Case study analysis and the remediation of misconceptions about respiratory physiology

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Cliff, William H. Case study analysis and the remediation of misconceptions about respiratory physiology. Adv Physiol Educ 30: 215–223, 2006; doi:10.1152/advan.00002.2006.—Most students enter the physiology classroom with one or more fundamental misconceptions about respiratory physiology. This study examined the prevalence of four respiratory misconceptions and determined the role of case analysis in the remediation of one of them. A case study was used to help students learn about oxygen transport in the blood and a conceptual diagnostic test was used to assess student understanding of the relation between PO2 and hemoglobin saturation by probing for the corresponding (SA/PO2) misconception. A 36% remediation of the SA/PO2 misconception was found to be associated with case analysis. This repair was selective since the frequency of three other respiratory misconceptions was found to be unchanged after classroom instruction about respiratory physiology in lectures and laboratories. Remediation of the SA/PO2 misconception before an instructor-led, in-class case review was superficial and temporary. Explanations provided by students who correctly answered the SA/PO2 conceptual diagnostic test showed improved conceptual understanding following case analysis. These results suggest that a learning strategy where students actively confront their faulty notions about respiratory physiology is useful in helping them overcome their misconceptions.

alternative conceptions; assessment; conceptual diagnostic test; conceptual change; active learning

ONE OF THE GREATEST CHALLENGES that instructors face in attempting to help students learn physiology are the ideas about the human body that students bring with them to the classroom. Many of these notions are at odds with scientifically acceptable conceptions about how the body works and can be surprisingly resistant to correction by conventional approaches to teaching (12). These faulty ideas or misconceptions can also arise during the course of instruction, as students continue to build their understanding of the subject during lectures, laboratories, or readings from the textbook (5, 6, 12). Michael et al. (6) reported the prevalence of four misconceptions in respiratory physiology among 700 undergraduates prior to instruction. The misconceptions and their respective prevalence (percentages of students with misconception) were as follows:

1. The PO2 in the blood is determined by hemoglobin (Hb) saturation (“SA/PO2 misconception”): 90%.
2. A change in inspired O2 must change alveolar CO2 (“O2/CO2 misconception”): 67%.
3. Increases in minute ventilation are the result of increased breathing frequency (f), but tidal volume (VT) does not change or decrease (“VT/f misconception”): 57%.
4. Increases in metabolism lead to increased ventilation because the body “needs” more oxygen (“Met/Vent misconception”): 32%.

In the present study, the prevalence of these four misconceptions was tested in students prior to instruction in respiratory physiology and again after all instruction was finished. The status of the SA/PO2 misconception and the impact of case study analysis on remediating this misconception were of particular interest.

A directed case study was created about carbon monoxide (CO) poisoning to help students learn about how oxygen is carried in the blood, the role of Hb in transport, the oxygen saturation curve for Hb, how the oxygen saturation curve for Hb can be used to determine the amount of oxygen carried in the blood and the amount delivered to tissues, and the contribution of oxygen transport in the blood to external respiration (3). Given the subject matter of this case, it was expected that as the students sought answers to the case questions, they would confront the SA/PO2 misconception.

As developed by Michael et al. (6), the SA/PO2 conceptual diagnostic test (misconception query) requires the student to predict the change in PO2 in the blood as a result of the poisoning of Hb by CO (see Appendix A: Pretest and Posttest Questions). A proper conception of the relation between PO2 and the oxygen bound to Hb under these circumstances would predict that the PO2 remains unchanged since PO2 is established by gas exchange in the lungs. Although none of the questions in the directed case study posed this same query, the understanding of the oxygen saturation curves needed to answer questions from the case should have engaged students in a consideration of the impact that CO had on PO2 of the blood. In fact, the blood gas values provided in the case indicated that PO2 was normal and students were required to use this fact to arrive at the relative affinity of Hb for CO. Furthermore, the case challenged students to consider whether chemoreceptor-mediated hyperventilation would occur under circumstances where the patient’s PO2 was normal. As such, the conceptual diagnostic test was an appropriate way to follow changes in understanding (probing for student learning of the relation between dissolved and bound oxygen in the blood) within the context of solving the case.

