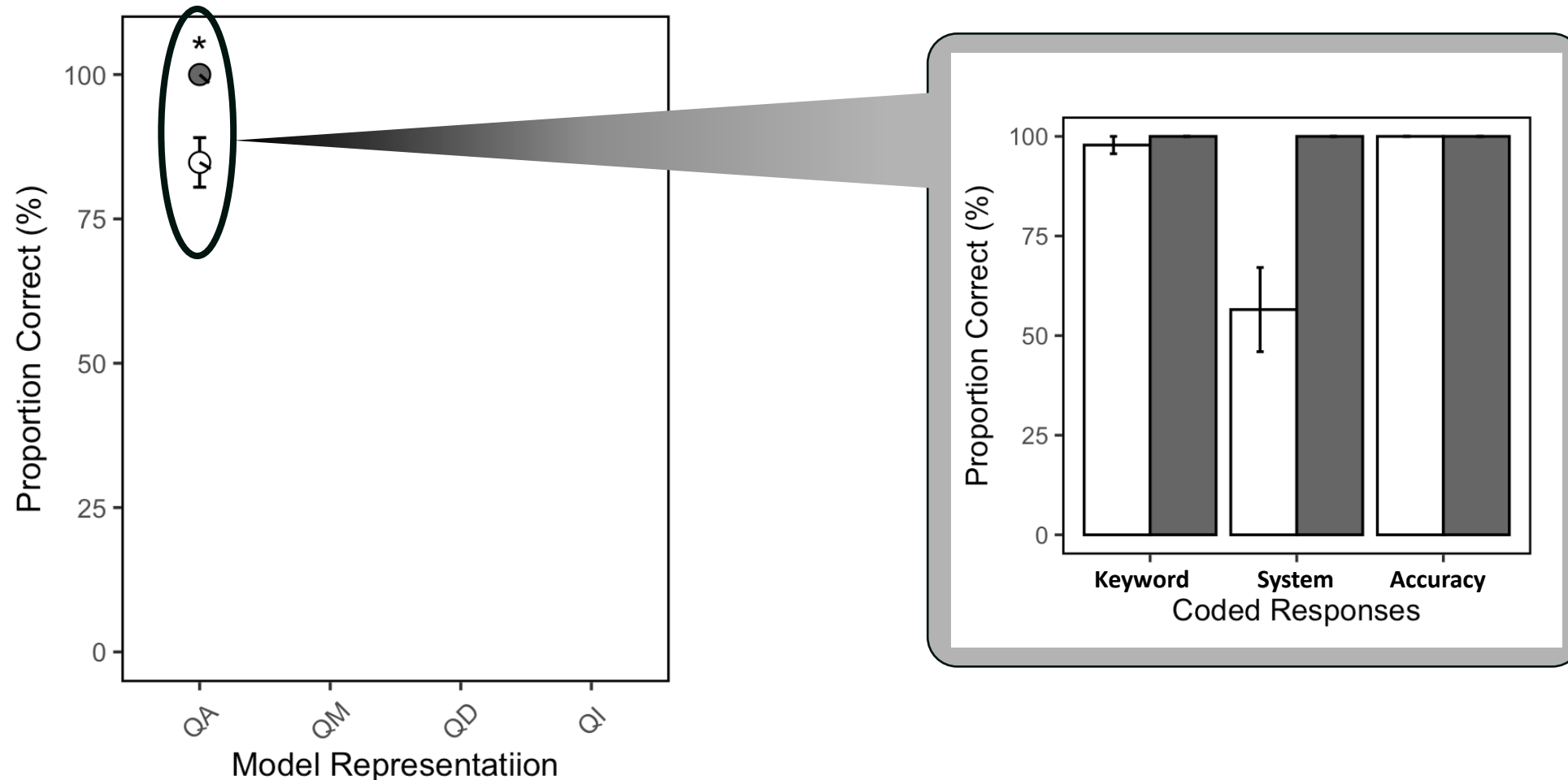
Skills in quantitative modelling increase by 8.1% after the instructor-led intervention
