



MATH AND SCIENCE @ WORK

AP* STATISTICS Educator Edition



PREDICTING METABOLIC RATES OF ASTRONAUTS

Instructional Objectives

Students will

- visually estimate correlation;
- adjust weights in a weighted average to visually determine a curve of best fit for estimating metabolic rates;
- find the sum of the squares of the differences between student estimates and NASA estimates of metabolic rates; and
- use the sums of squares to determine which students' estimates are closest to NASA's estimates.

Degree of Difficulty

For the average student in Advanced Placement Statistics, this problem is at a moderate difficulty level.

Class Time Required

This problem requires 30–45 minutes.

- Introduction: 5–10 minutes
 - Read and discuss the background section with the class before students work on the problem.
- Student Work Time: 15–20 minutes
- Post Discussion: 10–15 minutes

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's scientific laboratories.

The Biostatistics Laboratory (BSL) is one of several research laboratories which support ongoing biomedical research in human spaceflight conducted by NASA's Human Research Program. Lab personnel often aid in the preparation of research proposals that describe the experimental design, statistical modeling, and analysis of anticipated research data. Once data is gathered, statisticians also assist with the analysis and interpretation of the results.

One area of spaceflight in which the BSL has provided consulting is with the health concerns associated with Extravehicular Activities (EVA), or spacewalks. Results of the research analysis in this area helps engineers

Grade Level
11–12

Key Topics
Correlation coefficients, weighted averages, least squares

Degree of Difficulty
Moderate

Teacher Prep Time
10 minutes

Class Time Required
30–45 minutes

Technology
- TI-Nspire™ Learning Handhelds
- TI-Nspire document: *Metabolic_Rates.tns*

AP Course Topics
Exploring Data:
- Exploring bivariate data

NCTM Standards
Data Analysis and Probability

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design better spacesuits for future explorers.

There are a number of factors associated with life support that are considered when designing a spacesuit. Statisticians help to collect and analyze data about the different factors involved and how each one affects the astronaut's performance, comfort, and health during an EVA.

The spacesuit currently worn by astronauts performing an EVA is called an Extravehicular Mobility Unit (EMU). Fully equipped, an EMU becomes an astronaut's "one-person spacecraft". It must protect astronauts from multiple conditions that can be experienced in space. The EMU shields them from extreme temperature changes, and protects them from being injured from impacts of small bits of space dust and from radiation. It contains a life support system that supplies astronauts with breathable oxygen, removes exhaled carbon dioxide, and provides drinking water—enough resources for an eight and a half hour EVA. The EMU also supplies electricity to a number of other systems, including a Liquid Cooled Garment (LCG), which covers the entire body, except for the head, hands, and feet. During an EVA, adjustable amounts of cool water are pumped through the tubes (which are woven into the LCG) to keep each astronaut at his or her own temperature comfort level.



Figure 1: An astronaut during an EVA on the International Space Station



Figure 2: An artist depiction of astronauts exploring the lunar surface

As NASA prepares to explore new frontiers of space, the capabilities of the spacesuit used must be carefully considered. Human exploration in the next few decades could include more extensive exploration of the Moon, visits to near-Earth objects (like asteroids), and the exploration of Mars. These environments have different variables that would each contribute to the best design of a spacesuit. By designing models that factor in these variables, the work of statisticians continues to be an important step in NASA's goals for future exploration.

AP Course Topics

Exploring Data: Describing patterns and departures from patterns

- Exploring bivariate data
 - Analyzing patterns in scatter plots
 - Correlation and linearity
 - Least-squares regression line

NCTM Standards

Data Analysis and Probability

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them



- Select and use appropriate statistical methods to analyze data
- Develop and evaluate inferences and predictions that are based on data

Problem and Solution Key (One Approach)

Students are given the following problem information within the TI-Nspire document, *Metabolic_Rates.tns*, which should be distributed to their TI-Nspire handhelds.

An astronaut’s metabolic rate, the rate which a person expends energy, affects the factors associated with life support that are considered when designing a spacesuit. To determine the metabolic rate, numerous physiological variables are taken into account. The environment and the type of work being done by the astronaut will affect the metabolic rate. An experiment was created to develop a model that would predict metabolic rates of astronauts performing particular tasks in different environments. In this experiment, a person wearing a spacesuit performed tasks simulating a lunar exploration mission. These tasks included shoveling rocks, transferring objects to different locations, and walking at different speeds on various inclines. This experiment lasted for over three hours, during which minute-by-minute data were obtained. This data was analyzed and used by NASA biostatisticians to predict the metabolic rate of the subject involved in the experiment.



