STUDENTS' MISCONCEPTIONS ABOUT PERCEIVED PHYSIOLOGICAL RESPONSES

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Students' misconceptions about scientific phenomena can arise from at least two possible sources, the students' personal experience with those phenomena and things learned in the classroom. Misconceptions have been studied in a variety of science disciplines, but little attention has been given to the faulty models that students have for physiological processes. In this study 393 undergraduates in three different research universities were asked to predict the changes in heart rate and strength of cardiac contraction and breathing frequency and depth of breathing (physiological parameters that can be directly and personally perceived) under conditions that result in increased cardiac output or minute ventilation. One-third of those surveyed incorrectly predicted that heart rate would increase but that the strength of contraction would decrease or stay unchanged. Approximately one-half of the students predicted that breathing frequency would increase but depth of breathing would decrease (also erroneous). Explanations for these erroneous predictions were elicited, and the reasons offered revealed significant misconceptions about cardiac and respiratory mechanics. The persistence of such misconceptions was demonstrated in a small group of first-year medical students. A general approach to detecting and remediating misconceptions is discussed.

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Students at all educational levels enter the classroom with mental models of phenomena that may be at variance with accepted scientific models of those same phenomena. These ''faulty'' models have been called ''naive beliefs,'' ''preconceptions,'' ''alternative conceptions,'' and ''misconceptions'' by various investigators (22). Although each of these labels carries different implications about the origins and utility of these faulty models, the term ''misconception'' will be used in this paper to describe an incorrect model for a phenomenon regardless of its possible origin, etc.

Misconceptions have been studied in a wide variety of science disciplines, and in each field where they have been studied they exhibit a number of common characteristics (18, 22): *1*) they have their origins in students' experiences in the ''real world'' and/or in the classroom; *2*) they have some utility in the real world, however flawed they may reveal themselves to be in the classroom (in ''doing'' formal science); and *3*) they are difficult for teachers to correct, even with explicit remediation strategies.

Misconceptions in the physical sciences have, perhaps, been the most widely studied. In a subdomain of physics like kinematics it is clear that misconceptions arise from every individual's personal experience in the world of internally generated, and hence perceptible, forces and the perceived (seen, felt) motion that results (5, 9, 11, 12, 14). The world outside of the physics classroom does not always behave in a manner that is obviously consonant with Newton's three laws of motion. On the other hand, misconceptions about electricity and electrical circuits (3, 6, 23) undoubtedly arise in the classroom, because the phenomena being considered are not usually directly and personally observable in the real world outside of the classroom. Similarly, misconceptions in chemistry (10, 17) most likely have their origins in the classroom.

Misconceptions in the life sciences have not been as widely studied. Three topics that have been most extensively pursued are the structure and function of the mammalian circulation (1, 7, 15), photosynthesis (15), and genetics (4, 13, 19). In each of these areas it is likely that misconceptions, when present, arise from students' experience in the classroom; few of the specific phenomena being studied are likely to have been personally experienced by the students.

However, there are a large number of physiological responses that can be perceived directly by the individual in whom they occur. Changes in heart rate caused by exercise, shivering or sweating in response to changes in ambient temperature or as a consequence of a fever, and the increased breathing frequency on top of a mountain are all examples of physiological responses requiring no laboratory equipment to be observed. Do students have misconceptions about these phenomena? The studies reported here were aimed at providing an answer to this simple question.

PILOT STUDY

Methods. The approach taken in this study was to describe a set of commonplace situations, each of which is likely to have been personally encountered by the student respondents and each of which will give rise to directly perceivable physiological responses. The language used in describing these situations and the ensuing responses was kept as nontechnical as possible. Students were asked to make predictions about the occurrence of responses, or to predict the change in physiological parameters, that would result from the disturbance posed by the situation described.

The pilot study was carried out at a midwestern university. The subjects were 33 paid volunteers enrolled in an undergraduate systems physiology course offered by a department of biomedical engineering. Participants in this study were asked to provide information about their prior educational experiences and their future career plans (see Table 1).

The instrument used in the pilot study described six situations that would give rise to personally observable physiological responses (see Table 2). In two cases (exercise and exposure to cold) students were asked, ''What changes in the functioning of your body will you directly observe?'', and space was available to write any response the students chose to generate. For two situations (exposure to heat and exposure to high altitude) the physiological responses of interest were described, and the students were asked, ''What causes you to do each of the things described above?'' Space was available for written answers.

