Abstract

In the past few years, we have been developing Interactive video-enhanced tutorials (IVETs) which include web-based activities that lead students through a solution using effective problem-solving strategies. The IVETs, which are designed by incorporating multimedia learning principles, are adaptive and provide different levels of feedback and guidance for different students. They also adapt to students' affect by providing additional guidance to students who indicate they are confused, frustrated, or bored while completing the IVETs. This presentation will showcase our IVET on Thermal Equilibrium and present results from implementing it in a calculus-based course taught online in the past year.

Improving student understanding of Thermal Equilibrium with an interactive tutorial

ALEXANDRU MARIES, KATHLEEN KOENIG,
UNIVERSITY OF CINCINNATI

ROBERT TEESE ROCHESTER INSTITUTE OF TECHNOLOGY

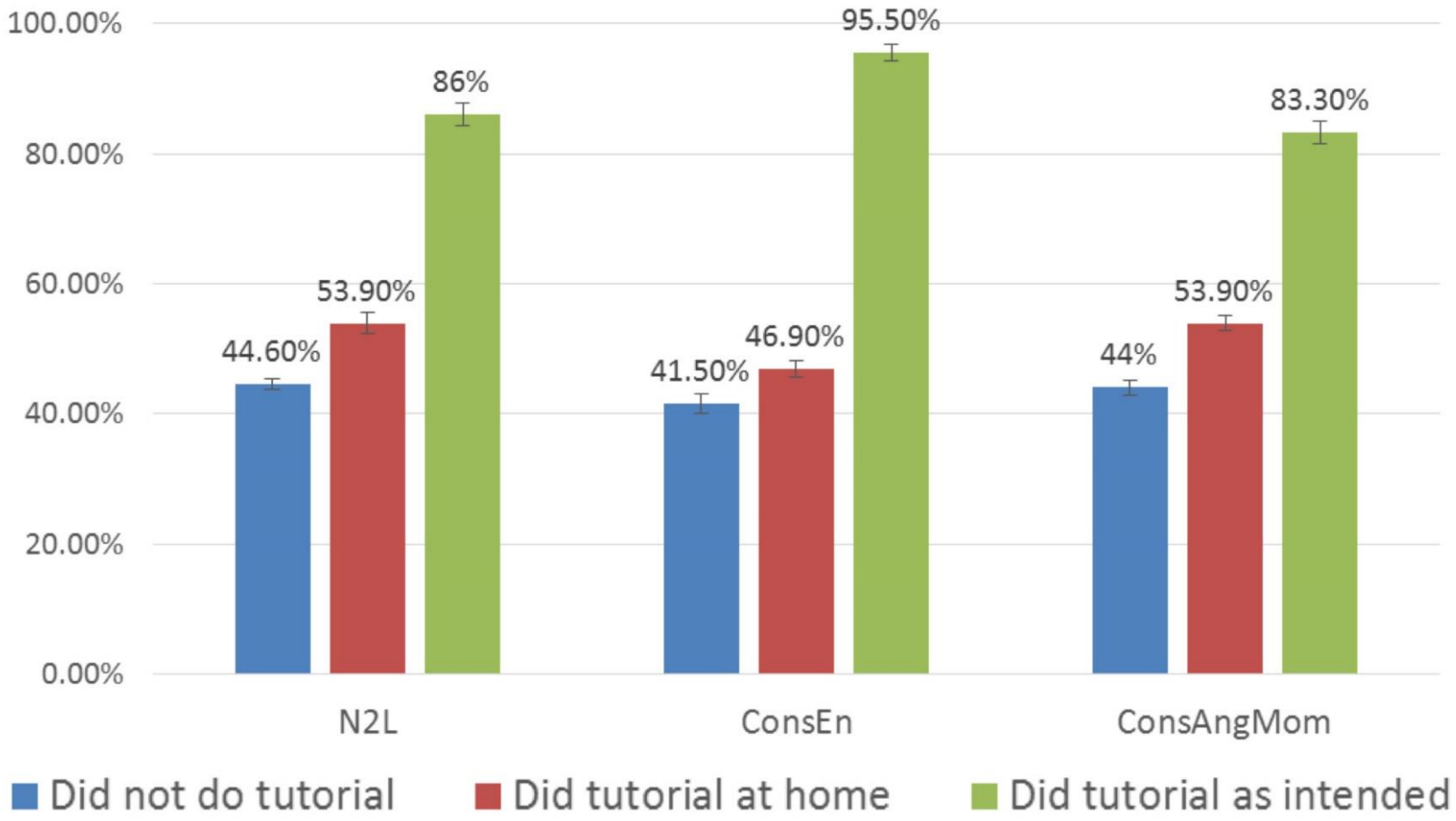
NSF IUSE DUE-1821396 NSF IUSE DUE-1821391

Problem Solving Tutorials – Univ of Pittsburgh

DeVore and Singh developed ~20 tutorials for introductory physics.

- Challenging problems
- Focus on problem solving skills
- Powerpoint
- Branching questions
- Guidance and feedback

Effectiveness of Tutorials



S. DeVore, E. Marshman, and C. Singh, “Challenge of engaging all students via selfpaced interactive electronic learning tutorials for introductory physics,” *Phys. Rev. ST Phys. Educ. Res.* **13** 010127, 1-18 (2017).

Interactive Video Vignettes (IVVs)

Designed to teach **concepts** for which students are known to struggle.

www.compadre.org/ivv or WebAssign

Project Goals

- Create and evaluate a set of 30 IVETs
- Conduct research on
  - impact of IVETs on student problem solving abilities
  - techniques that motivate appropriate student behavior when using IVETs
- Disseminate through ComPADRE, etc.

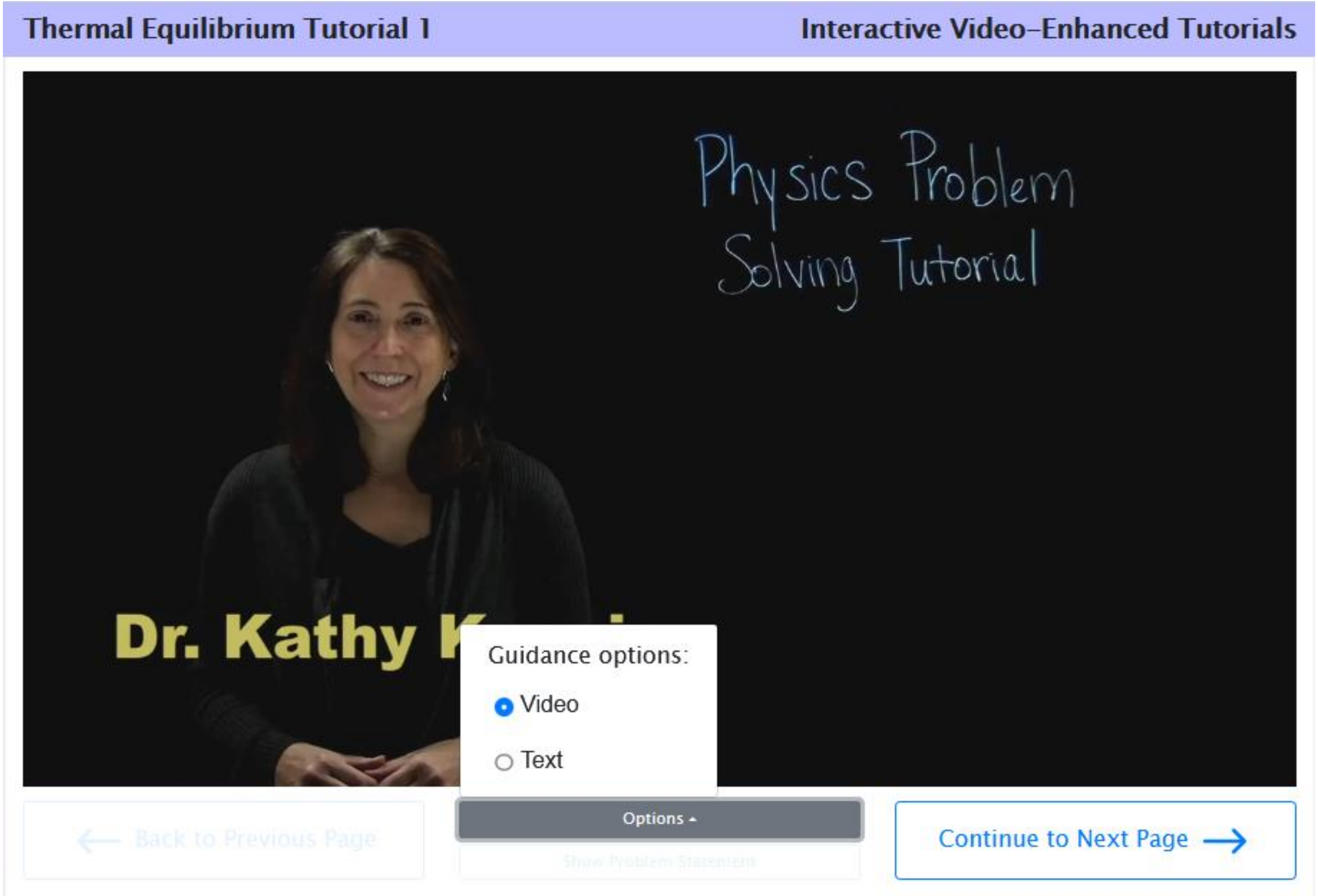
Features of Design of IVETs

- Developed based on multimedia learning principles (Mayer) and research on human learning and memory (Bransford)
- Problems challenge students while providing support designed to stretch students' zone of proximal development (Vygotsky)
- Student support delivered through mini-lectures, hints, or encouragement (affect) by a tutor (a real person in a video)

Features of Design of IVETs

- Multiple-choice questions guide students through an **expert-like problem-solving approach**
- Questions branch based on student responses, providing relevant feedback for incorrect (and correct) answers
- Self-paced
- 5-15 minutes

Thermal Equilibrium IVET



Text option

Here is the problem we'll use as an example in this tutorial.

In a container made of a perfect insulator, 150 g of ice at −5 °C is added to 500 g of water at 20 °C.

How much ice, if any, is left when thermal equilibrium is reached?

What is the final equilibrium temperature of the system?

