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Use of conceptual scaffolding to enhance students' understanding of Biology

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Abstract

This paper examines concrete attempts by teachers to enhance students' conceptual understanding of the concept of Chemiosmosis in Cellular Respiration and Photosynthesis in GCE A-Level Biology. Specifically, the interest is in mediating the visual with verbal and textual modes of communication for purposeful meaning-making in the construction of scientific texts. Teachers' attempts at making the visualization of the key processes concrete and the necessary links between topics clear through the use of Talk Moves (Chapin, O'Connor & Anderson, 2013) and visual representations of concept sketches (Johnson & Reynolds, 2005) are examined. This study is aimed at reinforcing the skills identified in the syllabus, mainly, demonstrating science inquiry skills in the use of appropriate models to explain concepts, solve problems and make predictions. Two groups of mixed ability students are involved in this study. Through teacher-guided group discussions where students' thinking is scaffolded, opportunities are provided for students to verbalise and deepen understanding of the targeted topic. Students represent their conceptual understanding in concept sketches which include key components of the processes. This exercise enables students to focus on the accurate use of scientific terminology and the understanding of the processes will facilitate their problem solving skills in novel contexts, a critical component for assessing higher-order thinking skills. This also serves as immediate feedback for the teachers, who can then address the misconceptions to benefit the entire class. Teachers' perspectives drawn from pre- and post-lesson focus group discussions, and from the results of written assessments, and students' feedback on classroom tasks and teachers' practice through surveys administered provide valuable input on the impact on students' learning and the challenges faced by teachers and students. Pedagogical implications and recommendations for the classroom integration of integrating visual, verbal and textual modes of communication to support content learning in Biology are discussed.

Introduction

Biology is a branch of science that is complex, abstract and yet content-driven, and hinges heavily on a mastery of biological concepts before the application of that knowledge to novel or different scenarios is possible. A-Level Biology students often have difficulty understanding the abstract concepts, some of which are hard to visualize as they take place at the cellular and molecular level. The vast amount of content that students have to grasp may also lead to confusion between concepts, an inability to master concepts in the limited time, which then results in students having an inadequate or incomplete understanding of these concepts. Our study attempted to address these issues in order to enhance the students' conceptual understanding of chemiosmosis, a process in cellular respiration and photosynthesis, a biological concept that students often have difficulty understanding. Beyond just conceptual understanding, we also hope to promote a classroom culture that encourages collaborative learning between students and interaction between students and teacher, as well as engenders independent learning and thinking in our students.

We hoped to achieve these objectives through two approaches – Teacher Talk Moves and Concept Sketch. These two approaches, when used in tandem, allow us to integrate visual, verbal and textual modes of communication in the teaching of the biological concept of chemiosmosis in cellular respiration. This will allow teachers to help students visualize key processes, establish links between concepts and clarify misconceptions or gaps in the students' understanding of the concepts.

Talk Moves

Teacher Talk Moves is a pedagogical tool that comprises strategic ways of asking questions and inviting participation in classroom conversations (Chapin, O'Connor & Anderson, 2013). The purpose of Talk Moves is to achieve student engagement in an intellectual discussion of the subject matter in the classroom (Chapin, O'Connor & Anderson, 2013). Teachers play the role of mediating the talk to open up the subject matter in a systematic way – from a highly scaffolded introduction to asking higher order thinking questions so as to develop a deeper analysis and evaluation. These questions, and their follow-up prompts (Table 1) also serve to clarify and sharpen students' understanding of concepts as they explain their ideas.

Table 1

Teacher Talk Moves categorised by five different focus areas, with frames for prompting and responding. (Adapted by ELIS from Michaels & O'Connor, 2012, and Zwiers & Crawford, 2011.)

Focus Area 1: Voicing and clarifying students' ideas		
Talk Move	**Frames for prompting**	**Frames for responding**
Seek Clarification	Can you elaborate on X? That's a complicated idea. Can you say it again loud and clear so that we all can understand?	What I mean is… In other words…
Re-voice for verification	So you're saying that… I wonder whether you mean…	Yes, that's right. No, what I really meant to say is…
Focus Area 2: Listening closely to other students		
Ask student to restate another students' contribution	What do you think X was saying? Can you put in your own words for us what X just told us?	I think what X was saying is… It sounds like X meant to say that…
Focus Area 3: Deepening individual students' reasoning		
Probe for reasoning or evidence	Why do you think that? What's your evidence for that?	The way I could tell was because… According to my calculation/measurement, …
Challenge students' statement or assumption	Does it always work that way? How does that link to what we said/found out earlier?	I guess another way to look at/explain it is… A possible connection is…