TABLE 1
Description of student populations studied

	Study 1 (Pilot) MWU	*Study 2* SWU	*Study 3* WSU
Number of students	33	171	189
Male/female	not available	37%/63%	43%/57%
Age	not available	70% between 18 and 21	74% between 18 and 21
Course enrolled in	systems physiology (biomed engineering)	life science (various)	physiology (various)
Career goals	79% premed	40% premed 40% other life science	45% premed 35% life science
Prior physiology	15%	55%	14%
Prior biology	49%	74% (with appreciable physiology)	60% (with appreciable physiology)
College physics	100%	41%	79%
College math	100%	91%	98%

MWU, midwestern university; SWU, southwestern state university; WSU, western state university.

TABLE 2
Situations in which physiological disturbances are present (Pilot study, MWU)

1. You spend the afternoon playing four vigorous sets of tennis against a closely matched opponent.
2. You are walking back to campus from a friend's house on the other side of town. A premature winter storm springs up, the temperature drops to below freezing, and it starts to snow.
3. It is a hot and sunny day and you spend several hours at the beach.
4. You've been waiting for the elevator for several minutes and finally decide to run up the 5 flights of stairs to your lecture.
5. You take a long, impromptu hike in the countryside on an unexpectedly hot day in September. When you return home you immediately (*A*) drink a couple of glasses of water and (*B*) eat half a bag of potato chips.
6. You arrive in Colorado early on the first morning of Christmas break and immediately go to the top of the mountain to begin skiing. By the middle of your first run you notice that (*A*) you feel short of breath and (*B*) you are breathing more rapidly than normal.

Two additional situations (a hot day at the beach and exercise) were also described, and a list of 13 perceptible responses was provided; students were asked to predict which of these responses would be ''directly observed'' to occur as a consequence of these situations. The exercise scenario, which yielded the results presented here, is reproduced in its entirety in APPENDIX A.

Results. A number of misconceptions were uncovered in this pilot study, although most were held by only a relatively small number of students. However, there was one very common misconception that was evident from an examination of the responses predicted to occur when an individual exercises.

All but one of the students surveyed correctly predicted that heart rate and the strength of contraction of the heart would be increased during exercise (see Table 3). However, although 32 of 33 respondents correctly predicted that breathing frequency would be increased, 15 of 33 (45%) did not predict that the depth of respiration would increase (see Table 3). In fact, 14 students (42%) predicted that breathing frequency would increase and that depth of respiration would decrease. Thus, although these students knew (either from direct personal experience or from something learned in the classroom) that the cardiac pump, the heart, increases its output during exercise by

TABLE 3
Predicted changes in CV and respiratory parameters caused by exercise (pilot study, MWU)

Heart will beat . . .	Faster	Slower	Same Rate
More vigor	32/33 (97%)*	1/33 (3%)	
Less vigor			
Same vigor			
Breathing will be . . .	Faster	Slower	Same Rate
Deeper	18/33 (55%)*		
Shallower	14/33 (42%)		1/33 (3%)
Same depth			

CV, cardiovascular. *Correct prediction.

increasing the frequency of beating (the rate) and the strength of each beat, they did not know that the respiratory pump behaves in the same way.

Discussion. The prevalence of the misconception found in this study is quite interesting because it is clear that all of the respondents are likely to have personally experienced the consequences of exercise (although there is no data available about how readily the four physiological parameters being considered can be perceived). However, this pilot study did not provide the respondents with an opportunity to explain the reasoning that led them to these particular predictions about the responses to exercise. Thus it was difficult to determine the origin(s) of the misconception that was revealed in the data. It was decided to more fully explore the students' model of the respiratory pump using an instrument with which the students' explanations for their predictions could be elicited.

STUDIES 2 AND 3

Methods. A second instrument to detect misconceptions was designed that would provide respondents with an opportunity to explain the predictions they had made. It was formatted in a way that permitted machine scoring and hence could be administered to large numbers of students.

Two large groups of students were studied (see Table 1): 171 students enrolled in a variety of life science courses at a southwestern state university and 189 students enrolled in a variety of physiology courses at a western state university.