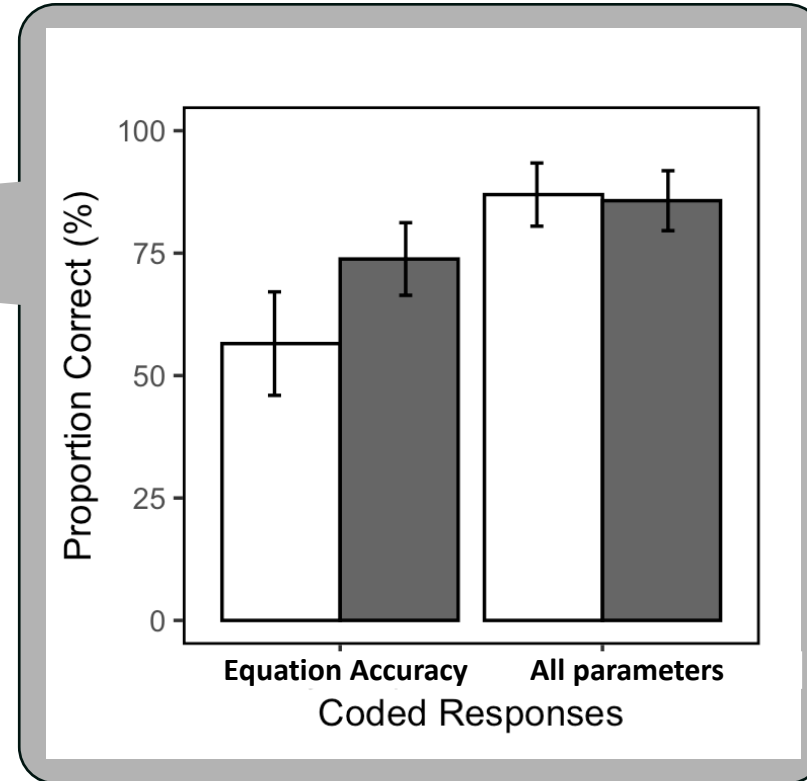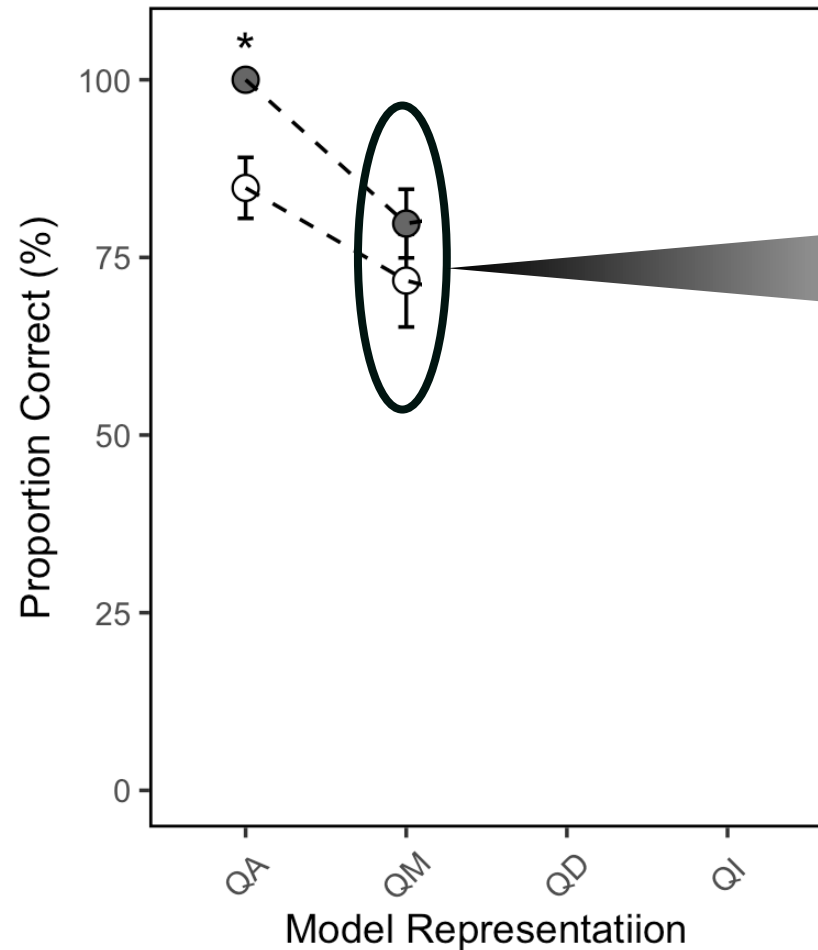
Skills in quantitative deployment increase by 17.4% after the instructor-led intervention