Focus Area 4: Engaging with each other's reasoning		
Elicit students' views on other students' ideas	Do you agree/disagree and can you explain why? Who has a similar/different idea about how this works?	I think X is right when he/she says…because… I have a similar/different view on this because I think…
Guide students to build on other students' contribution	Who can give further evidence to support X's view/claim? Can you apply this to any other situation/your everyday life?	I think I can expand on X's point that… I think another good example that supports X's point is…
Focus Area 5: Consolidating discussion points (in extended discussion)		
Get students to summarise/consolidate	What have we learned/discovered about X through our discussion? How can we bring all this together?	I think there are three things we have learned about X… Our discussion seems to suggest that…

Concept Sketch

In biology, the visual presentation of processes and concepts provides clear explanations and enables students to visualize and concretize relationships between concepts. Currently, teachers recognise the need to explicitly train students to interpret visual information in textbooks, slide presentations, websites, and classroom whiteboards, but for students to create these visual drawings is equally important for two reasons:

1. drawing is a powerful tool for thinking and communicating, regardless of the discipline (e.g., Roam, 2008).
2. drawing is a process skill that is integral to the practice of science, and used in the generation of hypotheses, the design of experiments, the visualization and interpretation of data, and the communication of results (e.g., Ainsworth, Prain, & Tytler, 2011; Schwarz et al., 2009;).

Many biology teachers draw models and visual diagrams in their classrooms and prompt students to do so as well, but teachers rarely recognise this strategy as a skill that can be taught to students (Quillin & Thomas, 2015).

Concept sketches have been known to help students articulate ideas, identify and arrange key concepts, and see how these ideas and concepts are connected. Research shows that they help students construct and organize knowledge and learn more than students who do not construct concept sketches (Esiobu & Soyibo, 1995; Novak & Wandersee, 1991). Sketching is a useful way to make thinking visible (Temple, 1994), because it is a visual organizer (flow charts, webs, mind maps, diagrams) that is fully annotated with concise labels that do the following:

- Identify the features of the concepts illustrated;
- Describe and explain the processes involved; and
- Explain the relationships between features and processes (Johnson & Reynolds, 2005), or illustrate hierarchies between related concepts (Novak, 1998).

Materials and Methods

Methodology

The study was carried out over a period of 10 months, spanning a total of four different school terms. It can be broken down into three phases; (1) Delivery of content through lectures, (2) Intervention and (3) Data collection, as shown in Figure 1.

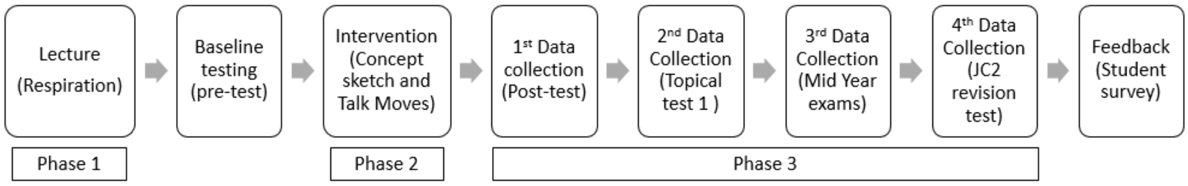

*Figure 1***.** Sequence of events in project.

Profile of Students and Teachers

The students who took part in the study were at the JC1 level and by the end of the study, had progressed to JC2. The subject, Biology, is offered at two different levels at the pre-university level, namely Higher One (H1) Biology and Higher Two (H2) Biology. H2 Biology has a slightly broader range of topics and a greater depth for certain topics. The study was conducted with 127 H2 Biology students from seven JC1 classes of mixed abilities. In total, there were three classes in the experimental group and four classes in the control group.

Three teachers who took part in the study executed the intervention and the administering of tests. The teachers who were teaching the cohort, Teachers A, B and C had five, three and half a year of teaching experience respectively. To reduce variation contributed by teachers, each teacher had one control and one intervention class.

Delivery of content

The main form of content delivery for both control and experimental groups was through lectures. For our study, we focused on the concept of chemiosmosis. Chemiosmosis was initially introduced in the topic, Cellular Respiration. The total duration allocated for the content delivery of Cellular Respiration was three lectures. The duration of each lecture was 50 minutes, resulting in an investment of 150 minutes of lecture time for content delivery. Of the 150 minutes, the amount of time allocated to the delivery of content pertaining specifically to chemiosmosis did not exceed 50 minutes. Prior to the lectures, students were supplied with the lecture notes for Cellular Respiration (34 pages, of which eight were linked directly to chemiosmosis). To ensure standardisation, students were not allowed to seek any consultation with their teachers regarding either topic before the administration of baseline testing.