Figure 3: A spacesuit engineer simulates lunar work in a crater of NASA Johnson Space Center’s Lunar Yard

Besides time (measured in hours), the data collected included the difference between the inlet and outlet temperature of the Liquid Cooled Garment (LCG), amount of carbon dioxide (CO₂) produced, amount of oxygen (O₂) consumed, and heart rate (HR). Data from each of these four variables were converted to equivalents of metabolic rate, represented in British Thermal Units (BTU) per hour. This conversion allowed the different forms of data collected (now in the same scale) to be compared and averaged to predict metabolic rate. Table 1 shows an abbreviated table of this data after conversion to equivalent metabolic rate units. The complete table is found on page 1.7 of the TI-Nspire document. In this activity, you will create weighted averages of these four different measures of metabolic rate to produce a best overall estimate of the actual metabolic rate.

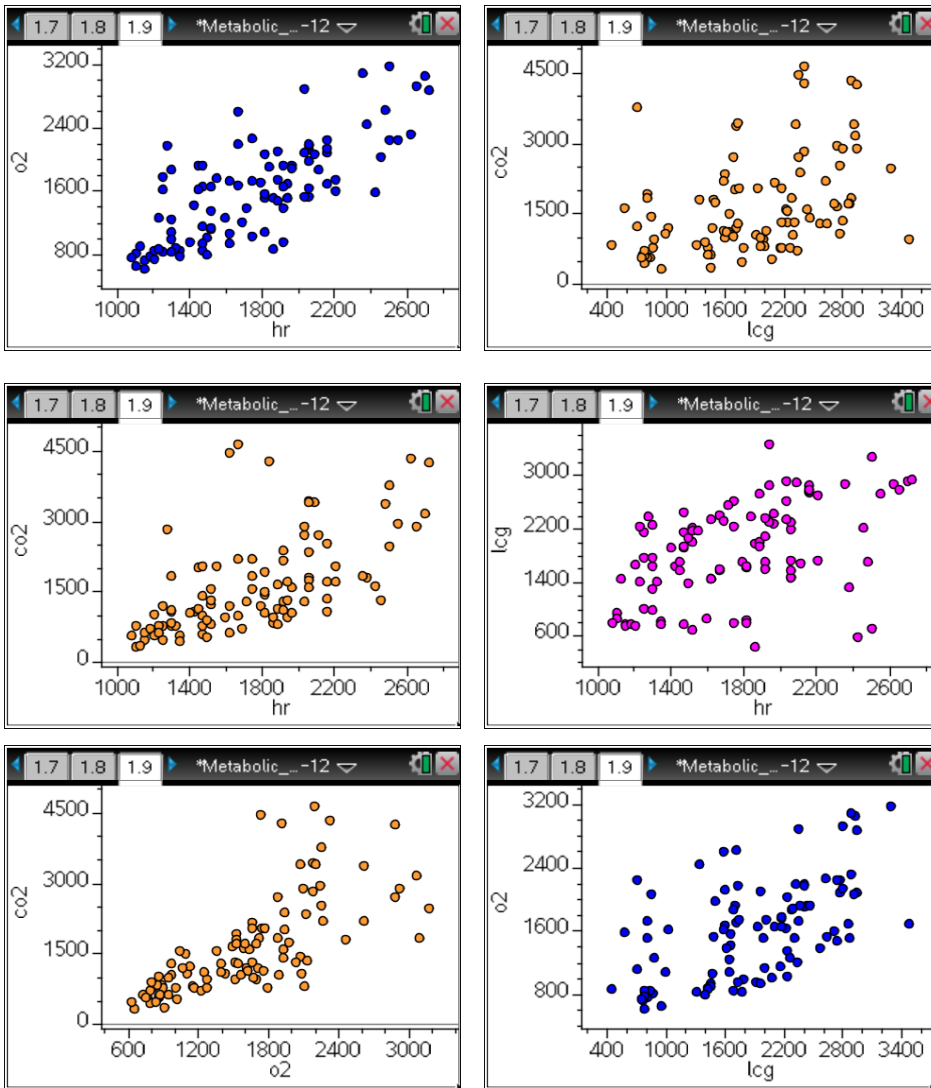
Table 1: Abbreviated Metabolic Rate Data

Time (hr)	LCG (BTU/hr)	CO ₂ (BTU/hr)	O ₂ (BTU/hr)	HR (BTU/hr)
0.00	945.5	349.1036	652.1	1104.198
0.02	780	491.2215	627	1153.184
0.03	862.4	801.092	813.1	1104.198
...