Analyze and **Evaluate** specific challenges in quantitative reasoning and identify common areas of struggle
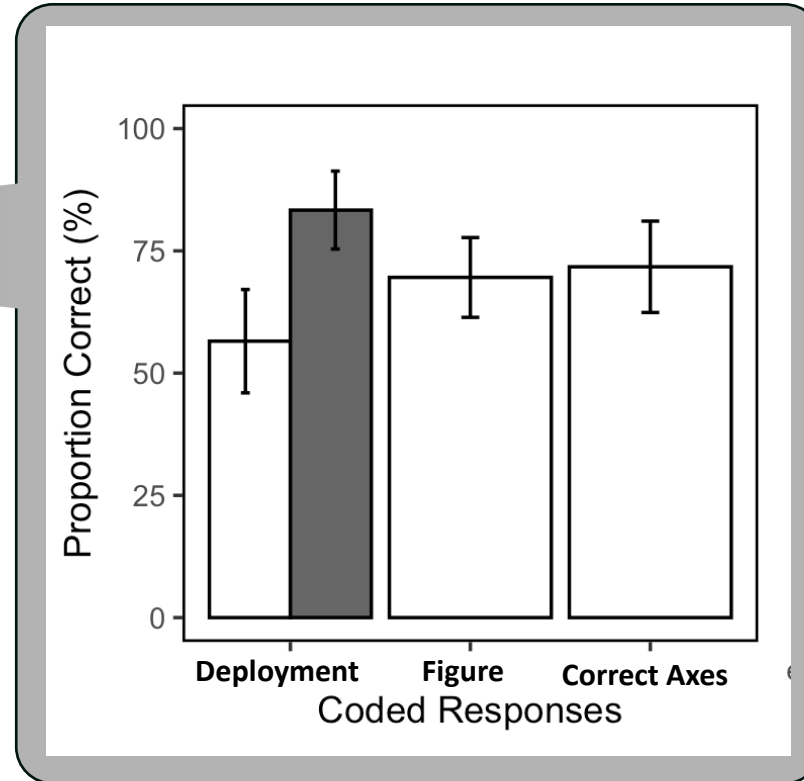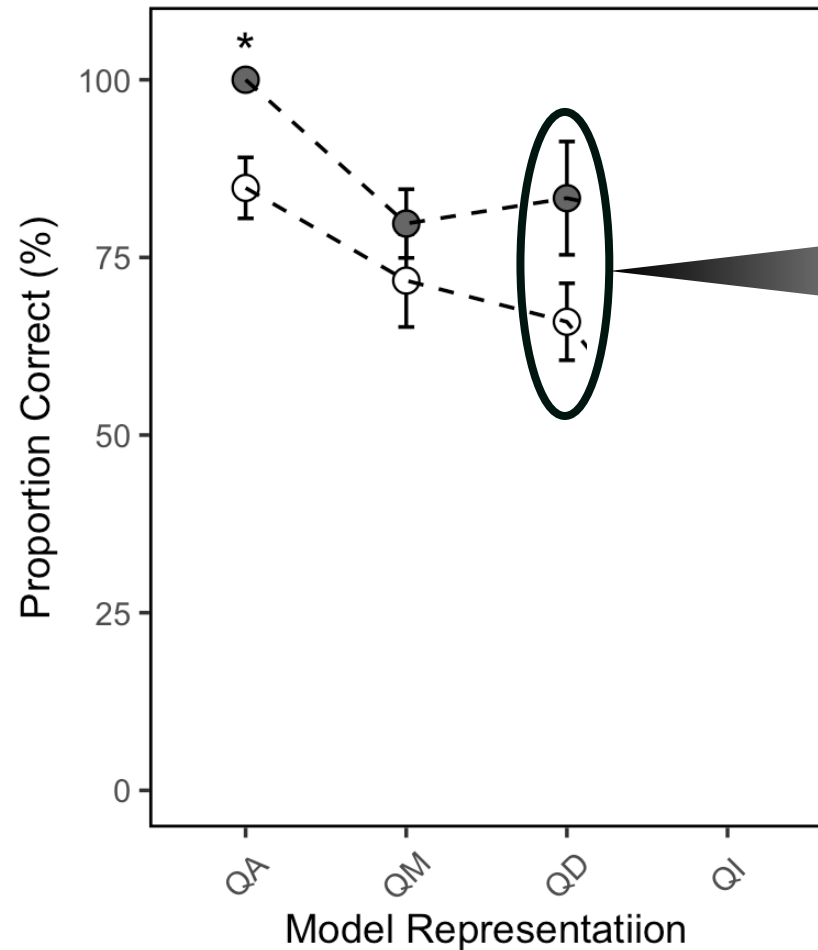