All students were surveyed during the first few days of classes. The students were not asked to volunteer, and the exercise was presented as a part of their course. They were not paid for participation.

Five situations were described that give rise to perceptible physiological responses: *1*) exposure to high altitude leading to changes in ventilation, *2*) exercise giving rise to a thermoregulator response, *3*) exercise-induced changes in cardiovascular function, *4*) ingestion of a large quantity of salt and the generation of thirst, and *5*) the onset of a fever.

For each of these situations, one component of the expected physiological response was described and the students were asked to make predictions about qualitative changes that would occur to a second component of the response. This format allowed routine machine scoring of a specially prepared Scantron form. For each situation, the particular prediction selected directed the student to a second question in which an explanation for that prediction was requested (20).

Two versions of this instrument were written. In both versions the initial prediction about the physiological response was chosen from a list: increase, decrease, or no change. In one version of the instrument, follow-up questions were presented in a predominantly multiple-choice format (one choice did permit a free response, an option that only 15% of students elected). The explanatory choices provided were derived from the explanations given by a small group of students who participated in the pilot study and from the author's interactions with other students in a medical physiology course. A second version of the instrument requested explanations in free response format only. Each version of the instrument was administered to approximately one-half of the students in each of the two groups that were studied. The two formats for one of the situations described (exposure to high altitude) can be seen in APPENDIX B.

In this article, only the predictions about the respiratory responses to high altitude and the cardiovascular responses to exercise will be considered. As was the case in the pilot study, other misconceptions were uncovered, although the number of students exhibiting them was small, making it difficult to arrive at general conclusions about them.

Results. Overall, more than two-thirds of the students in the two studies correctly predicted that during exercise the strength of the heartbeat would increase (Table 4). Twenty-five to thirty percent predicted that the strength of contraction would be unchanged. Only a very small percentage predicted that the strength of contraction would decrease. Thus a significant number (1/3) of this population of students (unlike those surveyed in the pilot study) exhibit a misconception about the cardiac pump.

Each prediction, whether correct or incorrect, was accompanied by an explanation; one-half of the students selected explanations from a list of multiple choices, whereas the other half of the population surveyed generated their own explanations.

Only 46% of the students who correctly predicted that the strength of the heartbeat would increase selected a correct explanation for this prediction (Table 5, *3Ab*). Thirty-seven percent selected a teleological explanation (Table 5, *3Ac*), whereas twenty-one percent incorrectly thought that increased heart rate causes increased strength of contraction (*3Aa*).

The students who thought that the strength of contraction would remain unchanged believed this occurred because the strength of the heartbeat is held constant by the nervous system (43%; Table 5, *3Cb*), is fixed

TABLE 4
Predicted responses to exercise and high altitude

	WSU	SWU
Exercise: heart rate increases and students predicted change in strength of heartbeat		
Increase*	121/189 (64%)	121/171 (71%)
Decrease	11/189 (6%)	5/171 (3%)
No change	57/189 (30%)	45/171 (26%)
High altitude: breathing frequency increases and students predicted change in depth of respiration		
Increase*	75/189 (40%)	75/171 (43%)
Decrease	96/189 (51%)	89/171 (51%)
No change	18/189 (9%)	10/171 (6%)

*Correct prediction.

TABLE 5
Explanations for predictions (multiple-choice format)

	WSU	SWU
EXERCISE		
An individual plays a vigorous set of tennis. He notices that his heart is beating quite rapidly.		
3. While playing tennis, the strength of his heartbeat will:		
a) increase*	54	57
b) decrease	6	3
c) remain unchanged	31	30
3A. The strength of his heartbeat will increase because		
a) the increase in heart rate directly causes an increase in the strength of contraction of the heart	7	17
b) of a response that increases the rate at which blood is pumped out of the heart†	27	24
c) the tissues of the body need more blood flow	21	20
3B. The strength of his heartbeat will decrease because		
a) the increased heart rate does not permit his heart to contract as strongly	2	2
b) if one cardiac parameter increases, the other must decrease	0	0
c) with the increased heart rate the body doesn't need as strong a contraction	3	0
3C. The strength of his heartbeat will remain unchanged because		
a) the strength of the heartbeat cannot vary	5	12
b) the strength of the heartbeat is held constant by the nervous system	14	8
c) the strength of the heartbeat can change, but it is not normally affected by exercise	7	5

*Correct prediction; †correct explanation.