METHODS

Conceptual diagnostic tests. The pre- and postconceptual diagnostic tests of respiratory misconceptions were identical to those developed by Michael et al. (6). These tests consisted of a series of a two-tiered queries designed to assess each misconception: the first query provided a short description of a situation in which a respiratory variable could be expected to change and asked the students to predict the change that might occur. Each of these situations was developed to uncover the frequency of a particular misconception. The followup
A correct understanding was indicated by the response that the PO2 students who change their answer from correct to incorrect. posttest answer from incorrect to correct compared with the number of significantly greater number of students who change their pre- to answer from correct to incorrect. Misconception repair is indicated by the probability that a student will change his/her answer from incorrect to correct as a result of instruction in respiratory physiology. The null hypothesis is that for students who change, the PO2 would be unchanged. Although this problem did not assess student misconception of the chemical equilibrium between the oxygen bound to Hb and the oxygen dissolved in the plasma in the same manner as the pre- and posttests, it did examine this concept via an analogous problem where the oxygen-carrying ability of the blood was impaired via the selective removal of red blood cells from the circulation. This variant was used to lessen the effect of repetition on student responses to the conceptual diagnostic questions.

Pretest to midtest to posttest comparisons of the prevalence of student misconceptions were made by the McNemar test for significance of change with Yates continuity correction (11) since the measurement was nominal or categorical (correct or incorrect prediction) and samples were related (each student served as his/her own control). Under these circumstances, the test was solely concerned with determining the significance of the changes between pre- and posttest performances (from incorrect to correct or from correct to incorrect). It was calculated as a \( \chi^2 \) value and is reported as a one-tailed \( P \) value since it was predicted that the probability that any student will change his/her answer from incorrect to correct should be greater than the probability that he/she will change his/her answer from correct to incorrect as a result of instruction in respiratory physiology. The null hypothesis is that for students who change, the probability that a student will change his/her answer from incorrect to correct is equal to the probability that he/she will change his/her answer from correct to incorrect. Misconception repair is indicated by a significantly greater number of students who change their pre- to posttest answer from incorrect to correct compared with the number of students who change their answer from correct to incorrect.

Classroom management of case analysis. This study was performed in the second semester of a two-semester Human Anatomy and Physiology course. The course consisted of 42 students who were primarily sophomore nursing, biology, and biology education majors (−50, −40, and −10%). The first semester of the course was taught by an instructor who did not use case studies. Case study methodology was introduced in the second semester by an instructor experienced with case studies. The students had completed three cases studies prior to their case work on the respiratory system.

The procedure for the in-class use of the directed case study and its application to the case at hand has been previously described (1–3). The following is a description of the instructional protocol together with the sequence of conceptual diagnostic testing. A timeline showing the series of classroom events associated with the case study analysis and diagnostic testing is shown in Fig. 1. The pretest misconception query was administered prior to the first lecture class on the respiratory system. The entire case study on CO poisoning was dispensed at the beginning of first lecture on the respiratory system. Students were given a week to perform the case analysis. This work was done entirely outside of regular class periods.

During this time, students learned the physiology of the respiratory system (pulmonary ventilation, respiration, gas exchange, gas transport, and control of breathing) via lectures, textbook readings, and laboratories. Topics presented in lectures were closely matched with those provided by the textbook, and equivalent emphasis was placed on the concepts of blood gas chemistry, control of ventilation, and respiration. Activities in the laboratory provided greater emphasis on metabolism, respiration, and the control of breathing and less stress on blood gas chemistry. The textbook and textbook supplements provided specific descriptions of the mechanism of CO poisoning, the physiological challenge, and adjustments to high altitude in the chapter on the respiratory system. Students were assumed to be familiar with the cardiovascular response to hemorrhage, blood gas disturbances, and exercise since this had been covered in a prior section of the course on the cardiovascular system.

As with previous cases during the semester, students were encouraged to work on the case in groups and no penalties were incurred for submission of identical answers. Interviews of selected students from the previous year suggested that the typical student spends a total of 2–3 h in the analysis of a case, initially as an individual effort and secondarily as part of a group. An informal check of the class and interviews with selected students indicated that 50–70% of students worked on the case in groups of 3–5 individuals, 20–30% of students worked in groups of 5 or more, and 10–20% of students worked individually or in pairs.

At the beginning of the first class following instruction on the respiratory system, the answers to the case study questions were collected from all the students and the midtest was administered. This

Fig. 1. Time sequence of the classroom activities associated with case study analysis and conceptual diagnostic testing.
conceptual diagnostic test assessed the prevalence of the Sa/Po2 misconception after the students had completed classroom instruction about respiratory physiology, had finished their case work, and had handed in their written analyses. This was done to distinguish the impact that the instructor-facilitated, in-class review of the case had on student learning compared with the student-generated, out-of-class case analysis. It was performed in the class period just prior to the review. No other written work was required, but students were encouraged and expected to make detailed notes of their individual and group analysis of the case questions to prepare for the in-class review of the case. The next class period was devoted entirely to a review of the case. The posttest misconception query was administered during the following week. At no time were the students told the correct answers to the pre-, mid-, and posttest questions, and, since these questions were only used for diagnostic purposes, they were not specifically discussed in class during the course of instruction.