- A. Use the scatter plot on page 1.9 of the TI-Nspire document to determine which pair of the four variables (LCG , CO_2 , O_2 , or HR) seems to have the strongest correlation, and which pair has the weakest correlation. (Change the variables by clicking on the labels at the bottom and left side of the plot.)

HR and O_2 seem to have the strongest correlation while LCG and CO_2 seem to have the weakest correlation. The LCG is not as strongly correlated with any of the other variables. Perhaps this is because astronauts adjust their LCG to comfort.



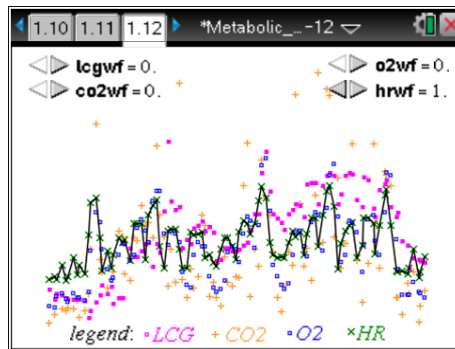
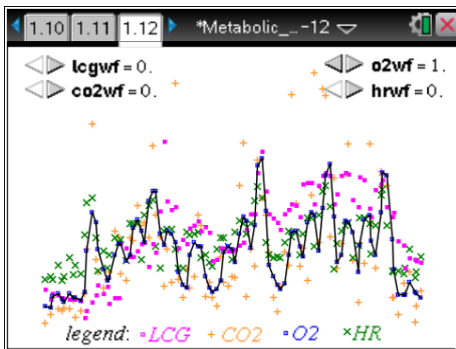
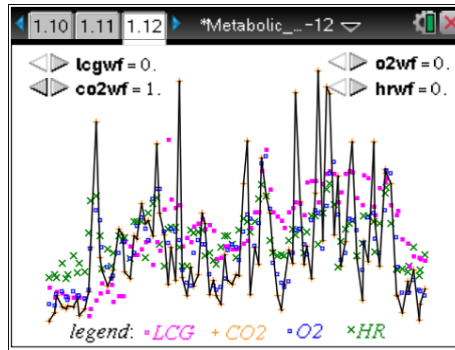
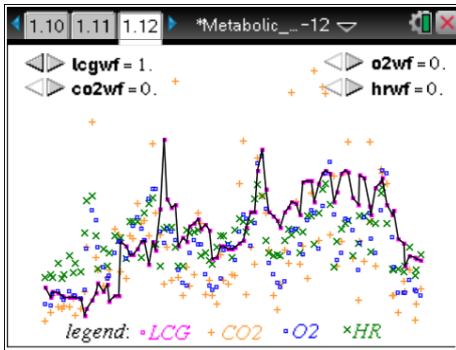
- B. The goal is to produce an estimated metabolic rate using all four different variables. A weighted average is a reasonable approach, but how might the weights be determined?

Page 1.12 shows time plots for each of the four variables and arrows that can be used to adjust the weight factors. Currently the weights are all set at 0. Change the weight factor of LCG to 1 and leave the others at 0. You will see a graph that goes through all of the points on the LCG time plot.

See if you can change the weight factors of the variables to result in the graph going through all of the points on the CO_2 scatter plot.

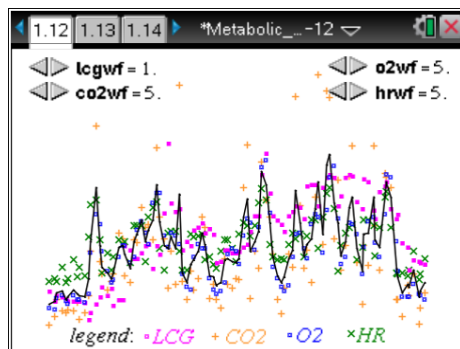


Now do the same thing for the O₂, and then for the HR scatter plots.



- 1.13 Go back to page 1.12 and adjust the weight factors so the graph uses all the variables to predict metabolic rate. Not all factors need be equal. If there are some variables you think should have more affect on the prediction of metabolic rate you can give them a greater weight. After you adjust the weight factors, record the selections and explain your reasoning.

