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Articles

A Case-based Approach Increases Student Learning Outcomes and Comprehension of Cellular Respiration Concepts*

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This study investigated student learning outcomes using a case-based approach focused on cellular respiration. Students who used the case study, relative to students who did not use the case study, exhibited a significantly greater learning gain, and demonstrated use of higher-order thinking skills. Preliminary data indicate that after engaging with the case study, students were more likely to answer a question addressing misconceptions about cellular respiration correctly when compared with students who did not use the case study. More rigorous testing is needed to fully elucidate whether case-based learning can effectively clarify student misconceptions related to biological processes.

Keywords: Case-based learning, cellular respiration, undergraduate, misconception.

Case-based learning (CBL) is a pedagogical method that uses case studies as active learning tools. A case study is composed of an engaging and/or controversial story, usually a dilemma that requires a basic understanding of scientific principles [1]. Qualitative studies of problem-based learning methods suggest students comprehend concepts, retain content longer, and achieve critical thinking and real-world problem solving skills [2–6]. However, student learning gains beyond qualitative, formative data have not been sufficiently investigated, especially in the biological sciences [7].

Aerobic cellular respiration is typically regarded as a difficult topic for students to learn and for instructors to teach since it is a complex biological process that involves integrating multiple concepts [8]. The case study entitled "The Mystery of the Toxic Flea Dip" was created in an interrupted case study format as one approach for students to learn the process of aerobic cellular respiration [9]. The case is based on actual events in which a 4-year-old girl died from rotenone poisoning after washing her dog with flea dip [10]. The case is divided into four sections where students read the case scenario, brainstorm causes of death, analyze data from an autopsy report, and integrate knowledge about cellular respiration to determine the mechanism of how rotenone inhibits mitochondrial function. An interrupted case study format was chosen since this format allows for lecturing interspersed with active engagement with the case's sections.

This investigation's goal was to address three research questions:

1. Is there a significant difference between the performance on content assessments of students who use the case study (+CS) and those who do not use the case study (−CS) in learning about cellular respiration?
2. Does the case study effectively address the common misconception that breathing is synonymous with cellular respiration?
3. Do +CS students perceive and demonstrate usage of higher-order thinking skills to a greater extent relative to −CS students?

METHODS

Students participating in this study were enrolled in either undergraduate general biology or introductory cell biology courses and included both non-biology and biology majors. Classes were randomly assigned as a −CS or a +CS group. Students were made aware that they had an opportunity to participate in this study and signed consent forms if they agreed to participate. The study design, protocol, consent form, and instruments were approved by the appropriate Institutional Review Boards for involvement of human subjects. The −CS group consisted of 63 students (30% male, 70% female) with 45 completing both the pre- and post-tests, 1 completing the post-test only and 55 completing the post-survey. The +CS group consisted of 94 students (41% male, 59% female) with 75 completing both the pre- and post-tests, 7 completing the post-test only, and 78 completing the post-survey. Statistical analyses were performed using SPSS Statistical Software v.14

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(SPSS Inc., Chicago, IL). An alpha value of 0.05 was selected as the significance level for all tests.

The pre-test and post-test were designed to assess comprehension of content that focused on important molecules, cellular organelles, and processes involved with cellular respiration. The tests were scored out of 10 points and were composed of multiple choice, short answer, open-ended, and true/false questions. To reduce pre-test sensitization, the questions on the pre- and post-tests focused on similar content but were not identical. The pre-test was administered at least 2 days before cellular respiration was covered in class. The case study (+CS) or a traditional lecture (−CS) was then implemented. The topic of cellular respiration was covered in one to three class sessions (each class session being 50–80 min), where the +CS group spent an average of 100 min of class time and the −CS group spent an average of 155 min of class time focused on cellular respiration. Students then completed the post-test and post-survey.

A normalized learning gain metric was used to compare learning outcomes across the different groups. The metric, $\langle g \rangle$, [(post-score − pre-score)/(maximum score − pre-score)], was calculated for each student who completed both the pre- and post-tests and averaged for each group [11]. The Student's *t*-test was used to determine significant differences in learning gain between the –CS and +CS groups. The effect size was also determined from the learning gain data.

To determine which students initially held the misconception that breathing is the same as cellular respiration, the pre-test included the question: "Breathing is the same process as cellular respiration (True/**False**)." For the post-test, the multiple choice question was the following: "What is true about breathing and cellular respiration? (a) breathing is the exchange of gases and cellular respiration is the formation of chemical energy, (b) they are the same process, (c) they both take place in the mitochondria, (d) none of the above." Students' responses on these questions were tabulated and the chi-square test was used to determine if a relationship existed between students' responses and the assigned group (Table IIIA and B). Students' performance on a pre- and post-test data analysis question was measured and the chi-square test was used to determine if a relationship existed between student performance and the assigned group (Table V).