TABLE 6
Explanations for predictions (multiple-choice format)

	WSU	SWU
EXPOSURE TO HIGH ALTITUDE		
An individual is transported rapidly to the top of a high mountain. She soon observes that she is breathing faster.		
1. At that time she will be breathing:		
more deeply*	30	37
less deeply	53	49
with her normal depth	8	5
1A. The volume of air that she moves with each breath, her depth of breathing, increases because		
breathing faster directly increases the depth of breathing	0	3
of a response that increases the rate at which air enters the lungs†	24	23
the body needs more oxygen	8	13
1B. The volume of air that she moves with each breath, her depth of breathing, decreases because		
breathing faster doesn't allow time to move as large a volume of air with each breath	15	11
the produce of breathing rate and depth of breathing is held constant by the body	1	6
the low atmospheric pressure that is present results in a smaller pressure gradient to produce air flow into the lungs	31	29
1C. The volume of air that she moves with each breath, her depth of breathing, remains unchanged because		
the depth of breathing is always held constant by the nervous system	1	0
the mechanical properties of the lungs and chest wall don't allow depth of breathing to change	1	1
depth of breathing is determined by the pressure gradient between the atmosphere and the lungs and that hasn't changed	5	2

*Correct prediction; †correct explanation.

and cannot vary (33%; *3Ca*), or simply does not vary during exercise (24%; *3Cc*).

Only a few students (total of 7) predicted that the strength of the heartbeat would decrease either because with increased rate there cannot be increased strength of contraction (*3Ba*) or because with heart rate increased the body doesn't ''need'' a stronger contraction (*3Bc*).

In contrast, only 40% of the students correctly predicted that depth of respiration would increase on exposure to high altitude (Table 4), less than 10% predicted that there would be no change, and 51% of the students predicted that the depth of respiration (tidal volume) would decrease.

More than two-thirds of the students who correctly predicted that the depth of breathing would increase on exposure to high altitude identified a correct explanation of this phenomenon, a physiological response that increases the rate at which air enters the lungs (Table 6, *1*). However, one-third picked explanations (Table 6, *1A*) that were either teleological (''the body needs more oxygen''), and hence in error, or simply erroneous (''breathing faster directly increases the depth of breathing'').

Those students predicting a decrease in the depth of breathing most commonly thought (Table 6, *1B*) that this was caused by the decreased atmospheric pressure present at high altitude (reflecting a misconception about the mechanics of breathing) or thought that with increased rate of breathing there was not time for as large a volume of air to be moved into the lungs (reflecting a misconception about the time course of inspiration and expiration).

Of the 10 students who predicted that the depth of breathing would be unchanged, most of them thought (Table 6, *1C*) that the pressure gradient between the atmosphere and the lungs was unchanged and therefore no change in depth of breathing would occur. This explanation also reflects a misconception about the mechanics of breathing.

It is difficult to concisely summarize the freely generated explanations for predicted changes in the depth of breathing. Of the 82 students correctly predicting that the depth of breathing would increase (see Table 7), only a handful produced explanations that included reference to a compensatory mechanism for reduced oxygen in the body. More commonly, a teleological explanation was advanced, i.e., the ''body needs more oxygen.''

TABLE 7
Explanations for predictions (samples from free responses)

EXPOSURE TO HIGH ALTITUDE
Depth of breathing increases because (correct prediction):
''. . . [T]o compensate having less O_2, one needs to take in deeper and fresher breath.'' (WSU)
''. . . [M]ust increase breathing rate, depth to maintain P_{O_2} in blood.'' (SWU)
Depth of breathing decreases because (most common incorrect prediction):
Reduced atmospheric pressure
''The pressure of air decreases as you go higher distances causing you to take smaller breaths.'' (SWU)
''Body pressure on lungs is greater than air pressure at higher altitudes; body must work harder to breathe deeply.'' (WSU)
Too little time for inspiration
''She is breathing quicker, and her lungs have less time to fill.'' (SWU)
''Rapidness of each breath does not allow for great depth. . . .'' (WSU)

Eighty-four students predicted that the depth of breathing would decrease, and among the individuals in this group the most common explanation was that with more rapid breathing there was not time to take in the normal amount of air. Also relatively common were explanations that included changes in atmospheric pressure (some recognizing that atmospheric pressure was decreased but a substantial number believing that pressure, or density of air, increased at the top of the mountain); with atmospheric pressure reduced, less air enters the lung during inspiration.