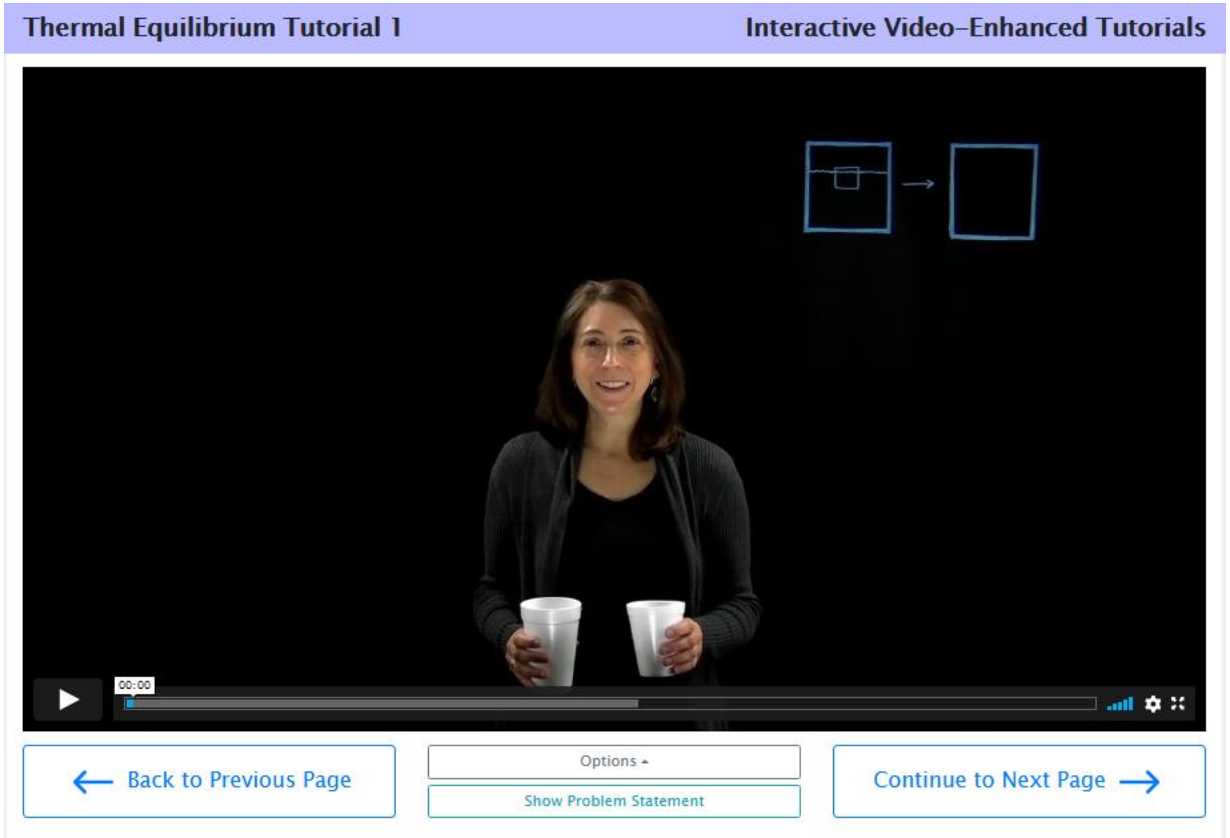
← Back to Previous Page

Options ▴

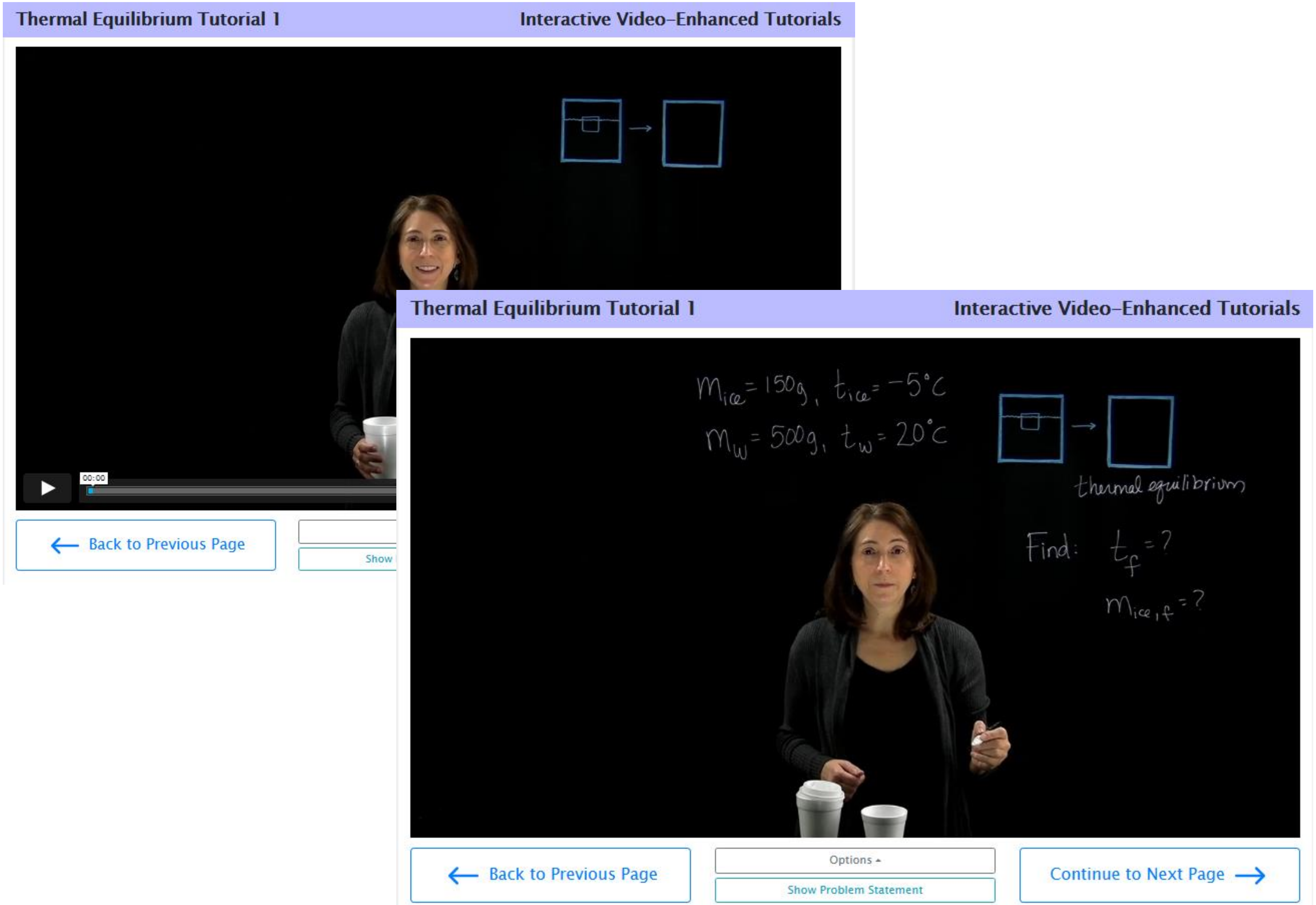
Show Problem Statement

Continue to Next Page →

Video option: Narrator presents problem to be solved.

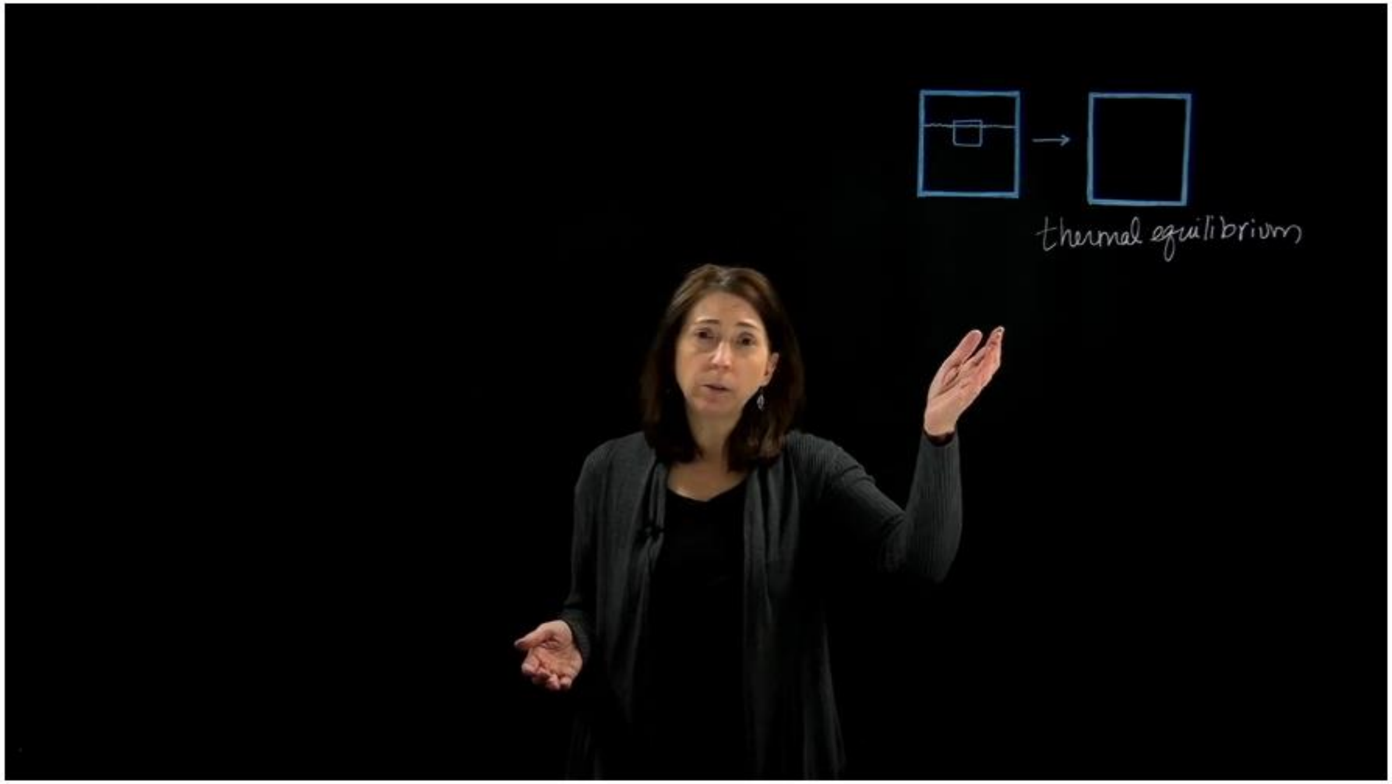


Video option: Narrator presents problem to be solved.



Tutorial starts by asking to identify the objects that are in thermal contact

Thermal Equilibrium Tutorial 1 **Interactive Video-Enhanced Tutorials**



Q1: Which objects are in thermal contact in this problem?

○ A. Water and the perfectly insulated container.

○ B. Ice and water.

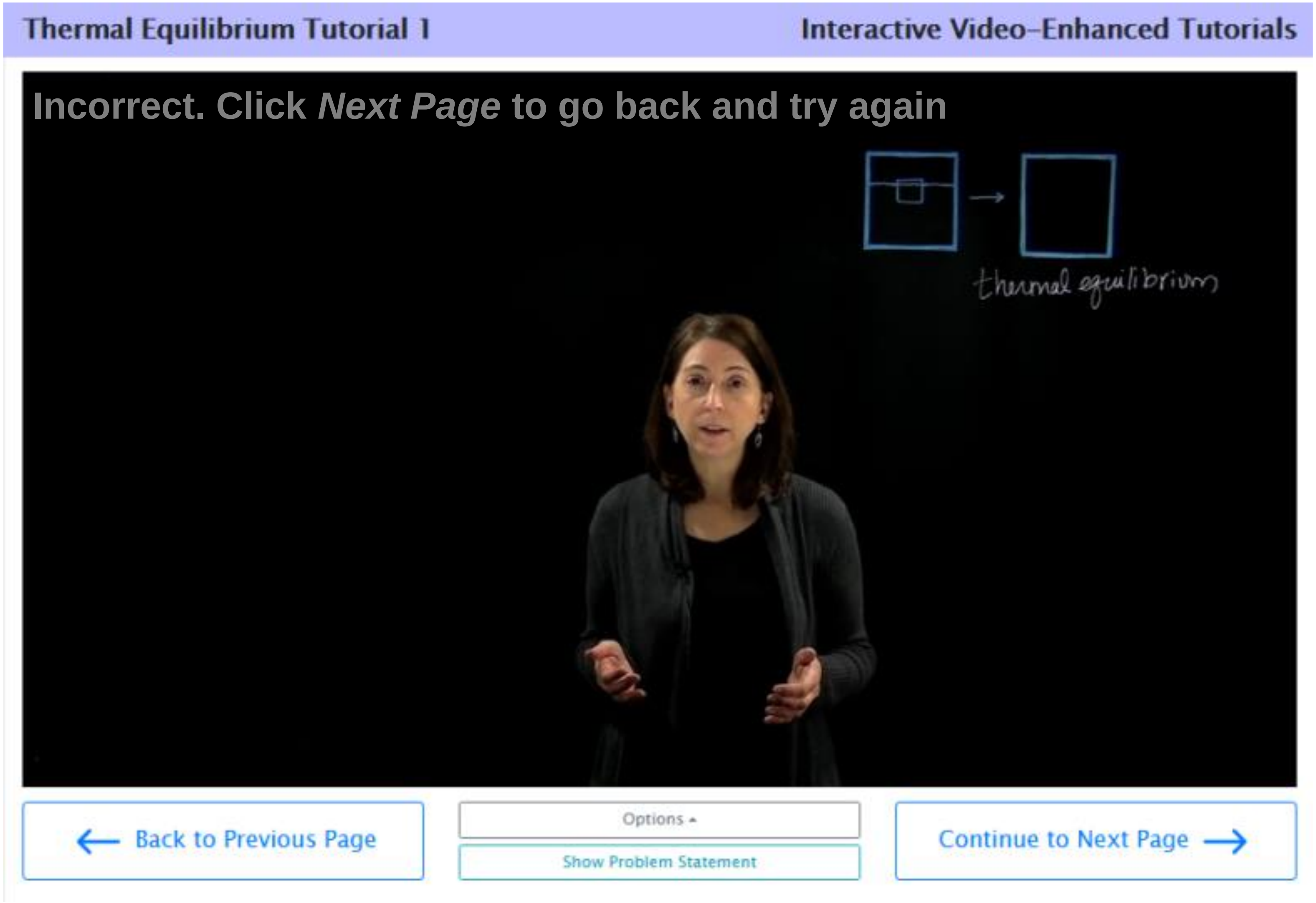
○ C. Ice, water, and the perfectly insulated container.

○ D. Ice, water, the perfectly insulated container, and the environment.

