

# Abstract

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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

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TECHNOLOGY



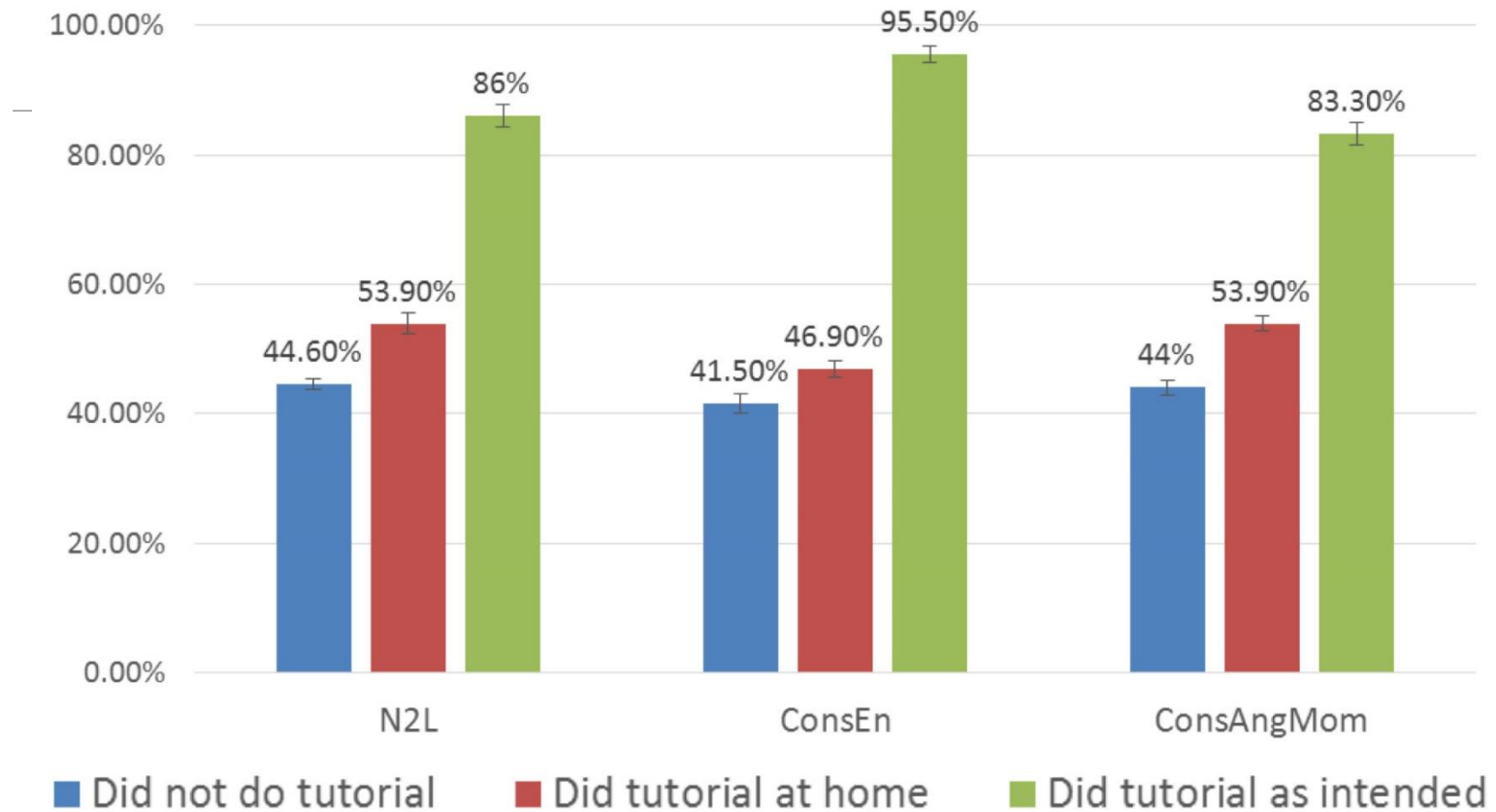
# Problem Solving Tutorials – Univ of Pittsburgh

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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 self-paced interactive electronic learning tutorials for introductory physics," *Phys. Rev. ST Phys. Educ. Res.* **13** 010127, 1-18 (2017).