Should we emphasize mathematical skills, or rely on custom-built tools to relate biology phenomena to mathematical models?
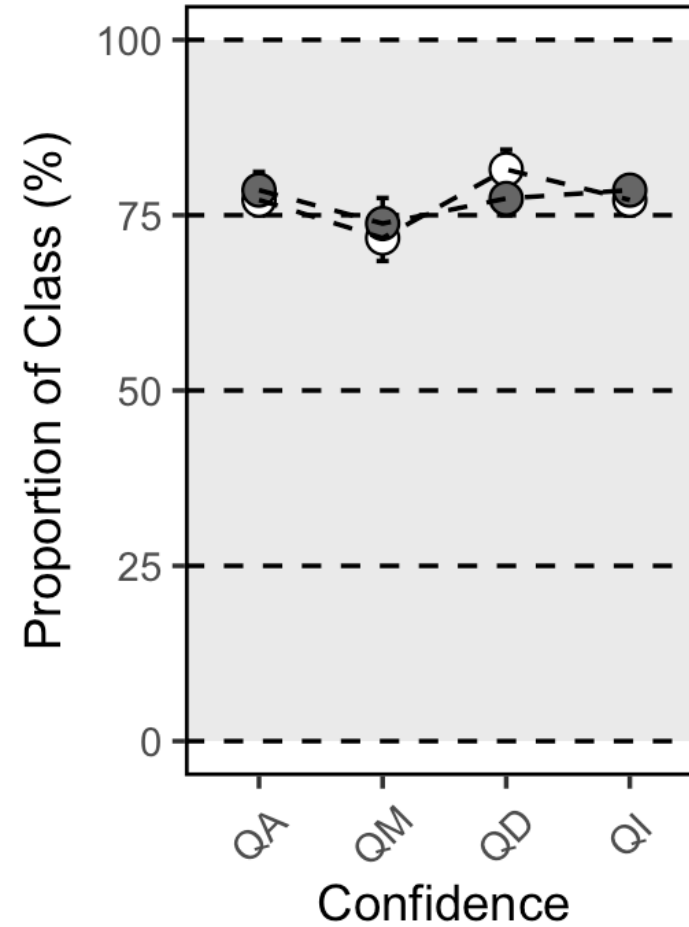