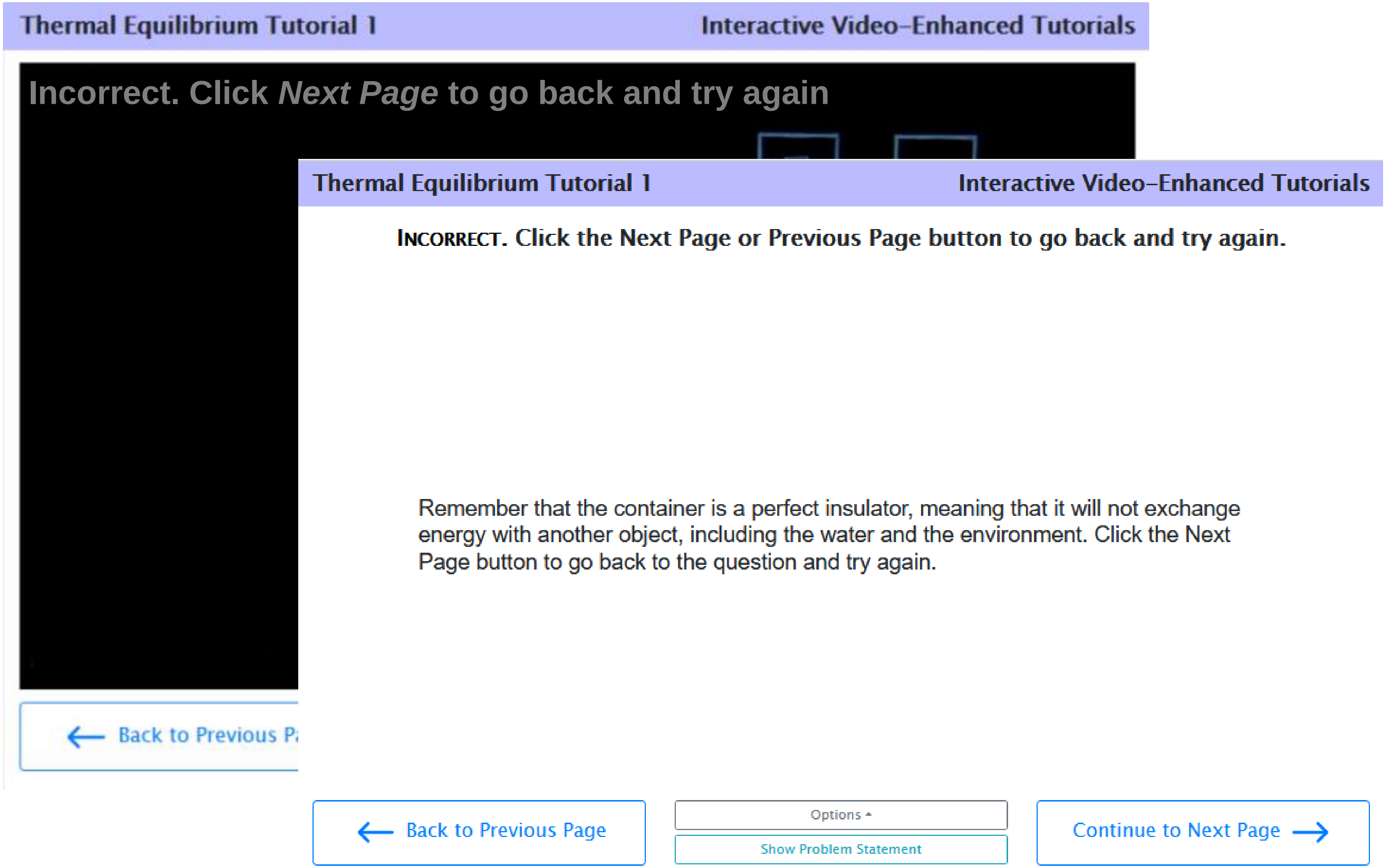
Show comments by other students

← Back to Previous Page | Options ▴ | Show Problem Statement | Continue to Next Page →

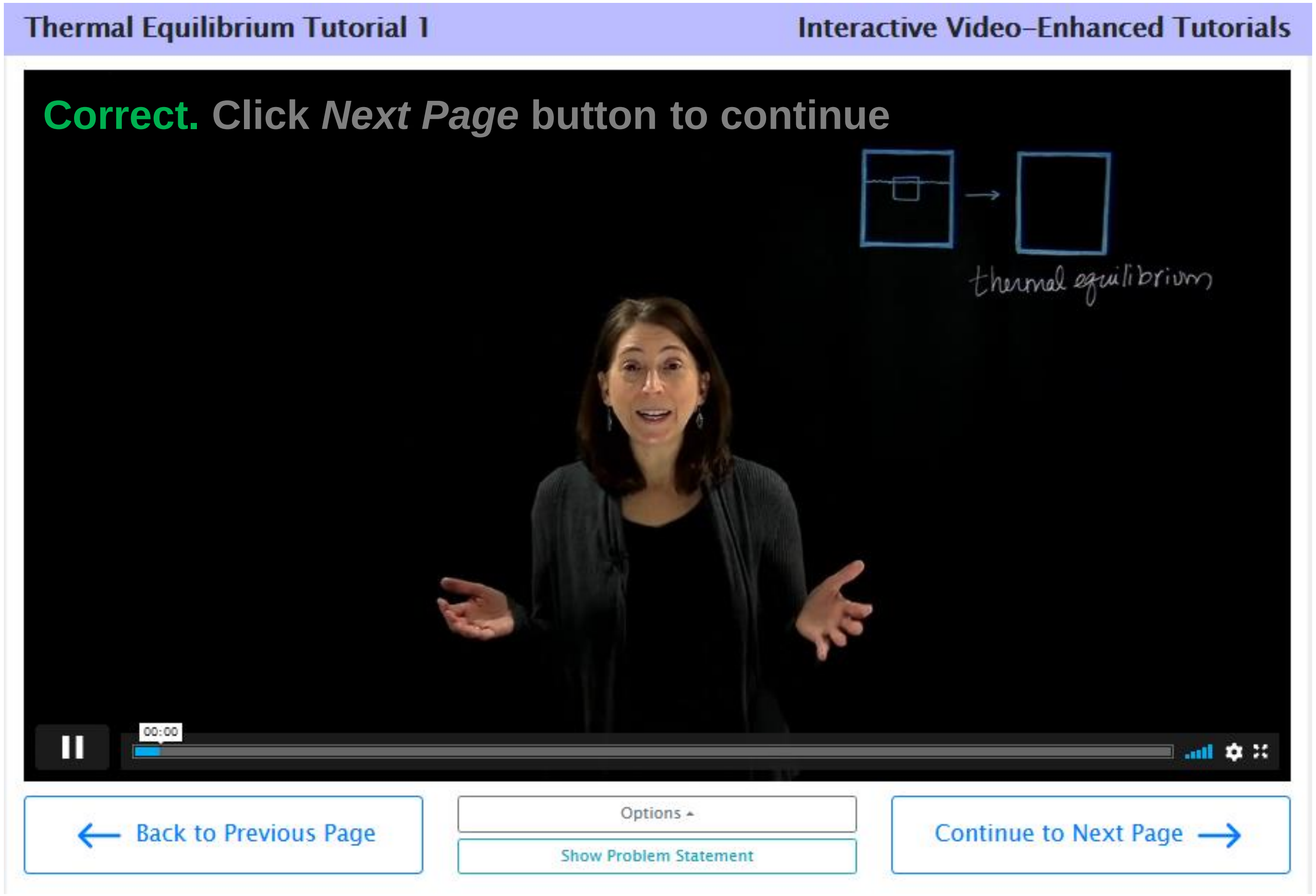
Feedback is provided for all incorrect as well as correct responses.



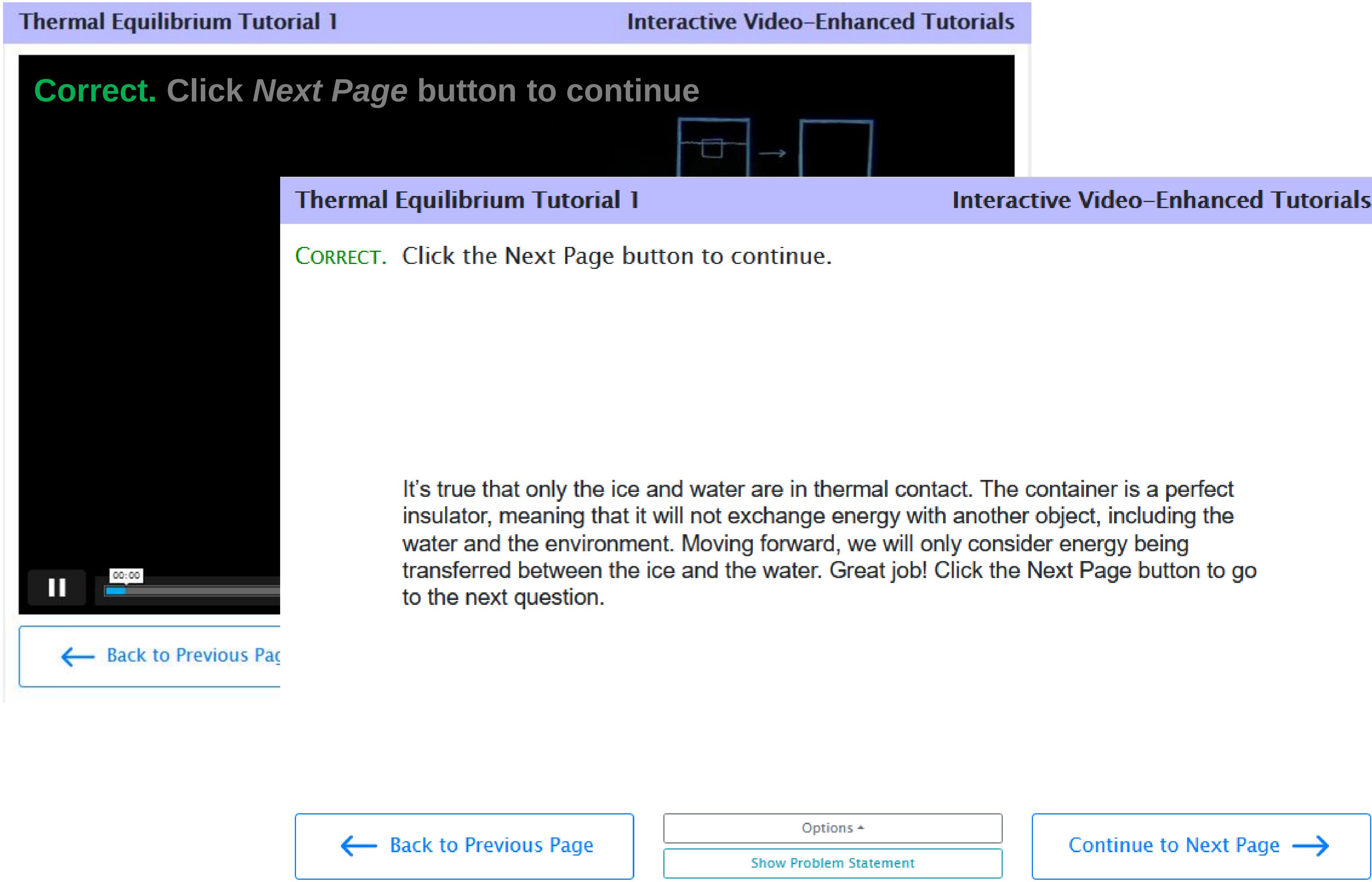
Feedback is provided for all incorrect as well as correct responses.



Feedback is provided for all incorrect as well as correct responses.