This particular study was part of a larger assessment project designed to examine the impact of case-based learning on student understanding of human anatomy and physiology. An analysis of the student answers to the case study is described in the companion study (3). The assessment protocols used in this project were approved by the Institutional Review Board for the Protection of Human Subjects at Niagara University. Students were informed of the nature of the project, and informed consent was obtained from all participants in this study. Extra credit for participation in the pre-, mid-, and posttests was applied to the portion of the course grade devoted to the learning assessment project (total = 5% of grade).

RESULTS

Prior to instruction, the pretest of student misconceptions uncovered a pattern of misconception frequencies that was similar to that found by Michael et al. (6). Figure 2 shows that Niagara University students exhibited an identical pattern of misconception prevalence but at slightly lower frequencies than the national averages (Sa/Po2 = 81%, 34/42 students; O2/CO2 = 58%, 24/41 students; VT/f = 55%, 23/42 students; and Met/Vent = 24%, 10/41 students). Figure 2 also shows the misconception prevalence in the posttest following instruction in respiratory physiology, including the classroom lecture and discussion, case study analysis, and a review of the case (Sa/Po2 = 59%, 25/42 students; O2/CO2 = 67%, 28/42 students; VT/f = 71%, 30/42 students; and Met/Vent = 19%, 8/42 students). The Sa/Po2 misconception was the only one that exhibited a significant reduction in the pre- to posttest frequency of misconceptions as determined by the McNemar test for the significance of change. A significantly greater number of students changed their pre- to posttest answers from incorrect to correct compared with the number of students who changed their answer from correct to incorrect ($\chi^2, P < 0.05$). There was no significant increase in the prevalence of the O2/CO2 or VT/f misconceptions ($\chi^2, P > 0.1$ and $P = 0.096$) and the prevalence of the Met/Vent misconception did not decline significantly ($P > 0.1$) when student answers were analyzed using the McNemar test.

A closer inspection of individuals who correctly answered “unchanged” on the pre- and posttests revealed a greater degree of repair of the Sa/Po2 misconception than is evident from a simple count of the total number or frequencies of correct replies. Table 1 shows that, of the seven students who correctly answered “unchanged” on the pretest, only three students retained the correct conception on posttest, i.e., who correctly answered “unchanged” on the pretest and “unchanged” on the posttest. Four students answered correctly on the pretest (“unchanged”) and incorrectly on the posttest (“decrease”). Thus, the net gain of students who answered correctly on the posttest after answering incorrectly on the pretest ($n = 14$) was higher than suggested by the overall change in the number of correct answers ($n = 10$, number of correct posttest answers minus number of correct pretest answers). This result is more apparent in Table 2, where the data are arranged in a 2 × 2 contingency table according to whether students responded correctly or incorrectly on the pre- or posttests.

When the pre- versus posttest data in Table 2 were analyzed using the McNemar test for the significance of change, it can be seen that, for the students who changed the category of their answers (incorrect to correct or correct to incorrect, $n = 18$), the number who performed better (changed their answer from incorrect to correct) on the posttest was significantly greater ($n = 14$, $P < 0.05$) than the number who performed worse (changed their answer from correct to incorrect, $n = 4$). Furthermore, comparison of the answers according to whether the students showed correction of the misconception (incorrect on the pretest and correct on the posttest, $n = 14$) versus the incorrect response on the posttest (incorrect on the pretest and posttest or correct on the pretest but incorrect on the posttest, $n = 25$) yielded a 36% remediation rate of the Sa/Po2 misconception (14 of 39 students). Students who answered correctly on both the pre- and posttests ($n = 3$) were not included in these analyses because the effect of case study analysis on their understanding could not be determined.

The numbers of each type of explanation selected by students who correctly answered the Sa/Po2 query on the pre- and posttest are shown in Table 3. A greater frequency of posttest explanations centered on the factors that determine Po2 in the blood is determined by hemoglobin (Hb) saturation (Sa/Po2 misconception); 2) a change in inspired O2 must change alveolar CO2 (O2/CO2 misconception); 3) increases in minute ventilation are the result of increased breathing frequency (f), but tidal volume (VT) does not change or decrease (VT/f misconception); and 4) increases in metabolism lead to increased ventilation because the body “needs” more oxygen (Met/Vent misconception). $n = 42$ students total. *$P < 0.05$ by McNemar’s test for significance of change.