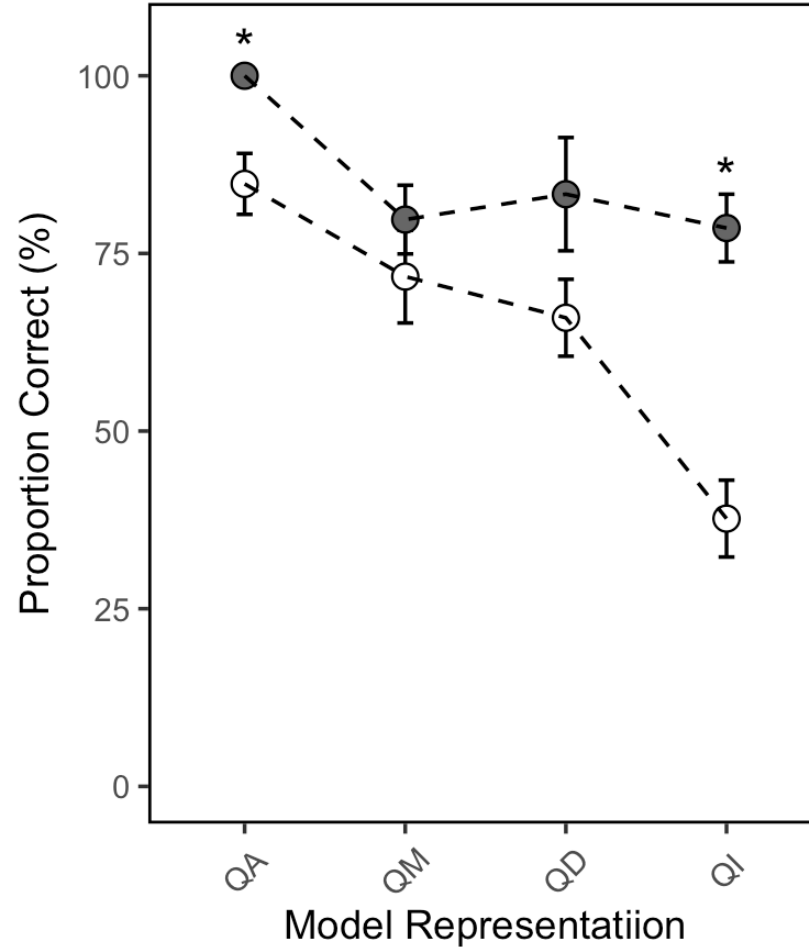
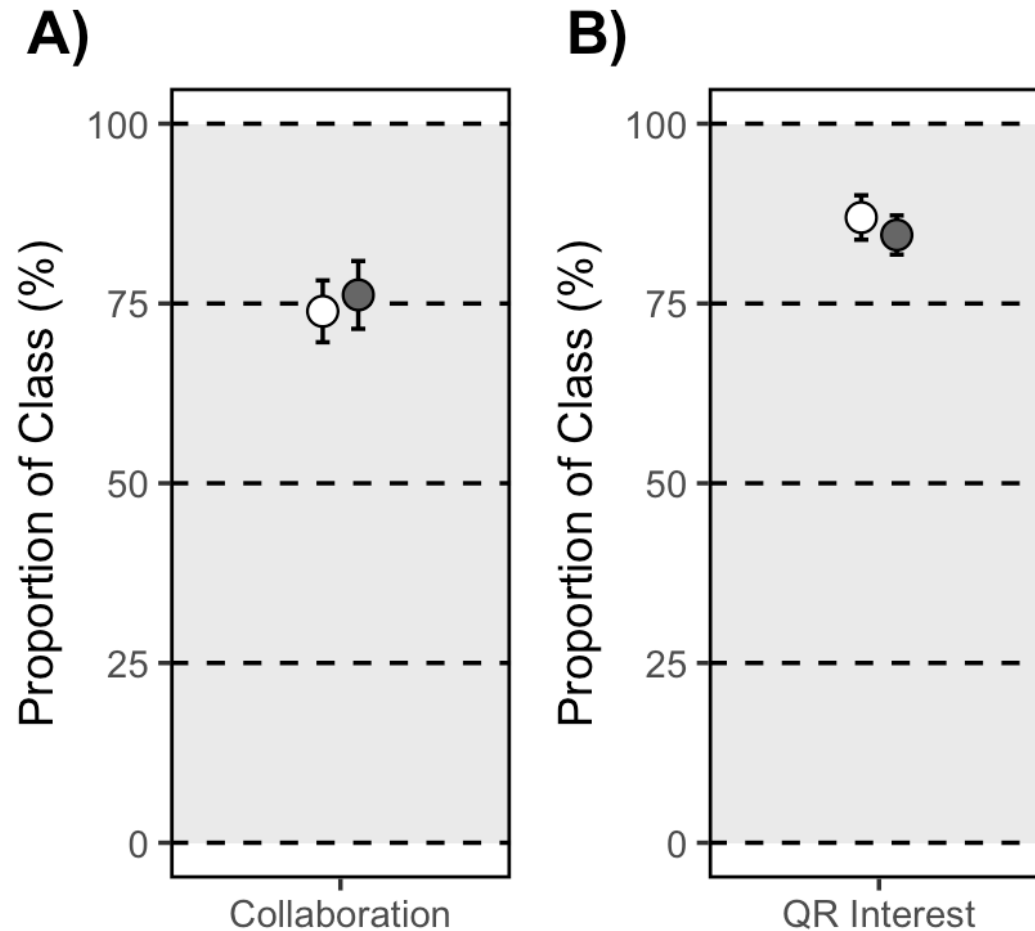# Skills in quantitative interpretation increased by 40.9% after the intervention