A post-activity survey measured students' perceptions of the learning experience and level of collaboration with other students. Survey questions were Likert scale (1 = strongly disagree, 5 = strongly agree) and open-ended format. The students' responses to an open-ended question were analyzed and common themes were gleaned to generate a categorical scheme (Table IV). Individual student comments were then scored based on this scheme. For example, a student's response "we were given a problem and enough information to solve it which allowed us to think hard about the problem" was scored once in the "problem solving" category and once in the "critical thinking" category. Thus, a student's response could be scored in one or more categories. Some students wrote multiple comments while others left this question blank. Instructors were also given a post-survey to gather their perceptions and feedback about the classes focused on cellular respiration.

TABLE I
List of topics discussed during cellular respiration sessions in both −CS and +CS groups

1. Steps involved in cellular respiration including glycolysis, Kreb's cycle, and electron transport chain
2. Products and reactants involved in aerobic cellular respiration
3. Cellular location of where reactions occur
4. Importance and production of ATP as an energy source
5. Enzymes and related molecules involved in cellular respiration
6. Role of oxygen in cellular respiration

TABLE II
Average normalized learning gain $\langle g \rangle$ achieved in the −CS (n = 45) and +CS groups (n = 75)

Group	$\langle g \rangle$
−CS	0.12 (0.05)[a]
+CS	0.48 (0.04)

[a]Numbers in parentheses indicate *SEM*, $p < 0.0001$.

RESULTS

Similarity of Content Delivered

Instructors who participated in this study ranged from postdoctoral fellows with at least one semester of teaching experience to instructors who were full professors with many years of teaching experience. However, all of the instructors were relatively new to teaching using the CBL approach. To determine the effectiveness of this CBL approach, it was important to ensure the similarity of content and concepts covered in −CS and +CS classes. This was performed by reviewing instructors' teaching materials to verify that the students were exposed to similar concepts in both the −CS and +CS classes and that the topics aligned with questions on the pre- and post-tests. Students' responses to the post-survey question "list three concepts that you learned today about cellular respiration" were analyzed as additional evidence to further elucidate what content was delivered. Students' responses to this question and content delivered by the instructors were aligned with the major topics listed (Table I). This suggests that both the −CS and +CS instructors covered similar content regardless of pedagogical methods used.

Students' Learning Gain

A hypothesis of this study was that students who learned cellular respiration via the case study (+CS) would achieve a higher average normalized learning gain $\langle g \rangle$ when compared with students who did not use the case study (−CS). Students in both groups demonstrated similar scores on the pre-test, suggesting that students had similar baseline knowledge of cellular respiration (−CS group, $M = 2.88$, SEM = 0.43; +CS group, $M = 2.63$, SEM = 0.30, $t(118) = 0.59$, $p = 0.557$). Analyzing aggregate data, students in the +CS group exhibited a significantly higher average normalized $\langle g \rangle$ ($M = 0.48$, SEM = 0.04) when compared with the −CS group ($M = 0.12$, SEM = 0.05) (Table II, $t(118) = 5.09$, $p < 0.0001$) with an effect size of $d = 0.98$. The learning gain, $\langle g \rangle$, ranged from 0.09 to 0.14 in classes in the −CS group and ranged from 0.17 to 0.58 in the +CS classes. These results suggest that students in the +CS group achieved a significantly higher learning gain relative to the −CS group.

Misconception Clarification

A common student misconception in biology is that breathing is the same process as cellular respiration [8]. One goal of the case study's design was to help students correct this misconception. It was hypothesized that stu-

Table III
Addressing the misconception that breathing and cellular respiration are synonymous

	Incorrect (%)	Correct (%)	
(A) Student outcomes on post-test misconception question[a]			
−CS ($n = 46$)	32.6 (15)	67.4 (31)	
+CS ($n = 82$)	15.9 (13)	84.1 (69)	
	Students without misconception (%)	**Students who did not correct misconception (%)**	**Students who corrected misconception (%)**
(B) Analysis of misconception clarification[b]			
−CS ($n = 45$)	33.3 (15)	29.0 (13)	37.7 (17)
+CS ($n = 75$)	49.3 (37)	13.3 (10)	37.4 (28)

[a] n = the total number of students completing the post-test. Number of students in each category is indicated in parentheses, (p = 0.044).
[b] n = the number of students who completed both the pre- and post-tests. Number of students in each category is indicated in parentheses (p = 0.074).