Fig. 2. Prevalence of respiratory misconceptions in students before (pretest) and after (posttest) instruction with case study analysis. The misconceptions were as follows: 1) O2 in the blood is determined by hemoglobin (Hb) saturation (Sa/Po2 misconception); 2) a change in inspired O2 must change alveolar CO2 (O2/CO2 misconception); 3) increases in minute ventilation are the result of increased breathing frequency (f), but tidal volume (VT) does not change or decrease (VT/f misconception); and 4) increases in metabolism lead to increased ventilation because the body “needs” more oxygen (Met/Vent misconception). $n = 42$ students total. *$P < 0.05$ by McNemar’s test for significance of change.
How We Teach

CASE STUDIES AND MISCONCEPTION REPAIR

Table 1. Answers to the Sa/Po2 conceptual diagnostic test by students before and after instruction with case study analysis

<table>
<thead>
<tr>
<th>Answers</th>
<th>Pretest Incorrect</th>
<th>Pretest Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest incorrect</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Posttest correct</td>
<td>14</td>
<td>3</td>
</tr>
</tbody>
</table>

Pretest vs. posttest (n = 42)*

<table>
<thead>
<tr>
<th>Answers</th>
<th>Pretest Incorrect</th>
<th>Pretest Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midtest incorrect</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Midtest correct</td>
<td>13</td>
<td>2</td>
</tr>
</tbody>
</table>

Midtest vs. posttest (n = 40)†

<table>
<thead>
<tr>
<th>Answers</th>
<th>Pretest Incorrect</th>
<th>Pretest Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest incorrect</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Posttest correct</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

n = 42 students total. The Sa/Po2 misconception is that the Po2 in the blood is determined by hemoglobin saturation. *Correct answers.

Table 2. Comparisons of pre-, mid-, and posttest performances on the Sa/Po2 conceptual diagnostic test by students

<table>
<thead>
<tr>
<th>Answers</th>
<th>Pretest Incorrect</th>
<th>Pretest Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest incorrect</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Posttest correct</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Midtest incorrect</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Midtest correct</td>
<td>13</td>
<td>2</td>
</tr>
</tbody>
</table>

Pretest vs. midtest (n = 40)†

Midtest vs. posttest (n = 40)‡

n, no. of students. *Pretest compared with posttest (P < 0.05); †pretest compared with midtest (P < 0.05); ‡midtest compared with posttest (P = 1.00).

Table 3. Explanations of correct answers to the Sa/Po2 conceptual diagnostic test by students before and after instruction with case study analysis

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The partial pressure of oxygen in the blood is determined by the partial pressure of oxygen in the lungs</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>b. The body keeps the partial pressure of oxygen constant</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>c. The body does not need additional oxygen since metabolism is unchanged</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>d. The partial pressure of oxygen in the blood is determined by oxygen solubility</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

DISCUSSION

Our demonstration of the persistence of the four respiratory misconceptions in a class of human anatomy and physiology students over the course of instruction in respiratory physiology illustrates the tenacity of these faulty conceptions. Nevertheless, a comparison of the pre- and posttest frequencies of these misconceptions demonstrates that the use of a case study about CO poisoning was associated with a selective 36% decrease in the prevalence of the misconception about the relation between the oxygen saturation of Hb and the Po2 in the blood. This remediation of the Sa/Po2 misconception associated with student analysis of a relevant case study points out that, under appropriate circumstances, correction of even the most prevalent misconception in respiratory physiology can be achieved. These findings provide hope that, through further instruction with case study analysis.

Fig. 3. Distribution of the answers provided by students to the Sa/Po2 conceptual diagnostic test before (pretest) and after (posttest) instruction with case study analysis. n = 42 students total.
refinement of the learning environment, improved forms of instruction may yield an even greater frequency of repair. They also suggest that a more careful inspection of the changes in student responses over the time course of the case study analysis (see Fig. 1) may clarify the reasons for the repair of the SA/PO2 misconception and give direction to the design of instructional refinements.