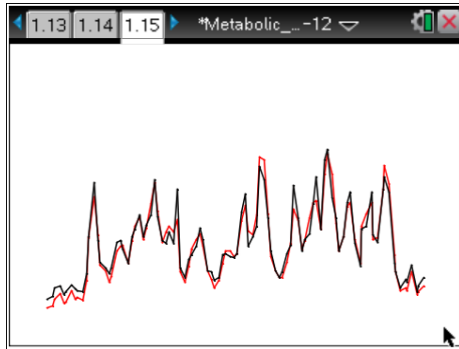
Answers will vary, but students should be able to justify their choice of weight factors. For example, LCG may receive a lower weight since astronauts adjust their LCG to individual comfort, which may not reflect metabolic rate.





1.14 Page 1.15 shows your estimates of metabolic rate in black along with a graph of NASA's estimates in red. Is your graph close to the NASA graph? Look at your classmate's graph. Who has the closest fit to the NASA graph? What is a good numerical way to determine the closest fit?

Answers will vary. There are various ways to decide the closest fit, but most should involve looking at the differences between the student's estimates and the NASA estimates (for example, the sum of the squares of the differences or perhaps the sum of the absolute values of the differences).



C. Page 1.17 shows the estimates you created with your weighted average in the first column and the estimates created by NASA in the second column. Find the sum of the squares of the differences between the two columns. What is your sum? Who has the lowest sum in your class? What does this mean? Why would you square the differences between the estimates?

Answers will vary. Students should recognize that the individual with the lowest sum of the squares probably has the model that is closest to the NASA estimates. Squares prevent underestimates from canceling overestimates.

	est	nasaest	squares
			$=(myest - nasaest)^2$
1	.032	586.897	16935.
2	.564	592.764	27489.7
3	.397	728.362	30637.1
4	.895	822.426	11123.7
5	.538	655.414	22237.8

	est	nasaest	squares	sumsquares
				$=sum(squares)$
1	.032	586.897	16935.	2.22341e6
2	.564	592.764	27489.7	
3	.397	728.362	30637.1	
4	.895	822.426	11123.7	
5	.538	655.414	22237.8	

Teacher Note: For students new to using TI-Nspire technology, more direction may be required. In the example screenshots above, the squares of the differences between the two columns were determined in column C, and the sum of the squares was determined in cell D1. To arrange the students' columns similarly, have them follow these steps.

1. Add the titles "squares" to column C and "sumsquares" to column D.
2. In the gray cell of column C, type $=(myest - nasaest)^2$ and press enter.
3. In cell D1, type $=sum(squares)$ and press enter.



Scoring Guide

Parts A, B, and C are scored as Essentially Correct (E), Partially Correct (P), or Incorrect (I).

Question	Score	Description
A	<i>Essentially Correct (E)</i>	Correctly lists both strongest and weakest pair
	<i>Partially Correct (P)</i>	Correctly lists either strongest or weakest, but not both
	<i>Incorrect (I)</i>	Does not correctly list strongest or weakest pair
B	<i>Essentially Correct (E)</i>	Lists and justifies all four weight factors with plausible links between weight factors and behavior of corresponding variables
	<i>Partially Correct (P)</i>	Lists weight factors, but only justifies one or two factors with plausible explanations
	<i>Incorrect (I)</i>	Lists weight factors, but does not justify
C	<i>Essentially Correct (E)</i>	Correctly computes squares and their sum, explains the meaning of the lowest sum, explains the reason for squaring differences
	<i>Partially Correct (P)</i>	Correctly computes squares and their sum, but has partially correct explanations
	<i>Incorrect (I)</i>	Does not compute squares and their sum correctly with missing or incorrect explanations



Point Distribution

Suggested 4 points total to be given as follows:

- 4 pts Complete Response** All three parts are essentially correct.
- 3 pts Substantial Response** Two parts are essentially correct, and one part is partially correct.
- 2 pts Developing Response** Two parts are essentially correct, and no part is partially correct.
OR
 One part is essentially correct, and one or two parts are partially correct.
OR
 Three parts are partially correct.
- 1 pt Minimal Response** One part is essentially correct, and no part is partially correct.
OR
 No part is essentially correct, and two parts are partially correct.

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP Statistics instructors.

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