# Interactive Video Vignettes (IVVs)

NEWTON'S THIRD LAW

INTERACTIVE VIDEO VIGNETTE



*Question 1: Which car exerts a larger force on the other car during the collision?*

- The heavier, faster car exerts a larger force on the small car.
- The forces exerted by both cars are equal.
- The lighter, slower car exerts a larger force on the large car.

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

[www.compadre.org/ivv](http://www.compadre.org/ivv)  
or WebAssign

# Project Goals

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- 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

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- 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

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- 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

Thermal Equilibrium Tutorial 1

Interactive Video-Enhanced Tutorials

Physics Problem Solving Tutorial

**Dr. Kathy K...**

Guidance options:

- Video
- Text

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# 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  $-5\text{ }^{\circ}\text{C}$  is added to 500 g of water at  $20\text{ }^{\circ}\text{C}$ .

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

What is the final equilibrium temperature of the system?

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# Video option: Narrator presents problem to be solved.

Thermal Equilibrium Tutorial 1

Interactive Video-Enhanced Tutorials



The video player shows a woman with dark hair, wearing a dark cardigan over a black top, holding two white plastic cups. She is smiling and looking towards the camera. In the background, there is a black screen with a blue diagram. The diagram consists of a large square on the left containing a smaller square in its upper-left corner, with an arrow pointing to a single large square on the right. The video player interface includes a play button, a progress bar showing 00:00, and icons for volume, settings, and full screen.

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# Video option: Narrator presents problem to be solved.

Thermal Equilibrium Tutorial 1

Interactive Video-Enhanced Tutorials

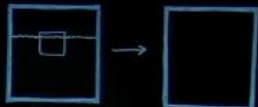


Thermal Equilibrium Tutorial 1

Interactive Video-Enhanced Tutorials



$m_{ice} = 150g, t_{ice} = -5^{\circ}C$   
 $m_w = 500g, t_w = 20^{\circ}C$

  
thermal equilibrium

Find:  $t_f = ?$   
 $m_{ice, f} = ?$

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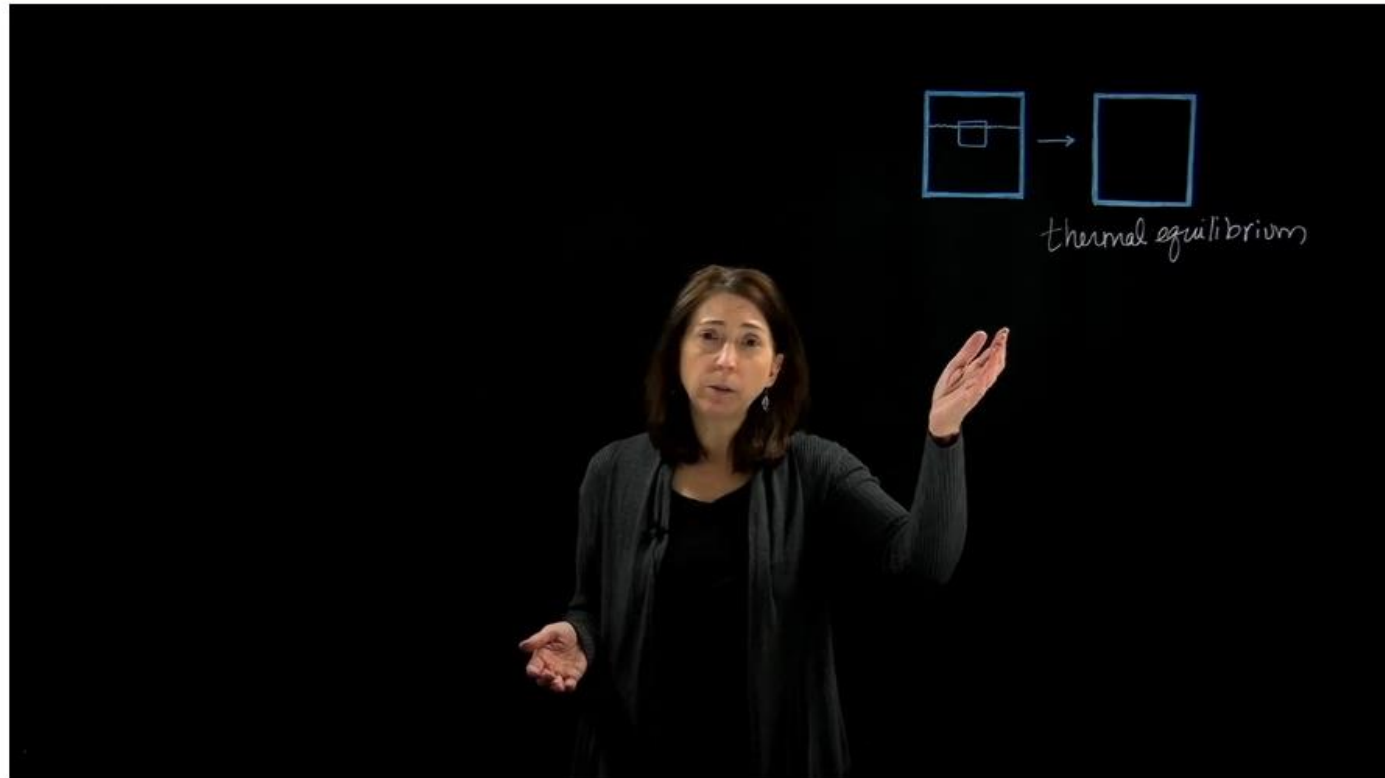
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# Tutorial starts by asking to identify the objects that are in thermal contact