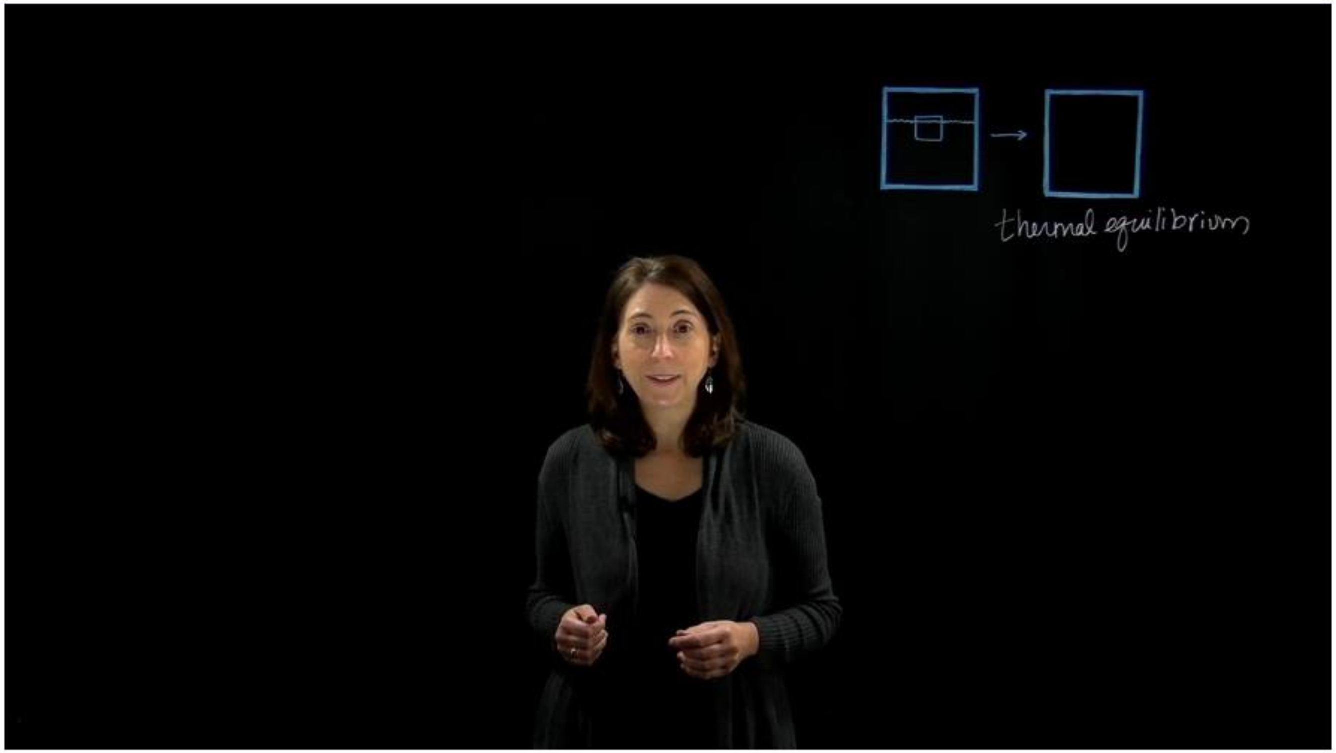


Feedback is provided for all incorrect as well as correct responses.



Multiple select questions used whenever practical to dissuade guessing

Thermal Equilibrium Tutorial 1 | **Interactive Video–Enhanced Tutorials**



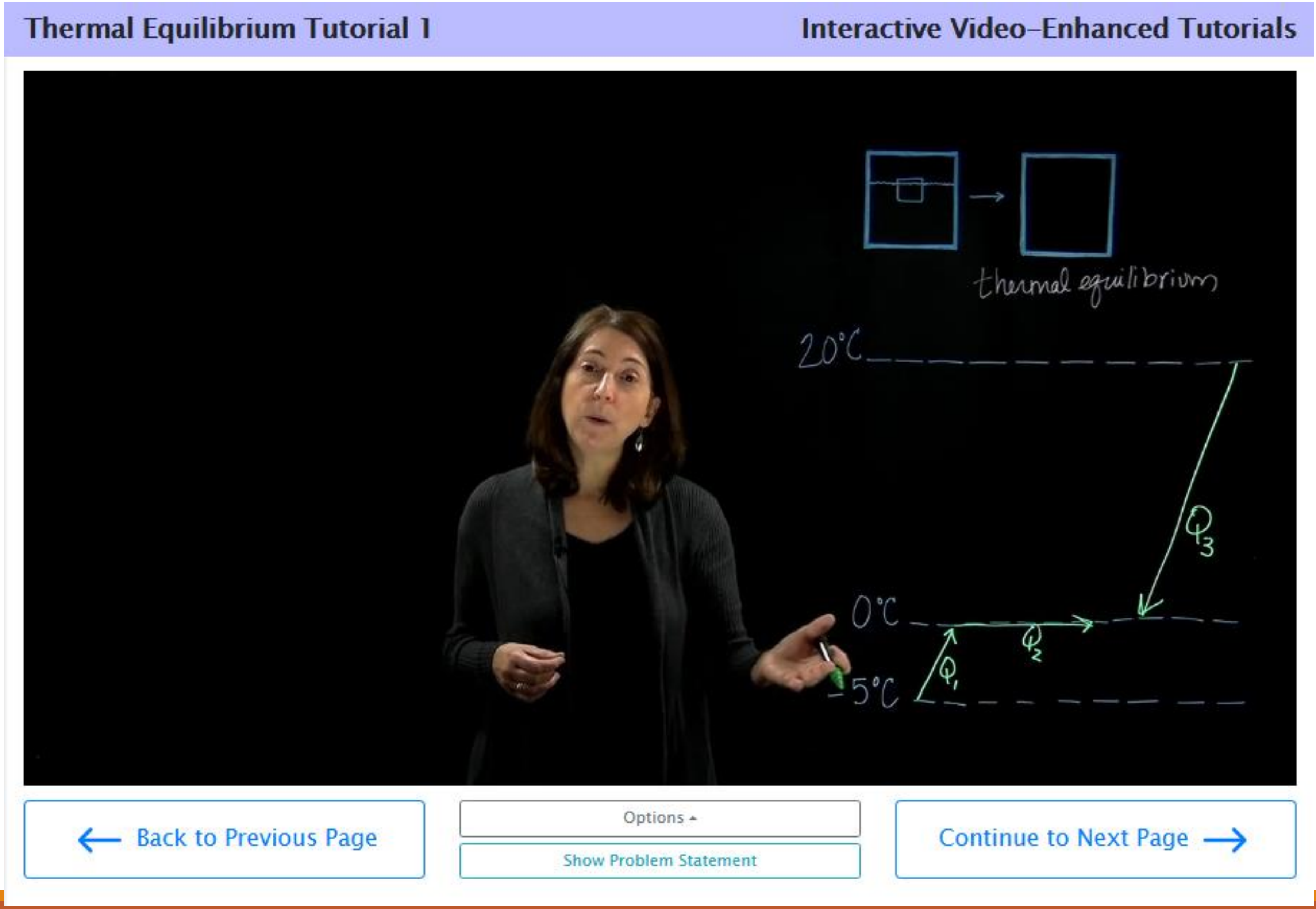
Q3: Which statement(s) is/are true about any system when it has reached thermal equilibrium? Choose all statements that are true.

- ☐ A. All components of the system are in the same state, such as all are liquids.
- ☐ B. All elements of the system have reached the same temperature.
- ☐ C. The transfer of energy has stopped.
- ☐ D. The total mass of the system will change if there is a phase change.

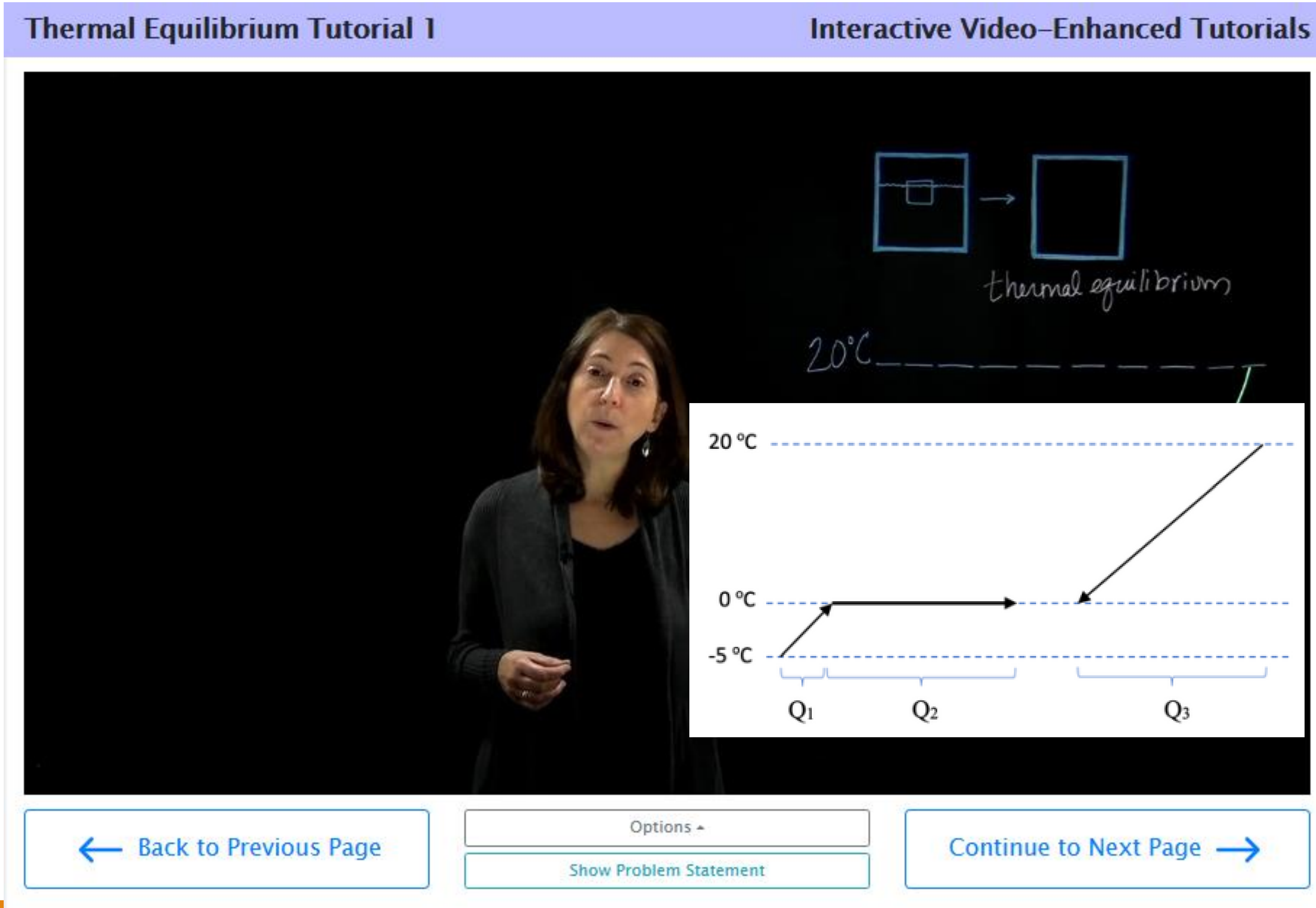
Show comments by other students

← Back to Previous Page | Options ▴ | Show Problem Statement | Continue to Next Page →

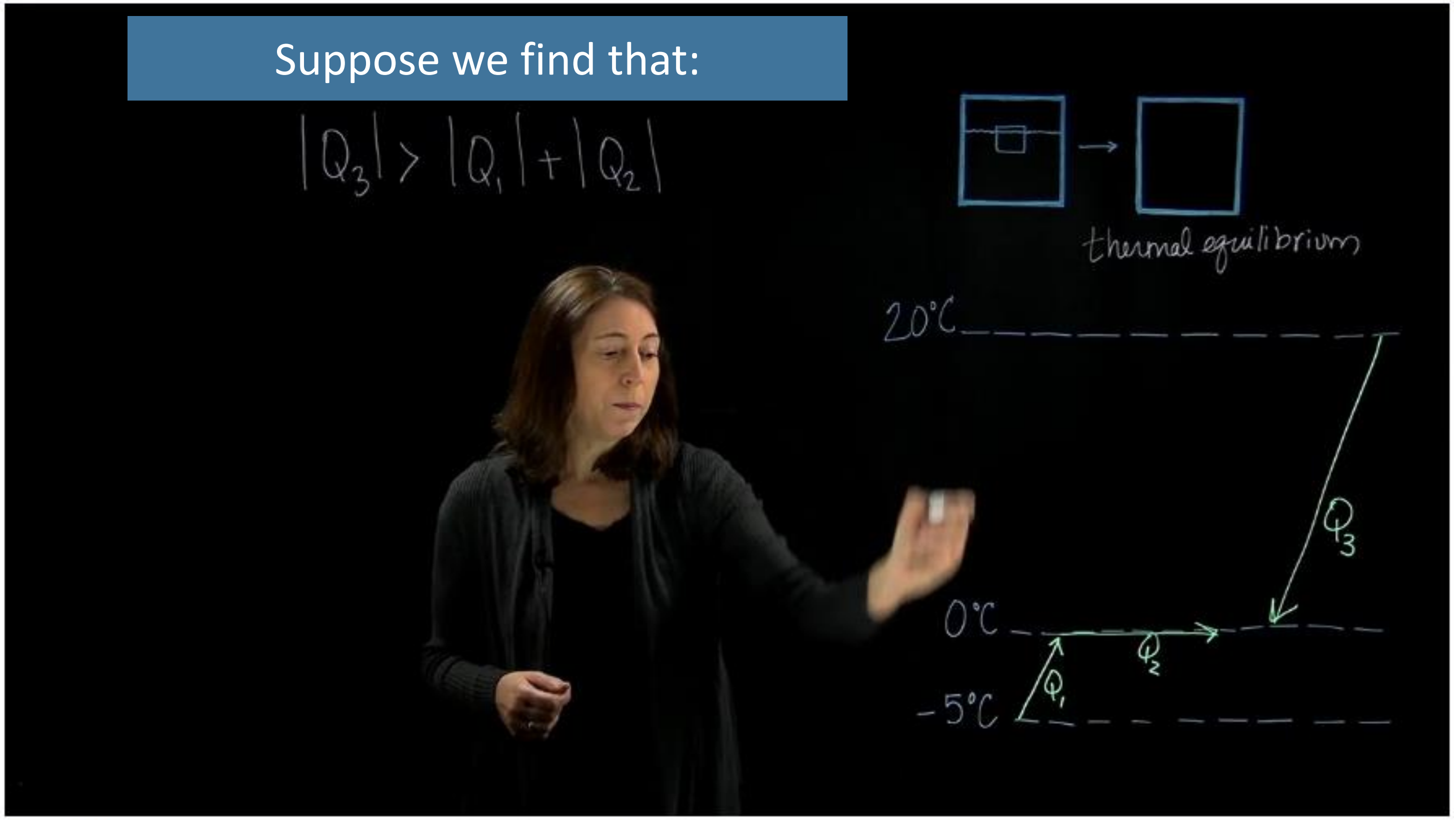
Conceptual emphasis and use of representations