Examination of the explanations selected by the students who correctly answered the SA/PO2 query on the pre- or posttests reveal an improved understanding of the conceptual relations underlying oxygen transport as a result of the case study analysis (Table 3). On the pretest, five of seven students who indicated “unchanged” provided an indirect or teleological explanation (answers b or c) for why the PO2 would remain unchanged. Only two students chose the most physiologically meaningful answer (answer a): that PO2 in the blood was determined by the diffusion of oxygen from the alveoli. No students picked the explanation that was chemically germane (answer d). As it is expressed on the query, this answer is causally incorrect. Nevertheless, it does reflect the phraseology found in a popular textbook in medical physiology (4) and would be proper if the concentration of oxygen in the blood was considered as the independent variable. Moreover, it indicates that a student has understood that the PO2 in the blood is in some fashion related to its solubility and not determined by the percent saturation of Hb. Thus, a consideration of the answers on the pretest showed that only two of seven students provided explanations that were physiologically or chemically meaningful. On the other hand, 11 of 17 students chose the physiologically or chemically relevant answers (answers a or d) on the posttest, including 8 students who chose the most accurate one (see Table 3). Therefore, the shift in the student responses to more accurate and meaningful explanations was also associated with student work on the case study and instruction in respiratory physiology.

Consistent with the report from Michael et al. (6), Fig. 3 indicates that prior to instruction approximately one-third of students held the misconception that CO binding to Hb leads to an increased PO2 in the blood. Figure 3 also shows that a marked reduction in the prevalence of this particular misconception occurred on the posttest and accompanied the pre- to posttest decrease in the overall prevalence of the SA/PO2 misconception. This association might suggest that the students who would be inclined to correct their misconception were those who had initially thought that CO poisoning would cause an increase in the PO2 dissolved in the blood. However, examination of individual student responses to the pre- and posttests proves this conclusion to be illusory (see Table 1). Of the 17 students who correctly answered “unchanged” on the posttest, 6 students originally had answered “increase,” 8 students had originally answered “decrease,” and 3 students had answered “unchanged” on the pretest. Thus, there was no underlying tendency of students to change their response from “increase” to “unchanged” as a result of their work on the case study or their learning of respiratory physiology.

Yet, it may be of interest to determine the reasons why these students initially held this particular form of the SA/PO2 misconception and why the overwhelming majority of them abandoned it over the course of instruction. As Michael explains, the most common explanation that students give for this misconception involves students seeing the blood as a closed system (6). Under these circumstances, CO in the blood would displace O2 from Hb and increase its concentration in the plasma. If this was the student’s understanding, then a prediction of an increase in PO2 would be logical and could be correctly explained by the answer that “oxygen is driven from hemoglobin into blood plasma.” However, a review of the explanations selected by students on the pretest shows that only 4 of 12 students who predicted an increased PO2 also chose this answer and apparently reasoned in this fashion. Five students chose a teleological answer, i.e., the body needs more oxygen in the plasma to compensate for the reduced amount bound to Hb (answer b), two students incorrectly indicated that CO stimulates ventilation (answer c), and one student failed to provide a proper answer. Thus, unlike the findings of Michael et al. (6), the pretest results from this study provided no single, dominant explanation for why these students held this misconception prior to instruction in respiratory physiology.

Furthermore, an examination of the posttest responses of the students who initially chose “increase” as their prediction of the change in PO2 reveals no clear pattern in their shifting answers and explanations. Students who explained the increase in PO2 according to either the closed compartment model or to teleology chose “decrease” or “unchanged” with equal frequencies on the posttest. Thus, there was no correlation between the pretest choice of an explanation for the increased PO2 with the posttest shift in the prediction of the change in PO2. Students abandoned the misconception that CO binding to Hb would increase PO2 in the blood for reasons that are not readily discernable from either their pretest explanations or from their posttest predictions or explanations. Nevertheless, the uniform tendency of these students to change their answer on the posttest indicates that misconceptions of oxygen transport associated with an initial prediction of an increased PO2 in the presence of CO (blood as a closed system or teleology) were tenuous and subject to change.

Also consistent with the findings of Michael et al. (6) was the observation that the most common form of the SA/PO2 misconception manifested itself as the prediction that the PO2 of the blood should decrease after poisoning with CO (see Fig. 3). Approximately 56% of all students exhibited this misconception on the pretest (23/42 students) or posttest (24/42
students) (see Table 1). Furthermore, 65% of these students (15/23 students) made the same prediction on both the pre- and posttests even after case study analysis and instruction in respiratory physiology. Presumably, this indicates that the faulty notions of gas chemistry and chemical equilibria underlying this form of the SA/PO2 misconception were particularly resistant to change. Alternately, elements of instruction may have actually reinforced them.

How do students make sense of this prediction? The most common explanation provided on the pre- or posttests was that “CO displaces oxygen in the blood” (12 of 23 answers on the pretest and 13 of 24 answers on the posttest). Taken at face value, this explanation suggests that students believed that PO2 is actually a measure of the O2 bound to Hb; hence, a displacement of O2 from Hb would be observable as a reduction in the PO2. This is the interpretation of Michael et al. (6). Alternately, students may have believed that since CO displaced O2 from Hb, it would somehow have reduced the O2 dissolved in the plasma. From this view, they indicated that they held another flawed notion, namely, that the percent O2 saturation of Hb determines the concentration of free O2 in the plasma. Both of these notions may signify more fundamental flaws in student understanding of the meaning of PO2 or the implications of chemical mass action and equilibrium.