Among the small number of students who thought that depth of breathing would be unchanged, a number produced explanations suggesting a confusion between tidal volume, how much air moves with each breath, and vital capacity or total lung capacity.

Discussion. Three hundred ninety-three students at three major universities enrolled in courses in the biological sciences were surveyed about their understanding of certain physiological responses, all of which are directly and personally perceivable. Their descriptions (the predictions they made about changes in function) of the behavior of the two physiological pumps, the heart and the respiratory system, seem to be based on faulty models, with the most prevalent misconceptions underlying their understanding of the behavior of the respiratory pump.

Two-thirds of the students understood that exercise results in increased heart rate and increased strength of contraction of the heart; of the one-third of students who incorrectly predicted the change in strength of contraction, most thought that there would be no change. On the other hand, only 40% of the students correctly predicted that exposure to high altitude would result in increased breathing frequency and increased depth of breathing, with one-half of these students predicting that breathing frequency would increase but that depth of respiration would decrease.

The physiological responses to be predicted were deliberately chosen to be ones that each student could personally perceive as they occurred. It is reasonable to assume that essentially all of the respondents have experienced exercise and the physiological changes that accompany it, although not every student will have been to a high enough altitude to have experienced the hyperventilation that results. Unlike many of the physiological phenomena that students study in the classroom, and unlike most of the phenomena studied in physics and chemistry, no scientific instrumentation is needed for students to build a personal mental model of what happens during exercise or exposure to high altitude. It seems likely, then, that these incorrect predictions result from misperception of the physiological responses that occur, something encountered in the classroom that distorts the interpretation of what occurred, or both (some interaction between perception and classroom learning).

It was not possible to determine directly whether the incorrect predictions made were the result of past misperception of the responses. However, the explanations offered for the incorrect predictions do suggest that the students' faulty models were at least a partial product of something learned in the classroom, because they overwhelmingly invoke physiological mechanisms that would only have been learned in the classroom.

Predictions that exposure to high altitude would result in increased breathing frequency and decreased depth of respiration were most commonly explained by invoking the decreased atmospheric pressure that would be present. It would appear, however, that these students do not understand that the reduced atmospheric pressure is present both inside and outside the lungs; thus reduced atmospheric pressure does not alter the expansion of the lungs during inspiration. The next most common explanation, that there is too little time for a normal inspiration to occur, clearly arises out of a misunderstanding, or lack of information, about the time course of inspiration and expiration.

If these students have misconceptions that were learned in the classroom, serious questions about classroom teaching practices need to be addressed. However, before turning to this issue, a comment about the persistence of such misconceptions, even in the face of apparently successful learning about the phenomena, is in order.

A demonstration of the persistence of misconceptions was serendipitously uncovered in the answers to an examination question produced by the 24 first-year medical students, who participate in a problem-based curriculum (2, 8). The students' knowledge of cardiovascular and respiratory physiology had been tested ~6 wk previously in the midterm examination; all students had earned a passing grade on that examination. In the final examination, the students were presented with a patient problem and they were given data from which one could conclude that a respiratory acidosis was present (this patient had elevated P_{CO_2} and a pH $<$7.4). They were then asked to predict the pattern of ventilation that would be observed in this patient. Almost all of them (22 of 24) correctly predicted (in freely generated responses, not selection from multiple choices) that alveolar ventilation in this patient would be decreased. Also, all of these students predicted that breathing frequency would be reduced. However, only 11 of 24 correctly predicted that tidal volume would be decreased as well; 2 students predicted that tidal volume would increase, and 9 predicted that it would be unchanged (i.e., they believed that alveolar ventilation went down solely because breathing frequency decreased). This is, of course, the identical alternative conception that was shown to be held by ~50% of the nearly 300 undergraduate students who were questioned in the study reported here.