Conceptual emphasis and use of representations



Conceptual emphasis and use of representations



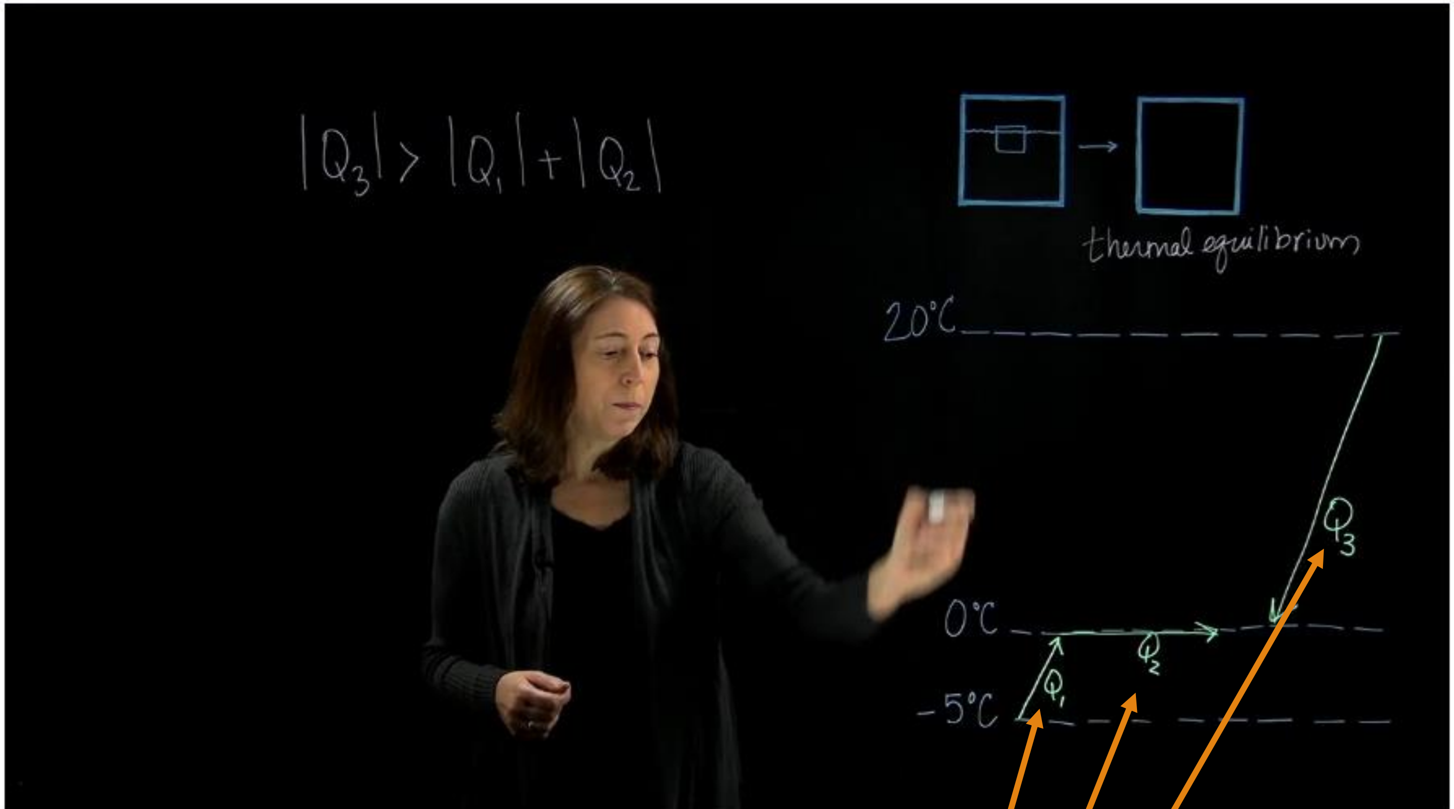
Q4: Which of the following must be true about the final temperature of the system given this scenario?

- A. It is between −5 °C and 0 °C.
- B. It is 0 °C.
- C. It is between 0 °C and 20 °C.

Show comments by other students

← Back to Previous Page | Options ▴ | Show Problem Statement | Continue to Next Page →

Conceptual emphasis and use of representations



Q4: Which of the following must be true about the final temperature of the system given this scenario?

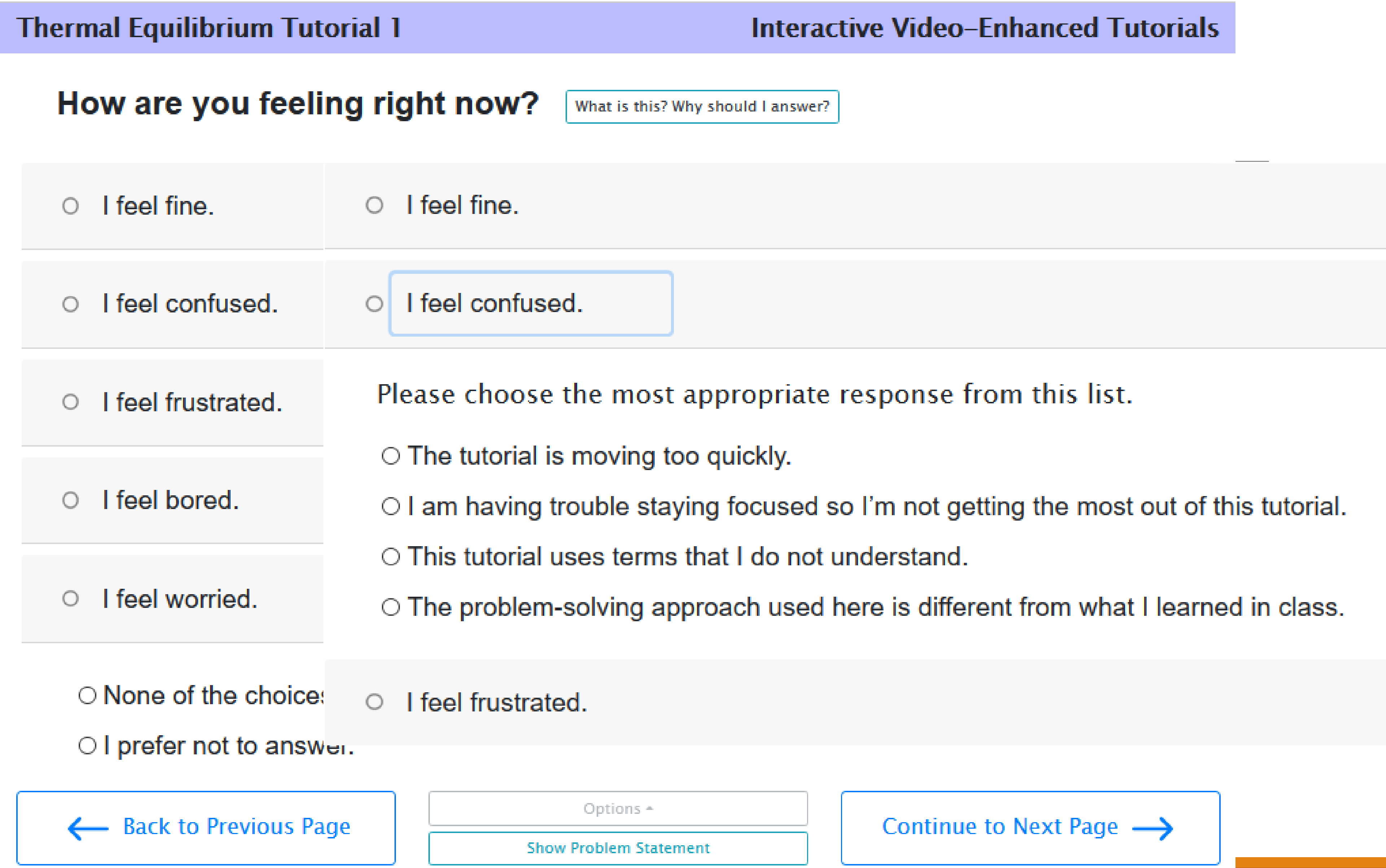
- A. It is between −5 °C and 0 °C.
- B. It is 0 °C.
- C. It is between 0 °C

Show comments by other students

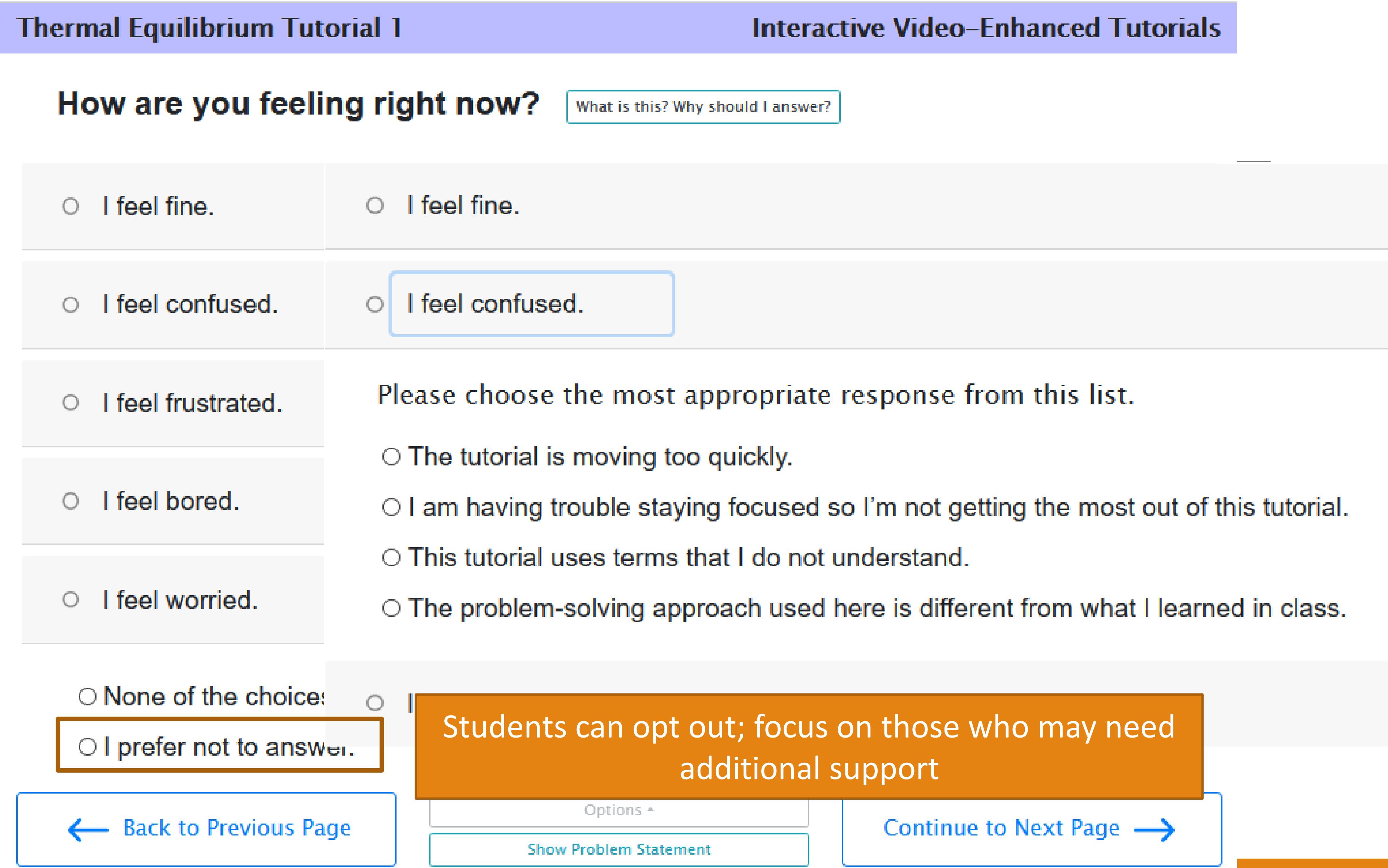
Students are then guided to calculate each heat, one by one
Focus on recognizing which specific/latent heat values to use
and how to write the change in temperature.

