

Characteristics of a Good Representation of a Historical Experiment

1. Uses a Narrative
 - T interesting to the student,
 - T includes original works,
 - T may include relevant bio,
 - T presents a problem, confrontation,
 - T students have time to interact with the narrative, including hands-on
2. Connect the story to the students prior knowledge.
3. Tap into students' ideas and compare them to the original, the narrative may be revisited several times.
4. Perform activities alternating between students ideas and the historical narrative.
5. Interpret data and compare to the original. The narrative may continue especially in the case of a discrepant event. In this case, students formulate new hypotheses, new tests and compare their ideas to the original.
6. Formalize scientific principles and connect to a "real life" experience of the student.

Introduction: The Experiments of Count Rumford

Benjamin Thompson was born on the 26th day of March, 1753 in Woburn, Massachusetts. His father died before he was two years old. Thompson had very little formal schooling, nevertheless, he possessed a tremendous appetite for scientific knowledge and from a very early age he devised his own experiments and built his own scientific instruments. His lifelong passion was the nature of heat and Thompson once wrote “To engage in experiments on Heat was always one of my most agreeable employments”.

Thompson was also a man of intrigue, an “Indiana Jones” sort of guy. During the American revolution he spied on the American forces and was the first person to use invisible ink as he passed information to the British. Ultimately, Thompson was forced to flee to Britain where he continued his illustrious scientific career. Eventually, Benjamin Thompson made his way to Barvaria. In 1784, Benjamin Thompson, now known as Count Rumford, was a special assistant to the Elector of Bavaria.

In Bavaria, Rumford was faced with two difficult, yet diverse, situations. First, he needed to make the military more efficient while saving costs. Secondly, Rumford faced an overwhelming problem with poor street beggars. In order to feed the military, Rumford turned them into part-time farmers and to dress them he established workhouses for the poor who would make their uniforms cheaply.

Rumford was meticulous about efficiency and he invented many practical appliances such as the percolating coffee pot, oven roaster, and kitchen stoves. Rumford performed many scientific experiments. To begin he would formulate scientific question and then devise experiments to test his hypothesis. For example, Rumford asked himself, “What kind of clothes would keep the military warm in the winter and cool in the summer?”

Rumford and the Nature of Heat

Introduction of Benjamin Thompson,

Student Activity #1:

Heat Graffiti

Materials: large sheet of newsprint for each group (alternately a blackboard could be used)

Purpose: To activate student's current knowledge of heat.

Instructions: (groups of three or four)

1. On the newsprint provided to your group write and/or draw **everything** you can think about heat. You have only ten minutes to complete this activity.
1. Present your results of #1 to the class.

Student Activity #2:

Know -Want to Know- Learned (KWL)

Materials: KWL chart can be drawn by the student on 8.5" x 11" paper

Purpose: To organize students' ideas about heat and prepare to generate hypotheses.

Complete a heat KWL chart. Summarize your graffiti ideas in the KNOW column. Next, make a list of questions that you want to know the answers to and list them in the WANT column. Later, we will complete the LEARNED column.

Heat and Cooling KWL Chart		
KNOW	WANT	LEARNED

Student Activity #3:
Experimental Design

1. Answer the question, what are some problems Rumford might face designing clothes for his military? List several scientific questions Rumford might ask.

Problem	Scientific Question

One of Rumford's scientific questions was "What kind of clothes would keep the military warm in the winter and cool in the summer?"