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

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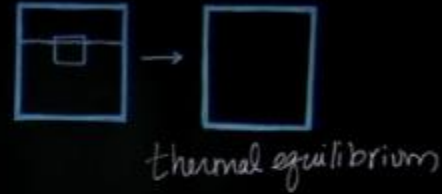
Options ▾

Show Problem Statement

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

Incorrect. Click *Next Page* to go back and try again



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Options ▾

Show Problem Statement

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

Incorrect. Click *Next Page* to go back and try again

**INCORRECT.** Click the **Next Page** or **Previous Page** button to go back and try again.

Remember that the container is a perfect insulator, meaning that it will not exchange energy with another object, including the water and the environment. Click the Next Page button to go back to the question and try again.

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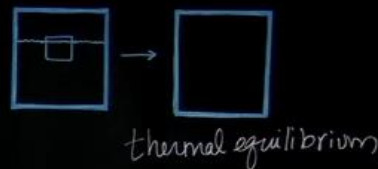
Options ▾

Show Problem Statement

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

**Correct.** Click *Next Page* button to continue



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Options ▾

Show Problem Statement

Continue to Next Page →



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

**Correct.** Click *Next Page* button to continue



**CORRECT.** Click the Next Page button to continue.

It's true that only the ice and water are in thermal contact. The container is a perfect insulator, meaning that it will not exchange energy with another object, including the water and the environment. Moving forward, we will only consider energy being transferred between the ice and the water. Great job! Click the Next Page button to go to the next question.

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# Multiple select questions used whenever practical to dissuade guessing



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

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# Conceptual emphasis and use of representations

The diagram illustrates thermal equilibrium between two systems. The top part shows two boxes, one containing a smaller square, with an arrow pointing to a single larger box, labeled "thermal equilibrium". Below this, a temperature diagram shows three horizontal dashed lines representing temperatures: 20°C at the top, 0°C in the middle, and -5°C at the bottom. A vertical line on the right side is labeled  $Q_3$ . A horizontal arrow between the 0°C and -5°C lines is labeled  $Q_2$ . A diagonal arrow between the 0°C and -5°C lines is labeled  $Q_1$ .

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# Conceptual emphasis and use of representations

The diagram illustrates the concept of thermal equilibrium. It shows a small square inside a larger square, with an arrow pointing to a single square, labeled "thermal equilibrium".

The graph shows temperature (T) on the vertical axis and heat (Q) on the horizontal axis. The temperature starts at  $-5^{\circ}\text{C}$  and increases linearly to  $0^{\circ}\text{C}$  during the first segment, labeled  $Q_1$ . The temperature remains constant at  $0^{\circ}\text{C}$  during the second segment, labeled  $Q_2$ . The temperature then decreases linearly from  $0^{\circ}\text{C}$  to  $20^{\circ}\text{C}$  during the third segment, labeled  $Q_3$ .