The second most common explanation for the decrease in PO2 was that the “partial pressure of CO reduces the partial pressure of oxygen” (6 of 23 responses on the pretest and 8 of 24 responses on the posttest). This explanation suggests that these students have discounted the implication of the binding of CO to Hb and have reverted to a form of the O2/CO2 misconception, namely, if the partial pressure of one gas increases in the blood, then the partial pressure of another gas must decrease (6). A greater percentage of students who chose this explanation for their pretest prediction changed their posttest prediction to the correct one compared with students who picked other explanations for their pretest predictions (50% vs. 33%). This result suggests that students who initially thought that CO poisoning should decrease PO2 because of a misconception about relative partial pressures of different gases in solution were more amenable to remediation than students who initially predicted a decrease based on faulty notions about partial pressure or misconceptions about chemical equilibrium or mass action. A more detailed inquiry into the reasons why students chose either of these two explanations for their answers may help clarify why a substantial number of students predicted that the PO2 in the blood of CO-poisoned individual will decrease.

Table 2 indicates that a significantly greater number of students changed their answer from incorrect on the pretest to correct on the midst compared with the number who changed their answer from correct to incorrect. If the midst is a valid measure of the prevalence of the SA/PO2 misconception, this result shows that a significant remediation of the SA/PO2 misconception was associated with instruction in respiratory physiology and the out-of-class work on the case study. Nevertheless, of the 15 students who correctly answered the midst test query on blood PO2, only 4 of these students correctly indicated that that the total amount of oxygen in the blood declined with selective replacement of whole blood with a plasma substitute (question 5 on the midstest). This latter finding shows that a correct understanding about the PO2 of the blood was not necessarily accompanied by a correct notion about its oxygen-carrying capacity under these circumstances. This result suggests that, despite the reduced prevalence of student misconceptions as measured by the survey, student conceptions about the relation between PO2 and oxygen transport capability remained ill formed at the time of the midstest.

Not surprisingly, a “decrease” in blood PO2 was the most common prediction about the PO2 on the midstest (22 of 40 students). Consistent with the high frequency of this answer on the pre- and posttests (Fig. 3), this response reflects the most commonly held aspect of the SA/PO2 misconception, namely, that if Hb levels in the blood are reduced, then the PO2 must also decrease (6). Supporting this interpretation is the finding that most of the students who predicted that the PO2 was decreased below normal also predicted that the oxygen-carrying capacity was reduced (17 of 22 students).

Comparison of the answers on the mid- and posttests showed that 6 of the 15 students who answered the midstest correctly answered the posttest correctly as well (Table 2). Two of these students had answered the pretest correctly. Thus, of the 13 students who showed that they had overcome the SA/PO2 misconception between the pre- and midtests, only 4 students showed evidence of retaining this repair by the time of the posttest. The other nine students abandoned their correct answer on the midstest and chose “decline” as their posttest prediction for the change in blood PO2 (see Table 2). The results of the midstest assessment indicate that, while substantial misconception repair was associated with out-of-class work on the case study, its effect on many students was superficial and temporary.

Nine of the seventeen students who answered the posttest correctly did so after answering both the pre- and mid tests incorrectly (Table 2). What might account for the improvement in student understanding between the midstest and posttests? The case study review was the only significant classroom activity that occurred during this time. During the review, which encompassed a complete class period, each case question was considered by having students explain their answers to the class. Within this framework, the instructor initiated an interactive discussion about each answer and other students raised specific concerns about the subject material. This format allowed students to clarify misunderstandings, review related facts, and reinforce and reemphasis subject material (1, 2). It is likely that these learning activities made significant contributions to the remediation of the SA/PO2 misconception compared with out-of-class components of the case analysis (individual and group work).

This finding is consistent with the oral reports of selected students obtained from structured group interviews (unpublished data). These students indicated that the discussion of the case during the study review was particularly valuable in helping them overcome misconceptions about the subject material. The congruency between the student self-reports and the improvement of conceptual understanding as indicated by the misconception queries suggests that greater attention needs to be devoted to defining what aspects of the case review promote misconception repair.