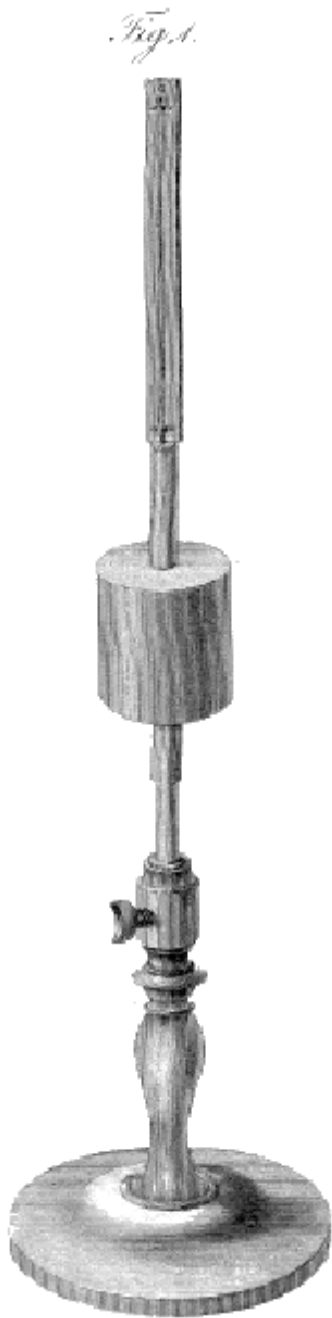
4. In your group, devise an experiment to compare the ability of various materials to keep an object warm. Carefully describe your experiment and sketch your proposed apparatus on one page in your Rumford journal. Present your ideas to the class
5. Read Rumford's description of his first experiment as described in his Enquiry concerning the nature of heat published by the Royal Society in 1804 (Rumford narrative part one). Answer the questions.

Questions for Discussion

- Where did Rumford get his thermometer?
- Why do you think the zero point was placed so high on the thermometer?
- Draw a sketch of Rumford's apparatus.

6. Complete a chart to compare and contrast your ideas with Rumford's original experiment. Compare your diagram of Rumford's apparatus to Rumford's original sketch. In your group, reflect on your experimental design. Describe any changes that you would make to your experimental design. _____

Compare and Contrast Chart		
Ideas similar to Rumford	Ideas different from Rumford	Comments



Activity #4 Rumford's Experiments on Heat

In this experiment we will reproduce Rumford's investigation into the cooling of a can of hot water. Using Rumford's notes (Rumford narrative part two), write out an experimental procedure for this investigation. Be sure to include safety considerations. Submit your experimental predictions, expectations and procedure for approval before you begin the experiment.

Most scientists have expectations about how their experiment will turn out. Record your expectations and make some numerical predictions of the experimental data.

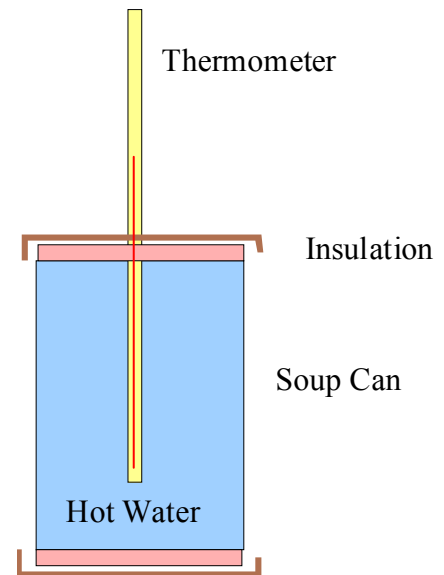
Container	Time to cool 10°
Naked	
Clothed	

Hypothesis 1:

Perform the Experiment and record your results

Results	Time to cool 10°
Naked	
Clothed	

Hypothesis 2:



Present your results to the class

Results

How do your experimental results compare to your predicted results?

Check your results with Rumford's results (Rumford narrative part three). How do your results compare?

Activity #5 Experimental Design - Interpreting Data

Formulate a hypothesis to explain the results of Rumford's first experiment on heat.

7. In your group, devise several experiments to further test your hypothesis. Carefully describe your experiment and sketch your apparatus.
8. Read Rumford's explanation of the results of his experiment (Rumford's narrative part four). In your group, reflect on your original experimental design. Describe any changes that you would make to your experimental design and submit a report

Conclusion

Keeping in mind the results of Rumford's experiments, how should we dress for winter activities such as skiing?

An Enquiry concerning the Nature of Heat, and the Mode of its Communication.

By Benjamin Count of Rumford, Y. P. R. S. Foreign Associate of the National Institute of France.

Read February 2, 1804

Part One



I shall begin by describing the apparatus which was provided for these researches. The thermometers, four in number, which were used in these experiments, were constructed under my own eye, and with the greatest possible care; and they appear to be very perfect. They are mercurial thermometers, graduated according to FAHRENHEIT, their bulbs are cylindrical, 4 inches long, and $\frac{4}{10}$ of an inch in diameter; and their tubes are from 15 to 16 inches long. The mercury with which they are filled is quite pure; and they are freed from air.