← Back to Previous Page | Options | Show Problem Statement | Continue to Next Page →

Tutorial responds to student affective states to help with motivation to engage



Tutorial responds to student affective states to help with motivation to engage



Affective responses

- Main goal is to help motivate students to engage properly with tutorial
- Important emotions to respond to obtained from literature on computer tutors and consultation with an expert in computational models of emotion
- Emotions are always validated first, then:
  - Confused: provided advice and more support
  - Frustrated/worried: emotional support and advice where appropriate
  - Bored: reminded that tutorial provides a problem solving strategy applicable to many problems

Affective response: Example

- Confused because tutorial is moving too quickly:
  - Yes, this problem certainly can be confusing and it has many different parts (validation)
  - Here are some things you can do to slow the problem down and regain focus:
    - Reread the problem statement. That will help you remember the end goal of the problem as well as keep the big picture in mind
    - You can also make sure that you are taking clear notes every step of the way; look over them
    - Sometimes, it's also helpful to just take a short break
    - On the next page, we're going to give you the option to watch a summary of what we've done so far. This will help recap the big picture of what we are doing and you should definitely choose that option.

Affective response: Example

- Confused because tutorial is moving too quickly:
  - Yes, this problem certainly can be confusing and it has many different parts (validation)

Similar approach for other affective states.

Content of the feedback (exact words) as well as the demeanor (tone, posture, facial expressions) developed in consultation with the expert in computational models of emotion.

  - Sometimes, it's also helpful to just take a short break
  - On the next page, we're going to give you the option to watch a summary of what we've done so far. This will help recap the big picture of what we are doing and you should definitely choose that option.

After answering the affect question, students provided with option to watch a summary of what was done so far

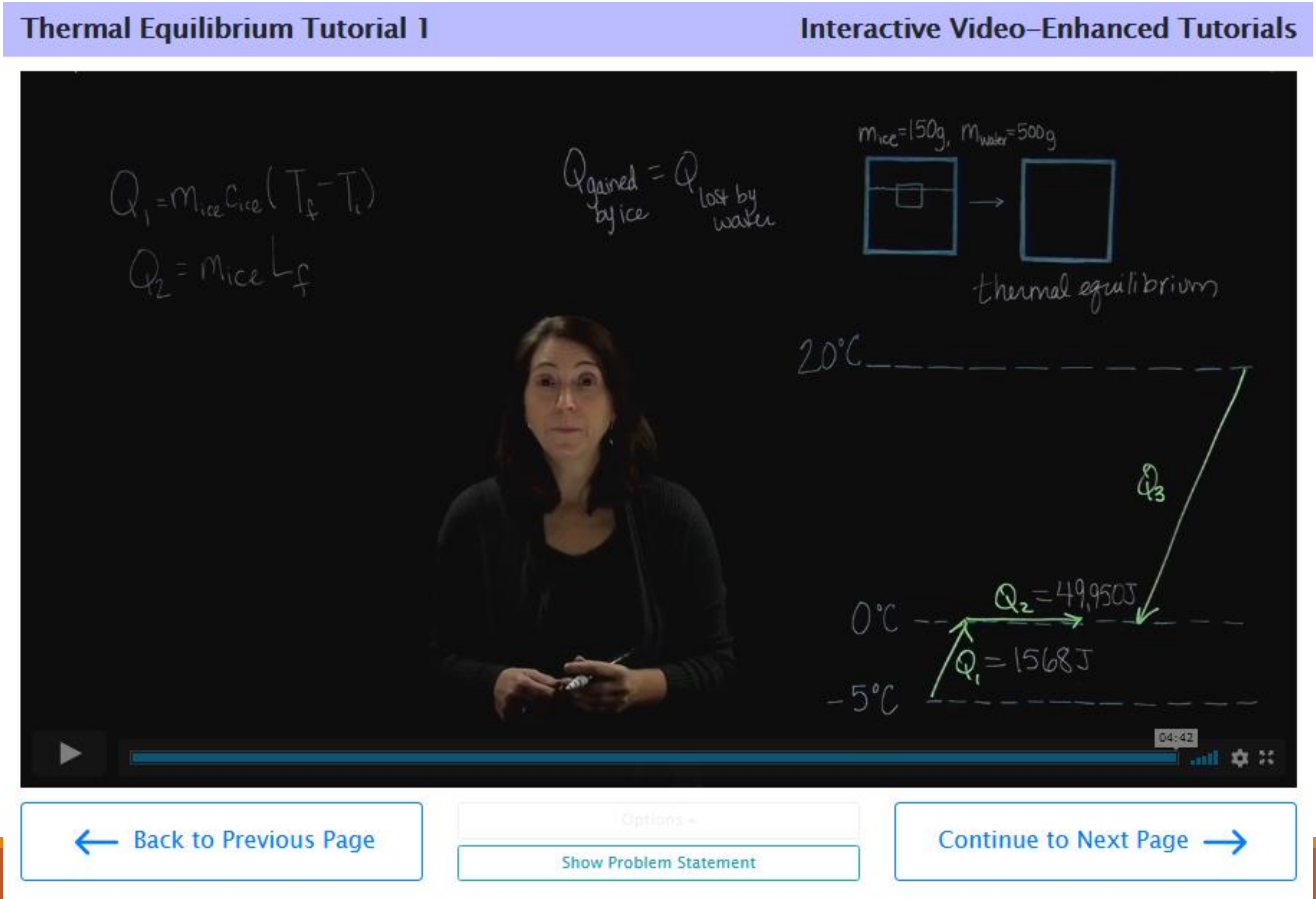
Thermal Equilibrium Tutorial 1 | **Interactive Video–Enhanced Tutorials**

Do you want to see a video summary of what we have done so far, or would you rather continue with the tutorial?

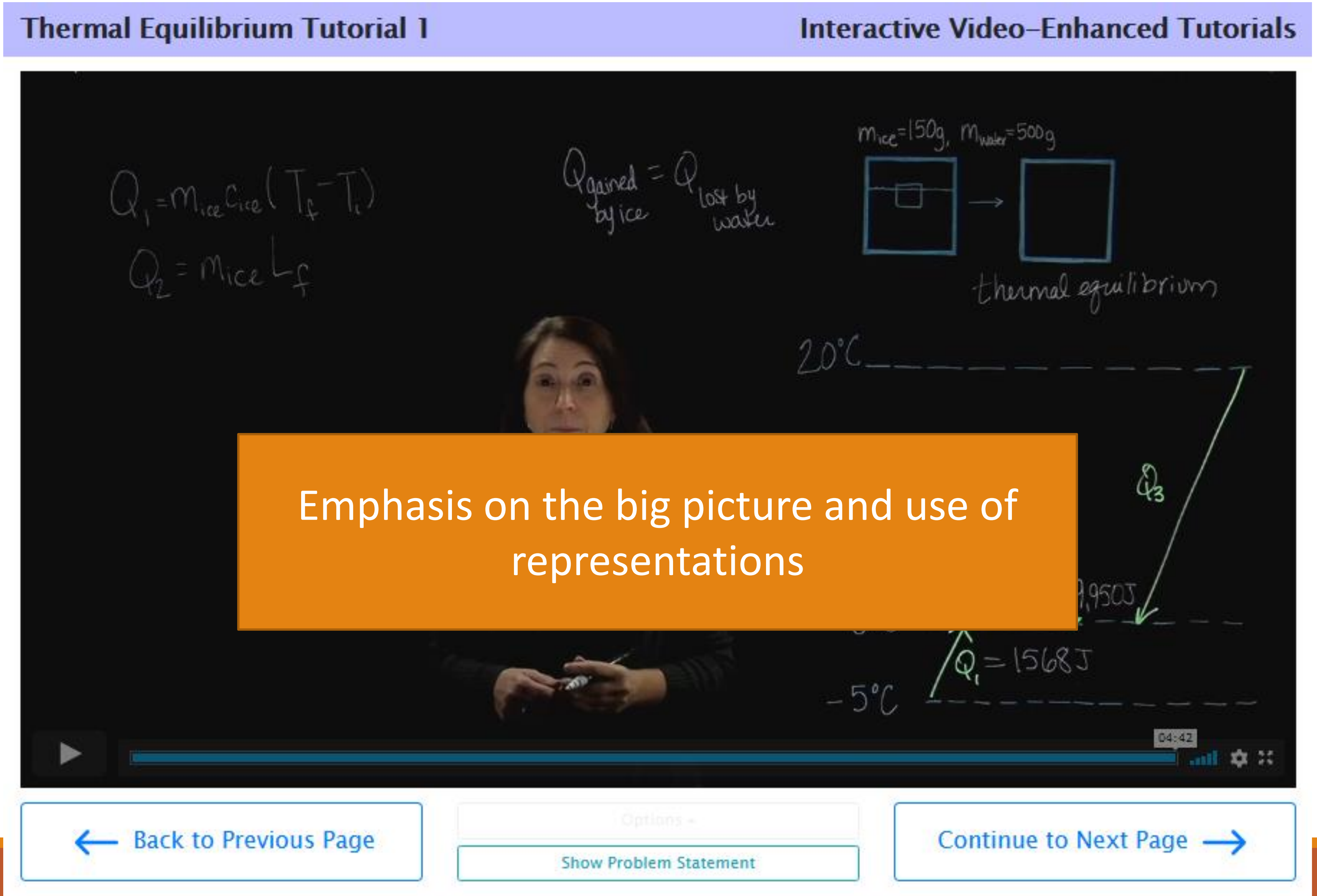
- A. Watch a video summary.
- B. Continue with the tutorial.

← Back to Previous Page | Options | Show Problem Statement | Continue to Next Page →

After answering the affect question, students provided with option to watch a summary of what was done so far



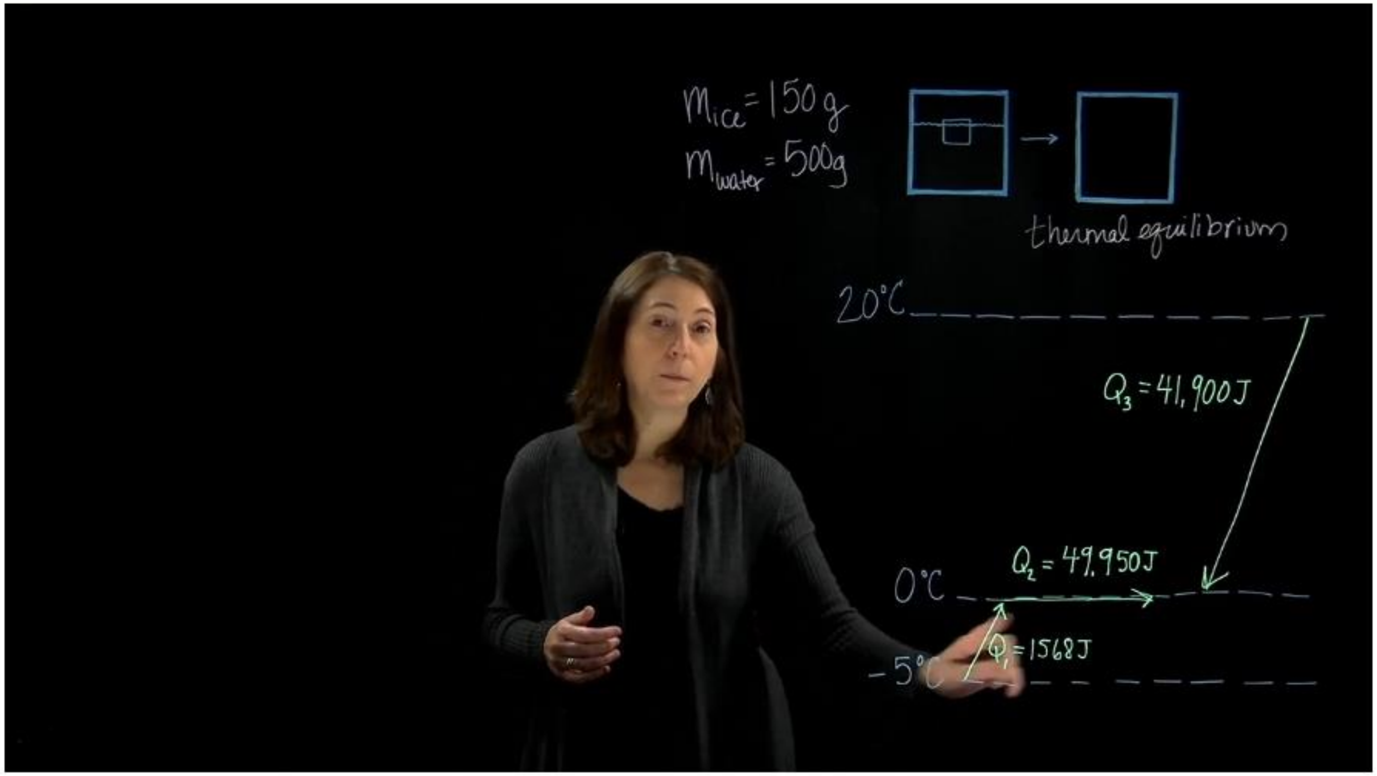
After answering the affect question, students provided with option to watch a summary of what was done so far