Table IV
Analysis of open-ended post-survey question: "In what ways were the classes that covered cellular respiration different from other class sessions this semester?"

Category	Sample comment	% Responses −CS ($n = 55$)	% Responses +CS ($n = 78$)
Promoted collaboration	"We were able to get into groups and learn from each other."	0 (0)	37.2 (29)
Hands-on activity involved	"It gave a more hands on approach that makes retaining the information much easier, and not to mention more enjoyable."	5.5 (3)	24.4 (19)
Critical thinking and problem solving skills	"I learned a lot more from this activity because it called for critical thinking." "It was a case study where you try to figure out what the problem was and how the problem came about."	0 (0)	23.1 (18)
Connected with real-world scenario	"There was something that we could relate what we were learning to real life."	0 (0)	15.4 (12)
Application of concepts	"It made us apply what we had learned in class to the case study."	0 (0)	10.3 (8)
No difference between this class and others	"There was no difference."	36.4 (20)	3.8 (3)

n = all students completing the post-survey. Number of students in each category is indicated in parentheses.

dents in the +CS group would have a significantly higher rate of misconception clarification when compared with students in the −CS group. The proportion of students who answered the post-test question correctly was measured to determine which students maintained the misconception after the classes focused on cellular respiration (inclusive of all students who completed the post-test). In the +CS group, 84% (69/82) of students answered the post-test question correctly when compared with 67% (31/46) of the students in the −CS group (Table IIIA). A chi-square test of independence was performed to examine the relation between the performance on the post-test question and the assigned group. The relation between these variables was significant (χ^2 (1, $N = 128$) = 4.84, $p = 0.044$). Students in the +CS group were more likely to answer the question correctly than students in the −CS group.

To determine which students clarified their misconception, students' performance on the pre- and post-test misconception questions was analyzed. The proportion of students who clarified their misconception (answered the pre-test question incorrectly then answered the post-test question correctly) was 37.7% for the −CS group and 37.4% for the +CS group (Table IIIB). A chi-square test of independence was performed to examine the relation between the change in performance on the misconception question and the assigned group. The relation between these variables was not significant (χ^2 (2, $N = 120$) = 5.21, $p = 0.074$). Further analysis of responses on the post-test such as a most frequent incorrect answer did not reveal consistent trends (data not shown) [12]. Thus, the data provide insufficient evidence that the case study clarified students' misconception.

Promoting Collaboration and Higher-Order Thinking Skills

A post-activity survey was used to gain information on the ability of the case study to promote collaboration. On the post-survey question, "students worked collaboratively during the class sessions on cellular respiration," students in the +CS group reported a significantly higher mean agreement rating ($M = 4.53$, SD = 0.7) when compared with the −CS group ($M = 3.90$, SD = 0.9, Wilcoxon,

TABLE V
Results from open-ended, data analysis question

<table>
<tr><th></th><th>Group</th><th>Incorrect</th><th>Correct</th><th>p Value</th></tr>
<tr><td>Pre-test question
Given the data below, what do you conclude about cellular respiration in Mary's muscle cells?
<table>
<tr><th></th><th>Normal muscle cells</th><th>Mary's muscle cells</th></tr>
<tr><td>Krebs cycle (ATP)</td><td>2</td><td>2</td></tr>
<tr><td>Amount of NAD+ (pmol)</td><td>75</td><td>75</td></tr>
<tr><td>Amount of glucose (mg/dL)</td><td>81</td><td>80</td></tr>
<tr><td>Electron Transport Chain (ATP)</td><td>32</td><td>0</td></tr>
</table>
Answer: Since no ATP is produced in the electron transport chain in Mary's cells, there must be a block before this step in the cellular respiration process.</td><td>−CS
+CS</td><td>71.1% (32)
82.7% (62)</td><td>28.9% (13)
17.3% (13)</td><td>
0.17</td></tr>
<tr><td>Post-test question
Given the data below, what do you conclude about cellular respiration in Patient #1's muscle cells?
<table>
<tr><th></th><th>Normal heart cells</th><th>Patient #1 heart cells</th></tr>
<tr><td>Glycolysis (ATP)</td><td>2</td><td>2</td></tr>
<tr><td>Krebs cycle (ATP)</td><td>2</td><td>0</td></tr>
<tr><td>Amount of glucose (mg/dL)</td><td>81</td><td>80</td></tr>
<tr><td>Amount of NAD+ (pmol)</td><td>75</td><td>75</td></tr>
</table>
Answer: There is no ATP being produced in the Krebs cycle in Patient #1's heart cells, therefore, there is a block before the Krebs cycle and cellular respiration isn't able to proceed.</td><td>−CS
+CS</td><td>68.9% (31)
42.7% (32)</td><td>31.1% (14)
57.3% (43)</td><td>
0.01</td></tr>
</table>

Number of students in each category is indicated in parentheses (−CS, $n = 45$. +CS, $n = 75$).