Their scales were divided with the greatest care; and they are graduated from about 10° degrees below the freezing point, to 5 or 6. degrees above the point of boiling water. The freezing point is situated about 5 inches above the upper end of the bulb. The reason for placing it so high, will be evident, from the details of the experiments in which these instruments were used.

The instrument I contrived for ascertaining the warmth of clothing, is extremely simple: it is merely a hollow cylindrical vessel, made of thin sheet brass. It is closed at both ends; and has a narrow cylindrical neck, by which it is occasionally filled with hot water. This vessel, being covered with a garment, made to fit it, composed of any kind of cloth, or stuff, or other warm covering, is supported, in a vertical position, on a wooden stand, which is placed on a table, in a large quiet room; and, one of the thermometers above described being placed, in the axis of the vessel, the time employed in cooling the water, through the clothing with which the instrument is covered, is observed and noted down.

Now, as the time of cooling through any given interval of the scale of the thermometer, will be longer, or shorter, as the covering of the instrument is more or less adapted for confining heat, it is evident, that the relative warmth of clothing of different kinds, may be very accurately determined by experiments of this sort.

I endeavoured, by covering up those ends with a permanent and very

warm covering, to oblige, most of the heat to pass off through the vertical sides of the instrument; to which it was easy to fit almost any kind of covering, and more especially coverings of various thicknesses of confined air, the relative warmth of which I was very desirous of ascertaining.

The means I employed for covering up the ends of the instrument were as follows. Having provided two thin cylindrical wooden boxes, (like common pill-boxes, but much larger,) something less in diameter than the body of the instrument, and $2\frac{1}{2}$ inches deep, I dried them as much as possible and I then perforated the bottoms of these boxes with round holes, just large enough to admit the neck of the instrument, and the cylindrical projection at its bottom; and then inverted them over the two ends of the instrument, filling the boxes at the same time with eider-down.

These boxes were fixed and confined in their places, by means easy to be imagined; and, in order to confine the heat still more effectually, each of the boxes was covered on the outside with a cap of fur, as often as the instrument was used; as was also that part of the neck of the instrument which projected above the box.

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Part Two

In each experiment, two similar instruments were used, the one naked, and the other covered; and, as the naked instrument always served as a standard, with which the results of the experiments made with the other were compared, it is evident, that this arrangement rendered the general results of the experiments much more satisfactory and conclusive than they could possibly have been, had the experiments made on different days, and with various kinds of covering.

The two instruments used in the experiment, placed on their wooden stands, being set down on the floor, were filled to within about $1\frac{1}{2}$ inch of the tops of their cylindrical necks with boiling hot water; and, a thermometer being put into each of them, they were placed, at the distance of 3 feet from each other, on a large table, in a corner of a large quiet room, where they were suffered to cool, undisturbed. Near them, on the same table, and at the same height above the table, there was placed another thermometer, (suspended in the air, to the arm of a stand) by which the temperature of the air of the room was ascertained from time to time. No person was permitted to pass through the room, while an experiment was going on; and, in order to prevent, as far as it was possible, all those currents of air in the room which were occasioned by partial heat, produced by the light which came in at the windows, the window-shutters were kept constantly shut; one of them only being opened for a moment, now and then, just to observe the thermometers, and note down the progress of the experiment.

Experiment No. 1. The large cylindrical vessel No. 1, with its ends covered with warm clothing, in the manner before described and its vertical sides (which were polished, and very clean and bright) exposed naked to the air, was filled with water nearly boiling hot, and placed on its wooden stand, on a table in a large quiet room, to cool; the air of the room being at the temperature of 45 degrees Fahrenheit.

Another cylindrical vessel, No. 2., in all respects like No. 1, and with its ends covered in the same manner, but with its vertical sides covered with a single covering of fine Irish linen, (such as is sold in London for about 4s. per yard,) closely applied to the body of the instrument, was filled with hot water at the

same time, and placed on the same table to cool. This experiment lasted many hours; and, in that; period, the temperature of the water, in each of the instruments, was carefully observed, and noted down, a great number of times.