Why should the process of case analysis help students overcome misconceptions in respiratory physiology? Posner’s model of conceptual change suggests a reasonable explanation (9). According to Posner, for students to arrive at a more
accurate conceptual understanding, they must face the inadequacies of their misconceptions. This confrontation, coupled with a desire for satisfactory resolution, leads them to seek new or revised concepts that have greater plausibility, clarity, consistency, or explanatory power.

It can be suggested that case analysis provides the first step in such a process of conceptual change. In the problem of CO poisoning, students must wrestle with their understanding of the physiology of blood oxygen transport to solve the case. In particular, they must 1) inspect blood gas measures and compare them with normal levels and 2) use the oxygen-Hb saturation curve to calculate how much oxygen is carried by the blood. In doing so, they determine that the CO-poisoned blood carries only one-half the normal amount of oxygen despite that fact that the Po2 remains normal. This disparity is designed to yield the cognitive dissonance necessary to confront the major misconception that students hold about the oxygen transport of the blood, namely, that Hb-oxygen saturation is equivalent to Po2 (6). To put together a coherent explanation of this disparity, this misconception must be addressed and the resolution of any inconsistencies must be achieved. This can occur as students work on the case individually or in groups and as they discuss the case with the instructor during the in-class review. It is from this viewpoint that case analysis is expected to begin to help students overcome the Sa/Po2 misconception and assist them in improving their conceptual understanding of blood oxygen transport.

If the present study supports such a contention, what are the implications of these findings for the teaching and learning of respiratory physiology? The results of the pre- and posttests cast doubt on the effectiveness of conventional forms of instruction in helping students overcome misconceptions. When the three respiratory misconceptions not addressed by the case study were considered, there was no change in the frequencies of these misconceptions despite student efforts to learn from lectures, textbook readings, and laboratory exercises. If one of our goals as instructors is to help students overcome misconceptions, then one implication of these findings is inescapable: conventional instruction is largely ineffective. If remediation of misconceptions is another one of our educational objectives, then we must adopt more effective strategies for misconception repair than provided by traditional approaches.

How does the effectiveness of case analysis compare with other strategies designed to help students overcome misconceptions in respiratory physiology? Modell et al. (7) have developed a laboratory exercise targeted to the Vt/f misconception and found that different introductory protocols resulted in different degrees of remediation. Some of the protocols yielded frequencies of misconception repair (≈35%) that were identical to the remediation of the Sa/Po2 misconception observed here in conjunction with case analysis. Nevertheless, given the differences in the misconceptions examined and the types of the instructional methods used, it would be premature to make specific comparisons between the results of these two studies.

Rather, it may be useful to consider the general lessons that can be learned about the repair of faulty notions about respiratory physiology from the findings of this investigation and that of Modell et al. First, as noted previously by Michael et al. (6), there are significant differences in the frequencies with which students brought respiratory misconceptions to the classroom. In the present study, these frequencies ranged from 24% to 81%. These results also confirm that the Sa/Po2 misconception was the most widespread, whereas these findings and the results of Modell et al. (8) are consistent with previous studies showing that the Vt/f misconception is found in about 60% of incoming students (6).

What does the initial prevalence of a misconception tell us, aside from the extent of the pedagogical problem? Does prevalence tell us anything about the difficulty that students will face in accommodating the proper conception and, therefore, about the persistence of the corresponding misconception? The experience of most instructors might lead them to conclude that the greater conceptual complexity of the Sa/Po2 misconception would make it more frequent than the Vt/f misconception and more likely to resist extinction. Does this suggest that misconceptions with higher initial frequencies are more difficult to remediate? A momentary reflection dismisses this notion. Misconceptions may be found with high prevalence yet be relatively straightforward and amenable to correction. Alternately, others might show lower frequencies yet be remarkably unyielding to remediation in the smaller populations of the students who hold them. Furthermore, the present results failed to show a statistical correlation between the initial frequency of a misconception and the extent of its remediation. Figure 2 shows that the Met/Vent misconception, at an initial prevalence of 24%, was no more amenable to remediation under conventional instruction than the O2/CO2 misconception, at an initial prevalence of 67%. These considerations suggest that we should be hesitant to infer correlations between the initial prevalence of a misconception and its degree of resistance to extinction.

Second, both studies indicated that the effectiveness of misconception repair depends critically on the learning strategy adopted. The present study showed no difference in the pre- and posttest prevalences of the Vt/f misconception among students after they received conventional instruction via lectures, textbook readings, and laboratories (see Fig. 2). Yet, Modell et al. (8) demonstrated that students who performed a laboratory exercise specifically designed to permit them to test their conceptions of the relation between breathing rate and depth showed a repair frequency of ≈35% for this misconception. This finding indicates that the efficacy of remediation hinges on the nature of the learning strategy employed and how the students are engaged in the process of learning.