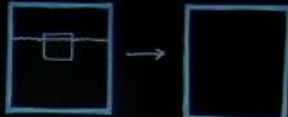
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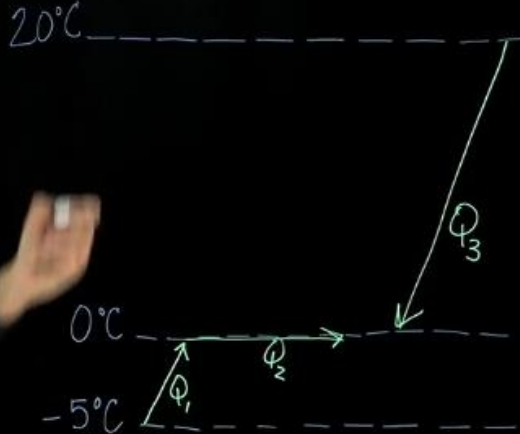
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# Conceptual emphasis and use of representations

Suppose we find that:

$$|Q_3| > |Q_1| + |Q_2|$$


thermal equilibrium



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

- A. It is between  $-5\text{ }^\circ\text{C}$  and  $0\text{ }^\circ\text{C}$ .
- B. It is  $0\text{ }^\circ\text{C}$ .
- C. It is between  $0\text{ }^\circ\text{C}$  and  $20\text{ }^\circ\text{C}$ .

Show comments by other students

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# Conceptual emphasis and use of representations

The chalkboard contains the following content:

- Equation:  $|Q_3| > |Q_1| + |Q_2|$
- Diagram: A square with a smaller square inside, followed by an arrow pointing to a larger square, with the text "thermal equilibrium" below it.
- Temperature scale: A vertical axis with dashed lines at  $20^\circ\text{C}$ ,  $0^\circ\text{C}$ , and  $-5^\circ\text{C}$ .
- Heat flow vectors:  $Q_1$  (upward arrow from  $-5^\circ\text{C}$  to  $0^\circ\text{C}$ ),  $Q_2$  (rightward arrow from  $-5^\circ\text{C}$  to  $0^\circ\text{C}$ ), and  $Q_3$  (upward arrow from  $0^\circ\text{C}$  to  $20^\circ\text{C}$ ).

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

- A. It is between  $-5^\circ\text{C}$  and  $0^\circ\text{C}$ .
- B. It is  $0^\circ\text{C}$ .
- C. It is between  $0^\circ\text{C}$  and  $20^\circ\text{C}$ .

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.

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

## How are you feeling right now?

What is this? Why should I answer?

<input type="radio"/> I feel fine.	<input type="radio"/> I feel fine.
<input type="radio"/> I feel confused.	<input type="radio"/> I feel confused.
<input type="radio"/> I feel frustrated.	<p>Please choose the most appropriate response from this list.</p> <ul style="list-style-type: none"><li><input type="radio"/> The tutorial is moving too quickly.</li><li><input type="radio"/> I am having trouble staying focused so I'm not getting the most out of this tutorial.</li><li><input type="radio"/> This tutorial uses terms that I do not understand.</li><li><input type="radio"/> The problem-solving approach used here is different from what I learned in class.</li></ul>
<input type="radio"/> I feel bored.	
<input type="radio"/> I feel worried.	
<input type="radio"/> None of the choices.	
<input type="radio"/> I prefer not to answer.	
	<input type="radio"/> I feel frustrated.

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

### How are you feeling right now?

What is this? Why should I answer?

- I feel fine.
- I feel confused.
- I feel frustrated.
- I feel bored.
- I feel worried.

- I feel fine.
  - I feel confused.
- Please choose the most appropriate response from this list.
- The tutorial is moving too quickly.
  - I am having trouble staying focused so I'm not getting the most out of this tutorial.
  - This tutorial uses terms that I do not understand.
  - The problem-solving approach used here is different from what I learned in class.

- None of the choices
- I prefer not to answer.

Students can opt out; focus on those who may need additional support

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# Affective responses

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- 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

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- 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

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.