Though it was easy to discover, by a single glance at the register, whether a covering which was put over one of the instruments prolonged the time of its cooling or not; yet, in order to compare the results of different experiments, and particularly of such as were made on different days, so as to determine with precision how much warmer one kind of covering was than another, it was necessary to fix on some particular interval in the scale of the thermometer, or number of degrees, commencing at some certain invariable number of degrees above the temperature of the air by which the instrument was surrounded, in order that the warmth of the covering, or its power of confining heat, might with certainty be estimated by the time employed in cooling through that interval. The interval I chose for comparing the results of my experiments, is that which commences with the fiftieth, and ends with the fortieth degree of Fahrenheit's thermometer, above the temperature of the air in which the instrument is exposed to cool. When, for instance, the air was at 58 degrees, the interval commenced at the 108th degree, and ended at the 98th. When the air was 64 degrees, it commenced at 114 degrees and ended at 104 degrees.

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Part Three

Passing over in silence, a number of experiments I made in order to get thoroughly acquainted with my new instrument, and to assure myself that the results of similar experiments made with them were uniform, and might be depended on, I shall now proceed to give an account of several experiments made with pointed views, the results of some of which were very interesting. The results of each experiment were entered on a separate sheet of paper; which paper was previously prepared for that use, by being divided into separate vertical columns, by lines drawn with a pen, and ruled in parallel horizontal lines with a lead pencil. The following is an exact copy of one of these register-sheets and contains the results of an actual and very interesting experiment. The result of this experiment (the details of which have already been given) was very remarkable: While the instrument No. 1, whose sides were naked, employed 55 minutes in cooling from the point of 94° to that of 84°, the instrument No. 2, whose sides were covered with linen, cooled through the same interval in 36 1/2 minutes.

Hence it appears, that clothing may, in some cases, expedite the passage of heat out of a hot body, instead of, confining it in it.

Time.		Temperature		Tem- perature of the air.	Time.		Temperature		Tem- perature of the air.
h.	min.	of No. 1, naked.	of No. 2, covered.		h.	min.	of No. 1, naked.	of No. 2, covered.	
10	10	126 ¹ / ₂	126°	43 ¹ / ₂	4	—	61 ¹ / ₂	53 ¹ / ₂	43 ¹ / ₂
—	30	109 ¹ / ₂	106 ¹ / ₂	43 ¹ / ₂	—	30	59 ¹ / ₂	52	—
—	45	105	100 ¹ / ₂	43 ¹ / ₂	5	30	57	49 ³ / ₄	42 ¹ / ₂
11	—	101 ¹ / ₂	94 ¹ / ₂	44	5	—	55 ¹ / ₂	49 ¹ / ₂	—
—	2 ¹ / ₂	—	94	—	—	30	54 ¹ / ₂	48 ¹ / ₂	—
—	15	97 ¹ / ₂	90 ¹ / ₂	—	7	—	53 ¹ / ₂	47 ¹ / ₂	42
—	30	94	86 ¹ / ₂	—	8	—	51 ¹ / ₂	46 ¹ / ₂	—
—	30	—	84	—	9	—	50	45 ³ / ₄	—
—	45	91 ¹ / ₂	82 ¹ / ₂	—	10	—	49	45	—
12	—	88 ¹ / ₂	79 ¹ / ₂	—	8	—	48	44	40
—	15	85 ¹ / ₂	76	—	with Mr. A's The instruments were now immersed into a warm room.				
—	25	84	—	—	8	2	43	43	62
—	30	—	74 ¹ / ₂	—	—	32	44 ¹ / ₂	44 ¹ / ₂	62 ¹ / ₂
—	40	80	70	—	—	47	46	46 ¹ / ₂	63
1	—	78	68 ¹ / ₂	—	9	24	48	49 ¹ / ₂	—
—	30	74 ¹ / ₂	64 ¹ / ₂	—	10	—	50	52	—
0	—	71 ¹ / ₂	61 ¹ / ₂	43 ¹ / ₂	—	41	51 ¹ / ₂	53 ¹ / ₂	—
—	30	68 ¹ / ₂	58 ¹ / ₂	43 ¹ / ₂	12	—	54	56 ¹ / ₂	—
8	—	65 ¹ / ₂	56 ¹ / ₂	—	12	25	54 ¹ / ₂	57	—
—	30	63 ¹ / ₂	54 ¹ / ₂	—	An end was now put to the experiment.				