Analyze and **Evaluate** specific challenges in quantitative reasoning and identify common areas of struggle
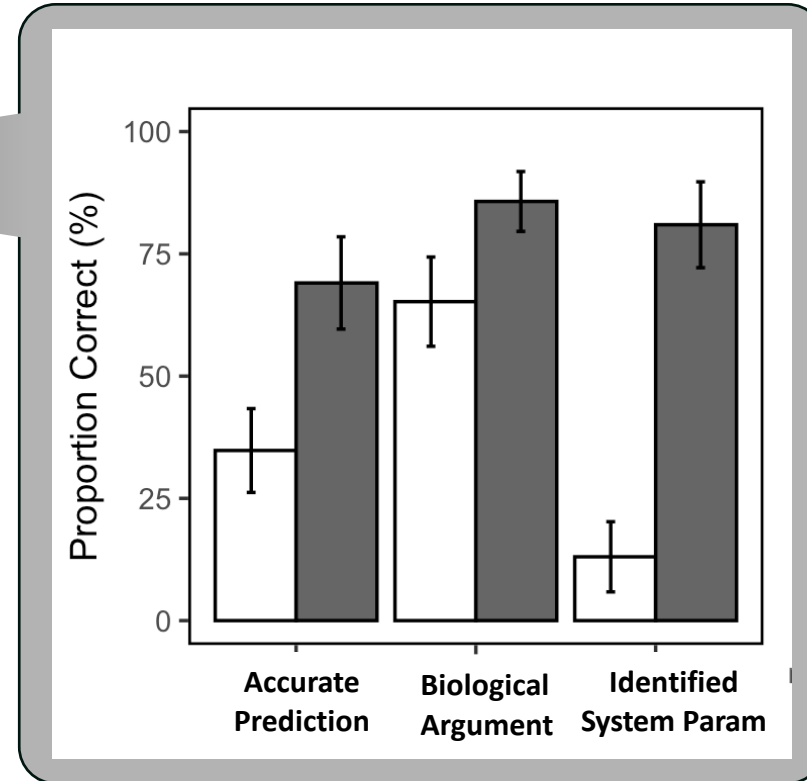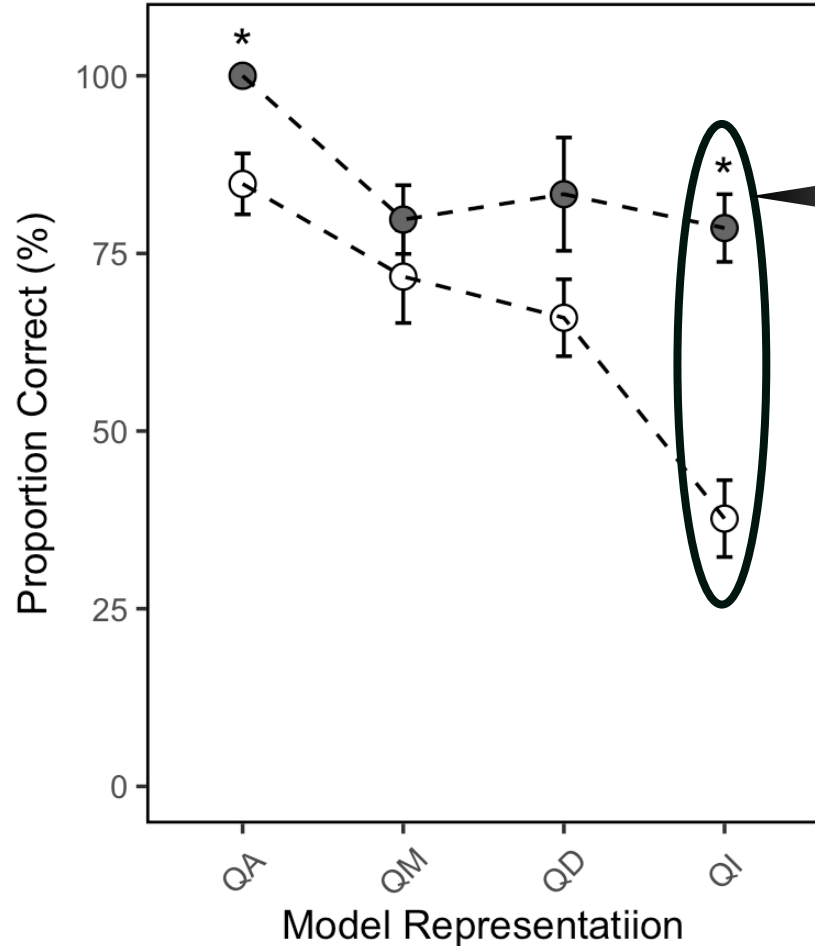
Confidence is not an indicator of Ability!