Furthermore, the results of Modell et al. (8) suggest a way to enhance and sustain the remediation of the Sa/Po2 misconception associated with case study analysis. Their study indicates that a key element to remediation of misconceptions appeared to be a public declaration of a prediction to the instructor. With the added dimension of instructor intervention to force students to verbalize their expected results for the laboratory exercise, Modell et al. (8) found a doubling of the frequency of a successful misconception repair. This approach suggests that remediation of the Sa/Po2 misconception by case study analysis would benefit from incorporating learning activities where the students must make a public prediction or defense of their notions about the effect of CO poisoning on the Po2 in the patient’s blood. Following the example described by Modell et al. (8), this prediction or defense should be made by students prior to student work on the case study. Consistent with
Posner’s model, this public declaration would serve to amplify the cognitive dissonance experienced by students as they address the paradox between the normal PO₂ and the abnormal Hb saturation revealed by the case. The amplification evoked by the need to make a public declaration should force a greater number of students to productively confront the SA/PO₂ misconception and should enable a greater percentage to achieve sustained remediation.

The work of Modell et al. (8) also suggests a reason for the failure to achieve a “sustained” remediation from the mid- to posttests. It is possible that the instructor-led discussion did not provide sufficient stimulus for many members of the class to critically reexamine their understanding of the chemistry of oxygen-Hb binding during the review of the case. Certainly, the student who was called upon to explain his/her answer was given such opportunity, as were presumably the others who carefully followed the classroom discussion. Nevertheless, it may be helpful to design elements into the case discussion that would engage more students in the process of retesting their mental models about how oxygen is transported in the blood. This modification of the case discussion may yield a more sustained remediation of the SA/PO₂ misconception following the summative review of the case. Strengthening the opportunity for students to retest their mental models here is also consistent with the indications given by students that the case discussion was particularly useful in helping them overcome misconceptions.

One might question, having considered some of the concerns raised this study, whether the pedagogical benefit gained from adopting a case-based strategy for remediating misconceptions in respiratory physiology justifies the educational costs incurred, i.e., whether the 36% remediation rate for the SA/PO₂ misconception associated with case study analysis is worth the extra effort expended. A complete answer to this question is beyond the scope of the present study and requires more extensive accounting of the educational gains and losses involved. For example, we do not know how the repair rate reported here compares with repair rates that could be achieved by other educational strategies. What can be said is that the educational costs associated with the present approach are minimal. With exception of the case review, class time spent on the analysis of the case was insignificant. Out-of-class faculty effort was modest and was spent mostly in preparation for the in-class discussion of the case. Furthermore, this particular case study approach has been shown to have benefits for students that extend beyond the remediation of misconceptions (1, 2, 10). Thus, it is reasonable to suggest that the gains in misconception repair achieved by the case-based approach described here are commensurate with the costs incurred by faculty members and students. Further investigation will be required to confirm this and to determine whether the addition of exercises such as the public defense of student mental models will yield even higher educational benefits in relation to costs.

The persistence of the SA/PO₂ misconception rests ultimately on difficulties that students have with fundamental concepts of gas chemistry, chemical equilibrium, mass action, and the diffusion of matter between compartments. It is the interconnected web of these central concepts—what might be called the students’ “conceptual ecology”—that becomes the background on which students attempt to solve the problem of CO poison-
a. The partial pressure of oxygen in the blood is determined by the partial pressure of oxygen in the lungs.
b. The body keeps the partial pressure of oxygen constant.
c. The body does not need additional oxygen since metabolism is unchanged.
d. The partial pressure of oxygen in the blood is determined by oxygen solubility.

Appendix B: Midtest Questions

In a remote wilderness location, an accident victim has lost a significant amount of blood via hemorrhage. However, emergency medical personnel have been able to infuse physiological saline (a plasma substitute) and restore this individual’s blood pressure and volume to normal. At this point in time, the victim’s
1. hematocrit (percent volume of the blood contributed by cells) should be:
   A. increased above normal.
   B. decreased below normal.
   C. normal.
2. ventilation rate should be:
   A. increased above normal.
   B. decreased below normal.
   C. normal.
3. partial pressure of oxygen in the blood should be:
   A. increased above normal.
   B. decreased below normal.
   C. normal.
4. total blood flow should be:
   A. increased above normal.
   B. decreased below normal.
   C. normal.
5. total amount of oxygen (ml/100 ml) in the blood should be:
   A. increased above normal.
   B. decreased below normal.
   C. normal.

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