M 9

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Part Four

This experiment lasted many hours; and, in that period, the temperature of the water, in each of the instruments, was carefully observed, and noted down, a great number of times.

The result of this experiment (the details of which have already been given) was very remarkable.

While the instrument No. 1, whose sides were *naked*, employed 55 minutes in cooling from the point of 94° to that of 84° , the instrument No. 2, whose sides were *covered with linen*, cooled through the same interval in $36\frac{1}{2}$ minutes.

Hence it appears, that clothing may, in some cases, expedite the passage of heat out of a hot body, instead of confining it in it.

Desirous of seeing whether the same covering would, or would not, expedite the passage of heat *into* the instrument; after having suffered both instruments to cool down to the temperature of about 42° , I removed them into a warm room, in which the air was at the temperature of 62° ; and I found that the instrument No. 2, which was clothed, acquired heat considerably faster than the other, No. 1, which was naked.*

* The details of this experiment (which was made on the 11th of March, 1803) may be seen in page 83.

The discovery of these extraordinary facts surprised me, and excited all my curiosity; and I immediately set about investigating their cause.

As it is well known that air adheres with considerable obstinacy to the surfaces of some solid bodies, I conceived it to be possible, that the particles of air in immediate contact with the surface of the cylindrical vessel No. 1, might in fact be so attached to the metal as to adhere to it with some considerable force; and, if that were the case, as confined air is known to constitute a very warm covering, it appeared to me to be possible, that the cooling of the vessel No. 1, might have been retarded by such an invisible covering of confined air; which covering, in the experiment with the vessel No. 2, had been displaced, and in a great measure driven away, by the colder covering, of linen, by which the body of the instrument was closely embraced.

I conceived that the linen must have accelerated the cooling of the instrument, either by facilitating the approach of a succession of fresh particles of cold air, or by increasing the effects of *radiation*; and, with a view to elucidate that important point, the following experiments were made.

Exper. No. 2. Removing the linen with which the instrument No. 2 was clothed, I now covered the sides of that instrument with a thin transparent coating of glue; and, when it was quite dry and hard, I again filled the two instruments (No. 1 and No. 2) with hot water, and observed the times of their cooling as before.

Result, or time of cooling 10 degrees, reckoned from the 50th to the 40th degree above the temperature of the air in which the instruments were exposed to cool.

Instrument No. 1, sides *naked* - - - 55 min.

Instrument No. 2, sides *covered with one coating of glue* $48\frac{1}{4}$ min.

SOUP No I.

Ingredients	Weight		Cost in		
	Avoirdupois		sterling money.		
	lb.	oz.	£.	s.	d.
4 viertls*[4] of pearl barley, equal to about 20 1/3 gallons	141	2	0	11	7½
4 viertls of peas	131	4	0	7	3¼
Cuttings of fine wheaten bread ...	69	10	0	10	2¼
Salt	19	13	0	1	2½
24 maass, very weak beer--vinegar, or rather small beer turned sour, about 24 quarts	46	13	0	1	5½
Water, about 560 quarts	1077	0			

	1485	10	1	11	8 13/22

SOUP, No II.

Ingredients.	Weight		Cost in		
	Avoirdupois.		sterling money.		
	lb.	oz.	£.	s.	d.
2 viertls of pearl barley	70	9	0	5	9 13/22
2 viertls of peas	65	10	0	3	7 5/8
8 viertls of potatoes	230	4	0	1	9 9/11
Cuttings of bread	69	10	0	10	2 4/11
Salt	19	13	0	1	2½
Vinegar	46	13	0	1	5½
Water	982	15			

	Total weight	1485 10			
Expenses for fuel, servants, repairs, &c. as before			0	3	5 5/12

Total daily expence, when dinner is provided for 1200 persons			1	7	6 2/3

This sum (1L. 7s. 6 2/3.) divided by 1200, the number of portions of soup, gives for each portion one farthing very nearly; or accurately, 1 1/40 farthing.