Other metrics

A)

B)

"Can't really be a scientist without quantitative reasoning "

"It is practical. **It is physiology in real life**, and I need that"

"I find **working together/collaborating is almost always better** as long as all parties actively listen and participate"

Future Recommendations for *PLB415*

Synthesize evidence on the status of quantitative reasoning and develop future instructional materials in PLB415

Build QR into curriculum

Design more quantitative reasoning exercises for students to explore more models throughout the semester

Develop exercises for each unit focused on a system/phenomena

+

Create custom tools to accompany each exercise

+

Expand coded responses to get more resolution out of analysis

Figure 1 from Eaton D.C. *et al.*, 2019

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Future Recommendations for *PLB415*

Biological Systems-Thinking (BST)

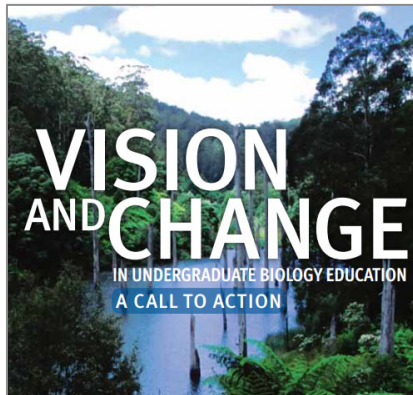Switch pedagogical style to align with this framework, while continuing to emphasize quantitative reasoning skills

"V&C gave instructors permission to abandon textbooks as curricular frameworks and, instead, focus on developing students' understanding of fewer foundational concepts…"

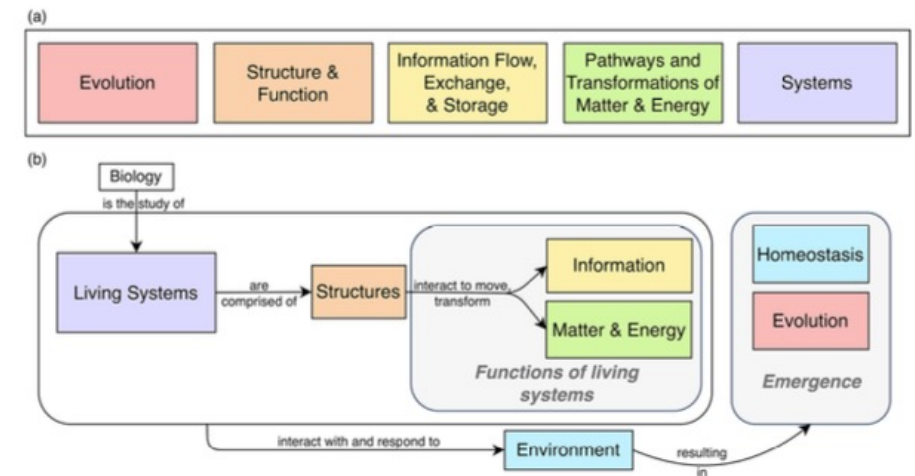FIGURE 1. The core concepts of biology as identified by *Vision & Change* (a) reconceptualized and expanded into the systems paradigm (b). Here, living systems are composed of structures that interact to perform diverse functions, subsequently interacting with and responding to the environment, giving rise to emergent processes, such as evolution and homeostasis.

Figure 1 from Momsen J. *et al.*, 2022

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Teaching-as-Research: *Acknowledgements*

- Seth Hunt
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- Sophie Buysse
- Berkley Walker
- Steering Committee

Literature Cited

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- Momsen, J., Speth, E. B., Wyse, S., & Long, T. (2022). Using Systems and Systems Thinking to Unify Biology Education. *CBE—Life Sciences Education, 21*(2), es3. doi:10.1187/cbe.21-05-0118