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

$Q_1 = m_{ice} c_{ice} (T_f - T_i)$   
 $Q_2 = m_{ice} L_f$

$Q_{gained\ by\ ice} = Q_{lost\ by\ water}$

$m_{ice} = 150g, m_{water} = 500g$

thermal equilibrium

20°C

0°C

-5°C

$Q_2 = 49,950J$

$Q_1 = 1568J$

$Q_3$

04:42

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

$Q_1 = m_{ice} c_{ice} (T_f - T_i)$   
 $Q_2 = m_{ice} L_f$   
 $Q_{gained\ by\ ice} = Q_{lost\ by\ water}$   
 $m_{ice} = 150g, m_{water} = 500g$   
thermal equilibrium  
20°C  
-5°C  
 $Q_3$   
9,950J  
 $Q_1 = 1568J$

04:42

Emphasis on the big picture and use of representations

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

The blackboard contains the following information:

- Masses:  $m_{\text{ice}} = 150 \text{ g}$  and  $m_{\text{water}} = 500 \text{ g}$
- Diagram: A small square inside a larger square on the left, with an arrow pointing to a single larger square on the right, labeled "thermal equilibrium".
- Temperature scale: Dashed horizontal lines at  $20^\circ\text{C}$ ,  $0^\circ\text{C}$ , and  $-5^\circ\text{C}$ .
- Heat values:  $Q_3 = 41,900 \text{ J}$  (between  $20^\circ\text{C}$  and  $0^\circ\text{C}$ ),  $Q_2 = 49,950 \text{ J}$  (between  $0^\circ\text{C}$  and  $-5^\circ\text{C}$ ), and  $Q_1 = 1568 \text{ J}$  (between  $0^\circ\text{C}$  and  $-5^\circ\text{C}$ ).

Q8. Which of the following statements is correct?

- A. All of the ice melts and the temperature of the final mixture is  $> 0^\circ\text{C}$ .
- B. Some of the ice melts and the temperature of the final mixture is  $> 0^\circ\text{C}$ .
- C. Some of the ice melts and the temperature of the final mixture is  $0^\circ\text{C}$ .
- D. Some of the ice melts and the temperature of the final mixture is  $< 0^\circ\text{C}$ .
- E. None of the ice melts and the temperature of the final mixture is  $< 0^\circ\text{C}$ .

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

The blackboard contains the following information:

- Masses:  $m_{\text{ice}} = 150 \text{ g}$  and  $m_{\text{water}} = 500 \text{ g}$
- Diagram: A small square inside a larger square, with an arrow pointing to a single larger square, labeled "thermal equilibrium".
- Temperature-Energy Diagram: A vertical axis with temperatures  $20^\circ\text{C}$ ,  $0^\circ\text{C}$ , and  $-5^\circ\text{C}$ .
  - An arrow from  $-5^\circ\text{C}$  to  $0^\circ\text{C}$  is labeled  $Q_1 = 1562 \text{ J}$ .
  - An arrow from  $0^\circ\text{C}$  to  $20^\circ\text{C}$  is labeled  $Q_2 = 49,950 \text{ J}$ .
  - A diagonal arrow from  $20^\circ\text{C}$  down to  $0^\circ\text{C}$  is labeled  $Q_3 = 41,900 \text{ J}$ .

Q9. Use the ideas above and determine how much energy is actually available to melt the ice, which was initially at  $-5^\circ\text{C}$ .

- 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



$m_{ice} = 150\text{ g}$   
 $m_{water} = 500\text{ g}$

Diagram showing a small square inside a larger square, with an arrow pointing to a single larger square, labeled "thermal equilibrium".

Temperature scale:  $20^\circ\text{C}$ ,  $0^\circ\text{C}$ ,  $-5^\circ\text{C}$

Energy values:  
 $Q_3 = 41,900\text{ J}$   
 $Q_2 = 40,332\text{ J}$   
 $Q_1 = 1568\text{ J}$

Q9. Use the ideas above and determine how much energy is available to melt the ice initially at  $-5^\circ\text{C}$ .

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

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

- A.  $m = 0.018\text{ kg}$
- B.  $m = 0.029\text{ kg}$
- C.  $m = 0.121\text{ kg}$
- D.  $m = 0.132\text{ kg}$

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

The blackboard contains the following content:

- Equation:  $Q_2 = mL_f$
- Calculation:  $m_{\text{ice melts}} = \frac{40,332 \text{ J}}{3.33 \times 10^5 \text{ J/kg}} = 0.121 \text{ kg}$
- Result:  $m_{\text{ice remaining}} = 0.029 \text{ kg}$  (boxed)
- Calculation:  $Q_2 = 49,950 \text{ J}$  (labeled "melt all ice")
- Initial conditions:  $m_{\text{ice}} = 150 \text{ g}$ ,  $m_{\text{water}} = 500 \text{ g}$
- Diagram: A box with a smaller box inside, with an arrow pointing to an empty box, labeled "thermal equilibrium".
- Temperature diagram: A vertical axis with  $20^\circ\text{C}$ ,  $0^\circ\text{C}$ , and  $-5^\circ\text{C}$ .
  - From  $-5^\circ\text{C}$  to  $0^\circ\text{C}$ :  $Q_1 = 1568 \text{ J}$  (upward arrow)
  - At  $0^\circ\text{C}$ :  $Q_2 = 40,332 \text{ J}$  (rightward arrow)
  - From  $0^\circ\text{C}$  to  $20^\circ\text{C}$ :  $Q_3 = 41,900 \text{ J}$  (downward arrow)

Show comments by other students

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Students provided option to watch a summary after finishing the problem

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.

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Video summary is ~8 minutes long.

The chalkboard contains the following content:

Equations:

$$Q_1 = m_{\text{ice}} c_{\text{ice}} (T_f - T_i)$$
$$Q_2 = m_{\text{ice}} L_f$$
$$Q_3 = m_w c_w (T_f - T_i)$$

Energy balance:

$$Q_{\text{gained by ice}} = Q_{\text{lost by water}}$$
$$|Q_1| + |Q_2| = |Q_3|$$

Masses:

$$m_{\text{ice}} = 150\text{g}, m_{\text{water}} = 500\text{g}$$

Diagram:

A diagram shows a small square (ice) inside a larger square (water) on the left, with an arrow pointing to a single larger square on the right labeled "thermal equilibrium".

Temperature diagram:

A vertical axis shows temperatures:  $20^\circ\text{C}$ ,  $0^\circ\text{C}$ , and  $-5^\circ\text{C}$ . A dashed line is at  $20^\circ\text{C}$ . A solid line starts at  $20^\circ\text{C}$  and goes down to  $0^\circ\text{C}$ . At  $0^\circ\text{C}$ , there is a horizontal segment to the right labeled  $Q_2 = 40,332\text{J}$ . From the end of this segment, a solid line goes down to  $-5^\circ\text{C}$ . A dashed line goes from  $20^\circ\text{C}$  down to  $-5^\circ\text{C}$ . A diagonal line connects  $20^\circ\text{C}$  to  $-5^\circ\text{C}$ . The energy  $Q_3 = 41,900\text{J}$  is associated with the dashed line, and  $Q_1 = 1568\text{J}$  is associated with the diagonal line.

Calculations:

$$m_{\text{ice melted}} = \frac{40,332\text{J}}{L_f} = 0.121\text{kg}$$
$$m_{\text{ice remains}} = 0.029\text{kg}$$

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# Reducing guidance to help students develop self-reliance

The blackboard contains the following content:

- Handwritten equations:  $m_{ice} = 25\text{ g}$  and  $m_{water} = 100\text{ g}$ .
- A diagram showing a small square inside a larger square, with an arrow pointing to a single larger square, labeled "thermal equilibrium".
- A horizontal dashed line at  $20^\circ\text{C}$ .
- A diagram showing a horizontal dashed line at  $0^\circ\text{C}$  and a lower dashed line at  $-5^\circ\text{C}$ . A green arrow labeled  $Q_1$  points from the  $-5^\circ\text{C}$  line up to the  $0^\circ\text{C}$  line. From the  $0^\circ\text{C}$  line, two green arrows labeled  $Q_2$  and  $Q_3$  point upwards and to the right.

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.

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# Does IVET impact student problem solving ability?

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Two sections of calculus-based physics included in study

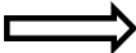
- Same instructor, materials, homework, exams
- Instruction related to specific and latent heat, some problems, but none in which the temperature range was not known
- One section given the Thermal Equilibrium IVET to complete at home
- One section given ~8 minute solution video showcased in the IVET 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

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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.  $T_f > 100\text{ °C}$
- b.  $T_f = 100\text{ °C}$
- c.  $T_f < 100\text{ °C}$

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



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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

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- 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.,  $Q_{\text{hot}} = -Q_{\text{cold}}$ )
    - 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!

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### IVETs we have developed so far:

- Thermal equilibrium
- Newton's 2<sup>nd</sup> 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)