Emphasis on the big picture and use of representations

After calculating all the heats, students determine the final temperature range

Thermal Equilibrium Tutorial 1 **Interactive Video–Enhanced Tutorials**

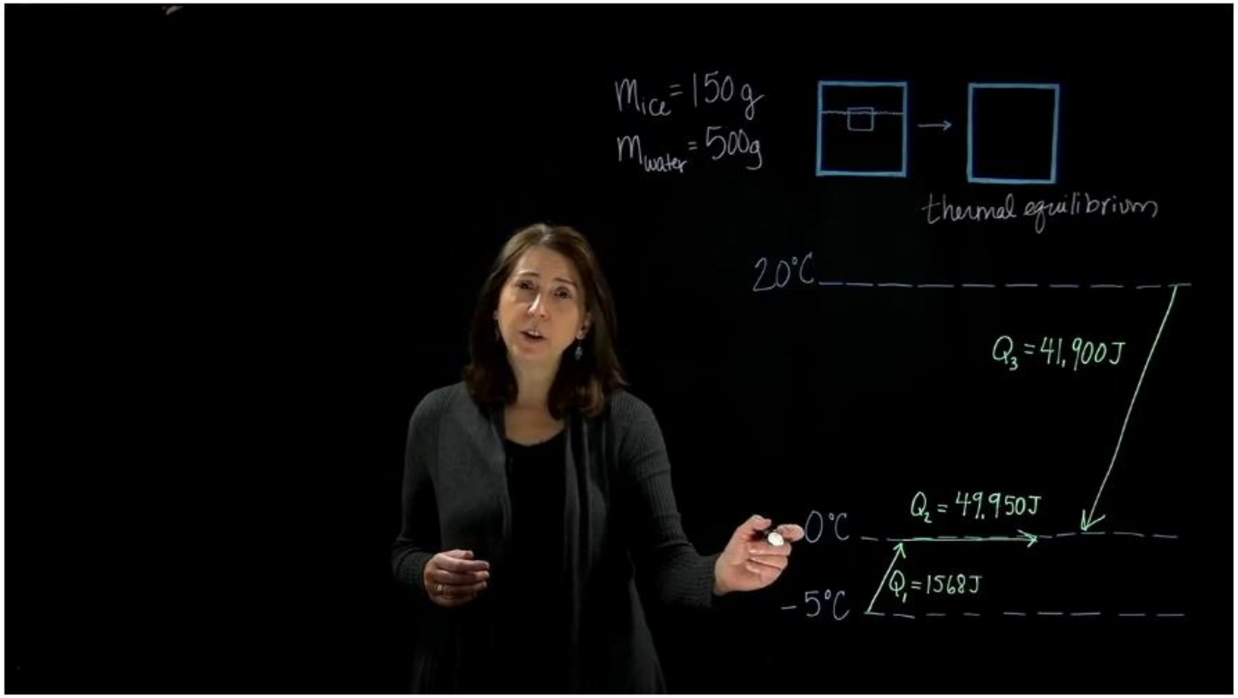


Q8. Which of the following statements is correct?

- ○ A. All of the ice melts and the temperature of the final mixture is > 0 °C.
- ○ B. Some of the ice melts and the temperature of the final mixture is > 0 °C.
- ○ C. Some of the ice melts and the temperature of the final mixture is 0 °C.
- ○ D. Some of the ice melts and the temperature of the final mixture is < 0 °C.
- ○ E. None of the ice melts and the temperature of the final mixture is < 0 °C.

Students then determine the amount of energy available to melt the ice, and how much ice remains at equilibrium

Thermal Equilibrium Tutorial 1 **Interactive Video–Enhanced Tutorials**

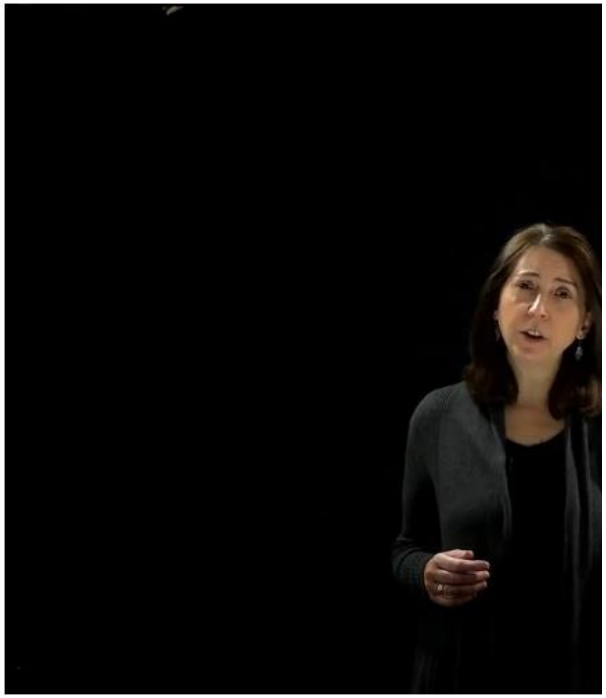


Q9. Use the ideas above and determine how much energy is actually available to melt the ice, which was initially at −5 °C.

- A. 6,482 J
- B. 8,050 J
- C. 9,618 J
- D. 40,332 J
- E. 93,418 J

Students then determine the amount of energy available to melt the ice, and how much ice remains at equilibrium

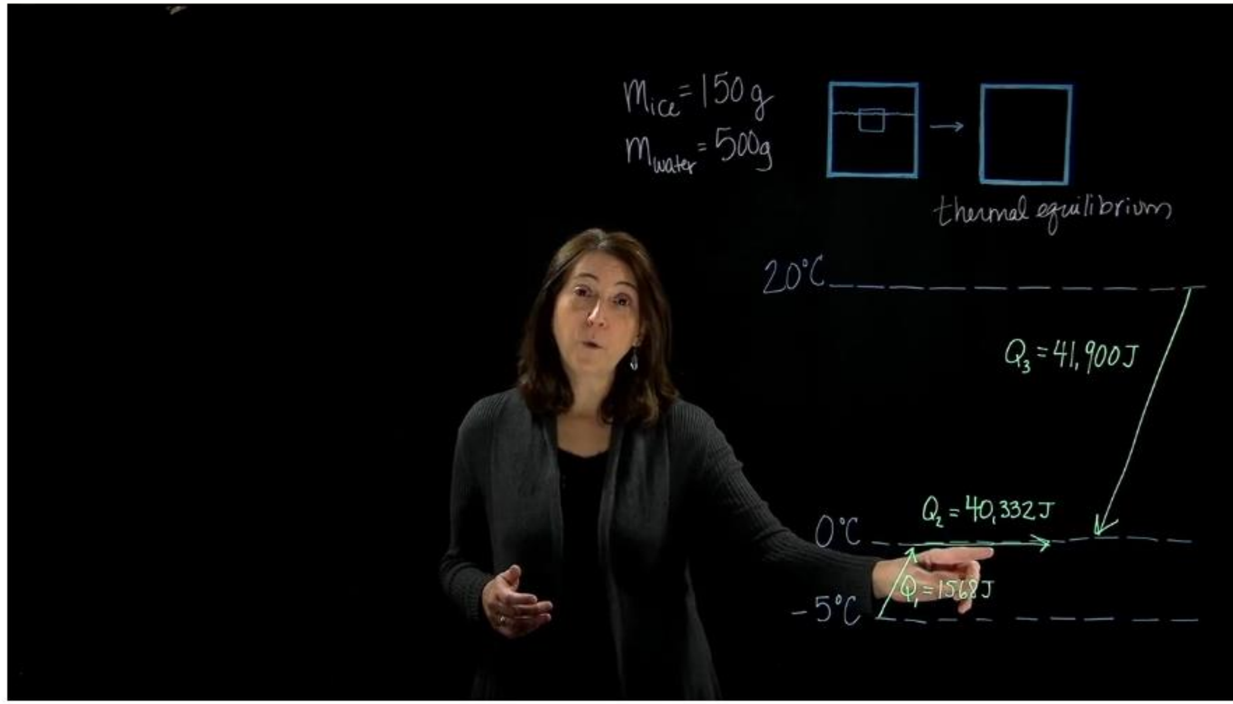
Thermal Equilibrium Tutorial 1



Q9. Use the ideas above and determine how much e
initially at −5 °C.

- A. 6,482 J
- B. 8,050 J
- C. 9,618 J
- D. 40,332 J
- E. 93,418 J

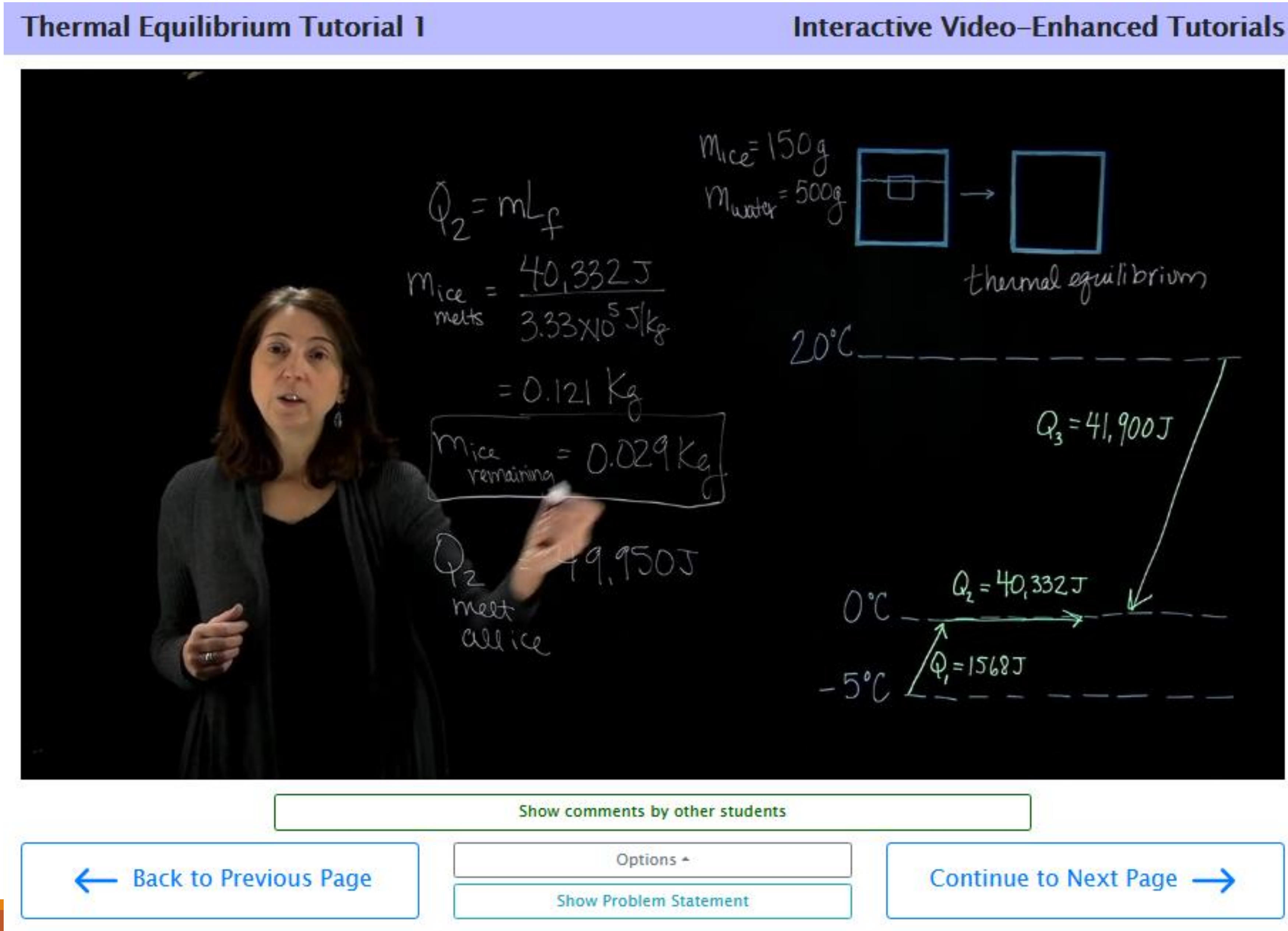
Thermal Equilibrium Tutorial 1 **Interactive Video–Enhanced Tutorials**



Q10. Let m represent the mass of the remaining ice. Which of the following is correct? .