What lessons can teachers of physiology learn from the presence and persistence of such faulty mental models of important physiological phenomena?

First, it is essential that we be aware of the existence of the phenomenon of misconceptions. We must also learn to detect the presence of specific misconceptions, whether we are interacting with a student one-on-one or interacting with a large group of students in the classroom. Only if we are aware of the presence of a misconception can we devise techniques to help students to correct their faulty models.

Second, it is essential that we consider whether there are things we do as teachers and/or as textbook writers that contribute to student construction of incorrect models of physiological phenomena. Feltovich et. al. (7) argued that the incautious use of oversimplified models and analogies can lead to misconceptions about muscle mechanics and specifically the mechanics of cardiac muscle, and Veiga et al. (21) reminded us that the language we use in communicating with our students can create or reinforce misconceptions.

Finally, we need to understand how to help students correct their misconceptions. In all domains in which the phenomenon has been investigated it has been found that simply telling students that their mental model of a phenomenon is incorrect has essentially no effect (22). The key to helping students correct their faulty models, the key to producing conceptual change, is to encourage students to actively confront the discrepancies between the behavior of their models and the demonstrable phenomenon of interest. We must allow (better yet, encourage) students to recognize the failures of their own models before we can assist them in building better ones. We must provide our students with active learning environments (16) in which the interactions between teacher and students make ''visible'' (to teacher and students) the misconceptions that are interfering with learning and thus make possible the remediation of those faulty models.

APPENDIX A
Instrument used in study 1 (exercise)

You've been waiting for the elevator for several minutes and finally decide to run up the 5 flights of stairs to your lecture. By the time you reach the 5th floor you will note which of the following:

heart will beat	faster ___
	slower ___
	at the same rate ___
heart will beat	more vigorously ___
	less vigorously ___
	with the same vigor ___
breathing will be	faster ___
	slower ___
	at the same rate ___
breathing will be	deeper ___
	shallower ___
	at the same depth ___
you will produce	a larger volume of urine than normal ___
	a smaller volume of urine than normal ___
	the same volume of urine as normal ___
your skin will become	pale ___
	red ___
you will	start to shiver ___
	stop shivering ___
you will	shiver vigorously ___
	shiver less vigorously ___
you will	drink a great deal ___
	reduce fluid intake ___
you will	feel short of breath ___
you will	feel fatigued ___
you will	feel hunger ___
you will	feel thirsty ___

APPENDIX B
Instrument used in studies 2 and 3

SITUATION I (''multiple choice'' format)
An individual is transported rapidly to the top of a high mountain. She soon observes that she is breathing faster.
At that time she will be breathing:
1. more deeply **(go to question labeled "MORE DEEPLY" on page 4)**
2. less deeply **(go to question labeled "LESS DEEPLY" on page 4)**
3. with her normal depth **(go to question labeled "WITH HER NORMAL DEPTH" on page 4)**
Enter all of your answers in the leftmost bubble (on the Scantron sheet) of the appropriate question number.
Go on to the back of this page (OVER) and answer ONLY the question to which you have been directed.

An individual is transported rapidly to the top of a high mountain. She soon observes that she is breathing faster.
Answer only one (1) of the following questions!
"MORE DEEPLY"
The volume of air that she moves with each breath, her depth of breathing, increases because **(answer only if you picked choice "MORE DEEPLY" on page 3):**
4. you always breathe deeper when you breathe faster
5. of a response to a sensed decrease of oxygen in the blood
6. the body needs more oxygen
7. None of the above explain my prediction; the depth of breathing increases because

____
____

SITUATION I (''free response'' format)
An individual is transported rapidly to the top of a high mountain. She soon observes that she is breathing faster.
1. At that time she will be breathing:
   a. more deeply **(go to Question 2 on page 3)**
   b. less deeply **(go to Question 3 on page 3)**
   c. with her normal depth **(go to Question 4 on page 3)**
Go on to the back of this page (OVER) and answer ONLY the question to which you have been directed.

An individual is transported rapidly to the top of a mountain. She soon observes that she is breathing faster.
Answer only one (1) of the following questions!
2. The volume of air that she takes in with each breath, her depth of breathing, increases, because (**answer only if you picked choice "a" on page 2**):

____
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