$p < 0.001$). Post-survey responses to the open-ended question, "In what ways were the classes that covered cellular respiration different from other class sessions this semester?," were analyzed for evidence of student-to-student collaboration. None of the students' comments from the −CS group were scored in the "promoted collaboration" category whereas 37% of the comments from the +CS group were scored in this category (Table IV).

It was hypothesized that this case study would promote higher-order thinking skills [13]. On the post-activity survey, a greater proportion of students in the +CS group reported, without prompting, usage of higher-order thinking skills such as critical thinking and problem solving skills (23%) and the ability to apply concepts learned from class (10%) when compared with the −CS group (Table IV). A greater proportion of the +CS students recognized that the case study allowed for hands-on interactivity (24%) and the opportunity to connect course content with a real-life scenario (15%) (Table IV). Thirty-six percent of students in the −CS group stated that the class sessions involving cellular respiration were no different from their regular class sessions, indicating that the instructors did not vary their pedagogical approach from their standard mode of teaching during these classes (Table IV).

In addition to students' responses on the post-survey, a higher-order thinking question was included on both the pre- and post-tests as one measure of students' data analysis skills (Table V). A chi-square test of independence was performed to examine the relation between the performance on the pre-test question and the assigned group. The relation between these variables was not significant, suggesting that students in both groups performed similarly on the pre-test question (Table V, χ^2 (1, $N = 120$) $= 2.21$, $p = 0.17$). However, the relation between performance on the post-test question and the assigned group was significant, suggesting that the +CS students performed better on the post-test question when compared with the −CS students (Table V, χ^2 (1, $N = 120$) $= 7.75$, $p = 0.01$).

Instructor Responses to the Case Study

Instructors who implemented the case study provided positive feedback about the case and the resulting student learning outcomes. Comments included "the case is a good way to get students to analyze data and highlight the important parts of cellular respiration" and the case was "useful in breaking up the presentation of this rather challenging material." All of the instructors who used the case study commented that they would be willing to use this case study and other CBL approaches in their future teaching.

CONCLUSIONS

Research in science education investigates how students optimally learn biological concepts and evaluates the most effective learning environments to achieve learning objectives [3, 14]. This current study begins to address how and what students learn from case studies [7, 15–17] and compares outcomes from the use of a case study in an interrupted case format with a traditional, lecture style format for content delivery [18]. Since this study tested the implementation of an individual case study, alternative experimental designs such as the counter-balanced design were not fully applicable in this context to answer the proposed research questions [7].

The data demonstrate that this case study leads to increased learning gains when compared with traditional modes of learning as measured by content and skills-based assessments in addition to a post-activity survey [18–21]. The learning gain results from this study fell within a medium range (0.3–0.7) as established by a previous study that compared active learning interventions *versus* traditional pedagogies [11]. Of note, the learning gains in the current study were achieved in a shorter amount of class time relative to the control group. The data also suggest that CBL can be used to address, but may not completely clarify students' misconceptions. The data revealed a positive change in clarifying a common misconception related to cellular respiration when examining post-test responses alone (Table IIIA) but the interpretation is limited since fewer students in the +CS group initially held the misconception (Table IIIB) and only one question on each of the pre- and post-tests was used to measure this change. Additional data are needed in future studies to further address how case studies may affect student misconceptions.

Observations reported in other studies indicate that CBL provides opportunities for developing and practicing high-order thinking and collaboration skills [5, 6, 22]. The results from this study demonstrate that students using the case study not only reported usage of higher-order thinking skills such as problem solving and data analysis but also demonstrated these skills on a post-test assessment to a significantly greater degree relative to students who did not use the case study. These data provide even stronger evidence that case studies promote usage of higher-order thinking skills when compared with student-reported evidence previously described [5].

Taken together, this investigation supports the hypothesis that CBL in science is an effective approach for students to learn biological processes in relevant, real-world contexts and results in significant learning outcomes. Future studies may investigate the effectiveness of how case studies are used in a course (i.e. as an in-class activity, out of class assignment, or an online assessment), if CBL leads to long-term content retention, and how best to design case studies to more effectively address misconceptions.

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