- A. m = 0.018 kg
- B. m = 0.029 kg
- C. m = 0.121 kg
- D. m = 0.132 kg

Narrator does a check of the final answer (units, reasonableness)



Students provided option to watch a summary after finishing the problem

Thermal Equilibrium Tutorial 1 | **Interactive Video–Enhanced Tutorials**

There is still one more question. But first, do you want to see a video summary of what we have done so far?

○ A. Watch a video summary, then go to question Q11.

○ B. Continue to question Q11.

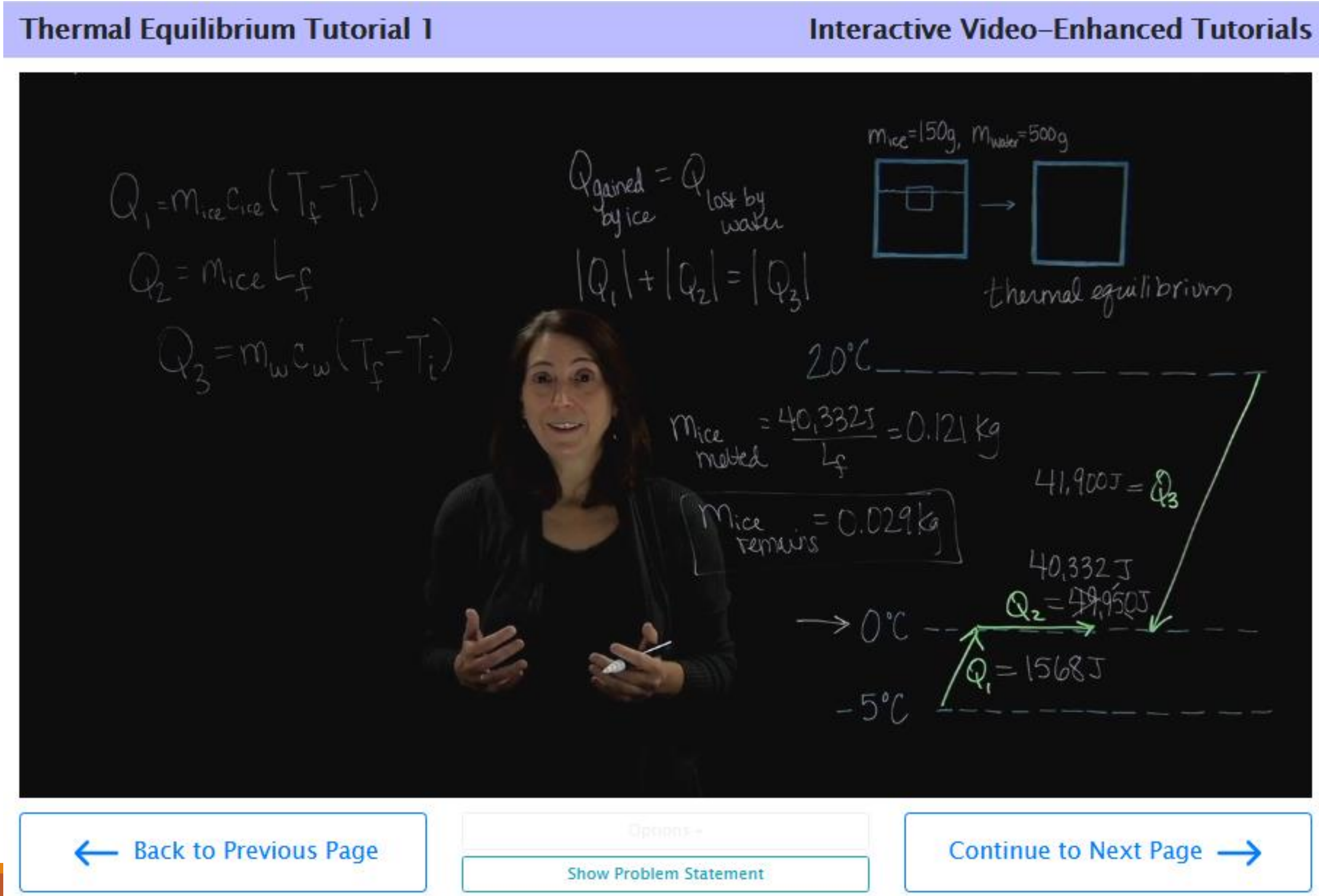
← Back to Previous Page

Options ▴

Show Problem Statement

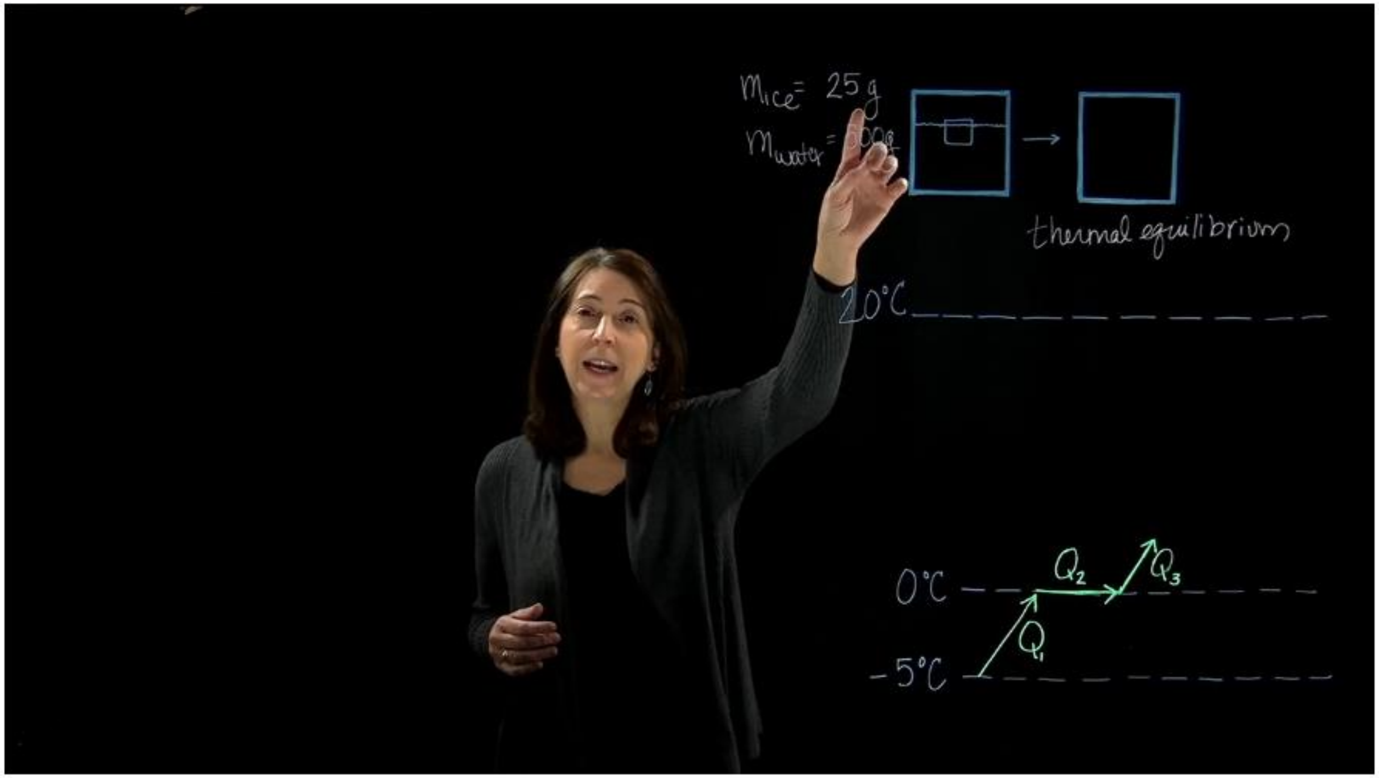
Continue to Next Page →

Video summary is ~8 minutes long.



Reducing guidance to help students develop self-reliance

Thermal Equilibrium Tutorial 1 **Interactive Video–Enhanced Tutorials**



Q11. Which equation would help us get started in solving for the final temperature when thermal equilibrium is reached? Q_4 represents the energy released by the warmer water.

- A. $|Q_1| + |Q_2| + |Q_3| = |Q_4|$
- B. $Q_1 + Q_2 + Q_3 = Q_4$
- C. $|Q_1| + |Q_2| = |Q_3| + |Q_4|$
- D. $Q_1 + Q_2 = Q_3 + Q_4$
- E. $Q_1 + Q_2 + Q_3 + Q_4 = 0$

List what things you learned from this tutorial.

Also, the developers would appreciate any feedback about how well the activity worked (technical problems, for example).

(Optional) Please answer the following question to help us improve the tutorial in the future. Your instructor will not see your response.

Midway through this tutorial, you were asked how you feel. Please share your thoughts about being asked this question as well as about the feedback you received after making a selection.

Then click the *Next Page* button in the lower right corner to finish.

← Back to Previous Page

Options

Show Problem Statement

Continue to Next Page →

Does IVET impact student problem solving ability?

Two sections of calculus-based physics included in study

- Same instructor, materials, homework, exams
- Instruction related to specific and latent heat, some problems, but none in which the temperature range was not known
- One section given the Thermal Equilibrium IVET to complete at home
- One section given ~8 minute solution video showcased in the IVET to watch
- Given as a prelecture
- Both groups given a transfer problem to complete in class (as a quiz) on the day the assignment was due.
  - Done during COVID -> students had 15 min to complete the quiz and scan and submit their solutions online
  - They could use any resource available (notes, textbook, even IVET/video)

Assessing Impact: Transfer Problem

In a container made of a perfect insulator, 80 g of water at 25 °C is combined with 10 g of steam at 110 °C. In which range will the final temperature of the system be it reaches equilibrium?

a. $T_f > 100$ °C
b. $T_f = 100$ °C
c. $T_f < 100$ °C

⇨ In the space below, show all calculations to justify your answer.

Assessing Impact: Transfer Problem

Distinguish students who learned something from IVET/video: did not try to calculate final temperature (did not include equations with T_f).

Group	IVET (N = 85)	Video (N = 103)
Tried to use approach from IVET/video	49.4%	41.7%

Slightly more students in the IVET group tried to use the approach they learned in the IVET, but not statistically significant (Chi-square test: *p* value 0.293).

Possible explanations for results

- No control over resources used during quiz
  - Limited time (15 min) but students could use anything since they were not monitored
- Difficult problem:
  - Does not ask for final temperature
  - Need to understand transfer of energy to be able to solve it
  - Cannot apply algorithmic approach (e.g., $Q_{hot} = -Q_{cold}$)
    - Roughly 50% of students tried
  - Single exposure to this type of problem via IVET/video
- Students from the section that got the video generally performed better than the other students
  - Classes taught back to back with same clicker questions and group problems -> video section generally did better
  - Slightly better performance on exams (75.9% compared to 72.6%)

Thank you!

If you are interested in seeing or using the IVETs we have, please email me!

alexandru.maries@uc.edu

IVETs we have developed so far:

- Thermal equilibrium
- Newton's 2nd Law (force on two blocks)
- Conservation of Energy (will string break on tire swing?)
- Linear Momentum and Energy (pendulum balls collide)
- Static Equilibrium (person on ladder leaning against wall)
- Torque and rotation (two masses hanging from pulley with two radii)
- Angular Momentum (bullet shot into wheel)