Intervention

The intervention lesson was carried out with the experimental groups during a 50-minute tutorial lesson. Students were not instructed to read up on the topic prior to the intervention. Students were grouped four to five per table. Placed on each table was a voice recorder for collection of verbal responses. At the back of the classroom, a video camera was set up to record the entire activity. Each student was also given an activity sheet (Appendix III). The teacher then proceeded to facilitate the intervention lesson using 'Talk Moves' and 'Concept Sketch'. The lesson plan is attached as Appendix I. During the intervention, students were tasked to draw/write down their responses to questions raised by their teacher/classmates. The teacher walked around and, depending on the question asked, used samples of the students' work for the activity. A visualizer was used for this step. The questions that were asked during the intervention were in accordance with the different focus areas of 'Talk Moves'. Activity sheets were collected back from the students at the end of the intervention.

Classes in the control group had the usual lecture summary lesson in place of the intervention lesson. Classes in both the control and experimental groups were exposed to the topic and tutorial questions for the same amount of curriculum time.

The other three teachers involved in the study sat in the lessons for the experimental groups. A debrief was conducted after every lesson observed to refine the lesson plan in the areas of questioning and scaffolding (e.g. through writing down key points on the whiteboard to guide students through the lesson).

Testing

Baseline testing

The baseline testing (also known as the pre-test for the experimental group) was carried out at the end of the Cellular Respiration lecture series for the experimental group. Prior to the test, students were not told to revise nor were they informed that there would be a test. For baseline testing, a 15-minute quiz was administered. The quiz used for the baseline testing can be found in Appendix II.

First data collection

The first data collection was carried out after the intervention had been implemented on the experimental group. It was administered to both the control and experimental group (known as the post-test for the experimental group). For the first data collection, 15 minutes of tutorial time was used. The paper used was identical to that used in the baseline testing (Appendix II). The scores collected were compared against the baseline test scores.

Second data collection

The second data collection was carried out approximately one month after the intervention. It was administered to both the control and experimental groups. For the second data collection, 50 minutes of tutorial time was used for administering Topical Test 3, in which, Question Two (Parts a to c) tested the concept of chemiosmosis, with a total of seven marks. (Appendix IV)

Third data collection

The third data collection was carried out approximately two months after the intervention. It was administered to both the control and experimental groups. For the third data collection, a 150-minute exam paper was administered, in which, Question Three (Parts a and b) tested the concept of chemiosmosis, with a total of six marks. (Appendix V)

Fourth data collection

The fourth data collection was carried out approximately six months after the intervention. It was administered to both the control and experimental groups. For the fourth data collection, 50 minutes of tutorial time was used for administering the revision test, in which, Question One (parts a to e) tested the concept of chemiosmosis, with a total of nine marks. (Appendix VI)

Student feedback

At the end of all data collection, the students of the experimental group were given a survey. The survey was aimed at finding out from the perception of the students, how useful the intervention was, the areas which they valued and the areas which could be improved. The survey also aimed at seeing the degree to which the students could recall the intervention activity. (Appendix VII)

Teacher feedback

Qualitative feedback was collected from the four teachers through post-lesson reflection (by the teacher who conducted the lesson) and team discussions, to determine the effectiveness of the intervention lesson and to raise any challenges a teacher may have had in the planning and implementation of the lesson package. Overall feedback for the ELIS project was also collected through discussions as a project team during one of the Professional Learning team meetings (Appendix VIII).

Analysis of results

The data analysis was carried out using the one-tailed *t*-test and paired sample *t*-test in Microsoft Excel.

Materials

All materials used for testing and the intervention are attached in the Appendices.

Results

Student worksheet and extracts from transcripts of the intervention lesson

Figure 2 below shows an example of a student's worksheet after the intervention lesson. Talk Moves that involved carefully crafted scaffolding questions facilitated the lesson which was aimed at clarifying and sharpening the students' understanding of the "chemiosmosis" concept.

The final picture was fully annotated with clear labelling of the organelle, the unique features of the concept of "chemiosmosis" (e.g. the stalked particle drawn in the correct orientation, concentration of H^+ ions in various compartments, etc.) and a concise paragraph to describe and explain the process. Thus, the worksheet serves as a visual organizer that makes the student's thinking visible to us and themselves.

To clearly illustrate the interplay of classroom talk (Talk Moves) with the visual (Concept Sketch) and textual (written answers), Figure 2 was annotated with extracts from the transcripts of the intervention lesson.

Effectiveness of Intervention Lesson

In order to evaluate the extent of the effectiveness of the intervention lesson, the pre- and post-test scores of the experimental classes were analysed (Table 2). The difference between the pre-test and post-test scores of the experimental group was statistically significant ($t(52) = -4.83$, $p < 0.01$). The students gained a higher mean post-test score ($M = 10.09$) than their mean pre-test score ($M = 8.15$) (Table 2). Students in the experimental group improved by 1.94 marks overall. This improvement can be seen in both Teacher A and Teacher C's classes. However, this improvement cannot be seen in Teacher B's classes as the students obtained the same high score for both tests. As the initial mean score was already high, the 'ceiling effect' was probably a factor here as it is unlikely for any group to have a mean equal to the total available once we add in other factors such as lapses in concentration that lead to student error.

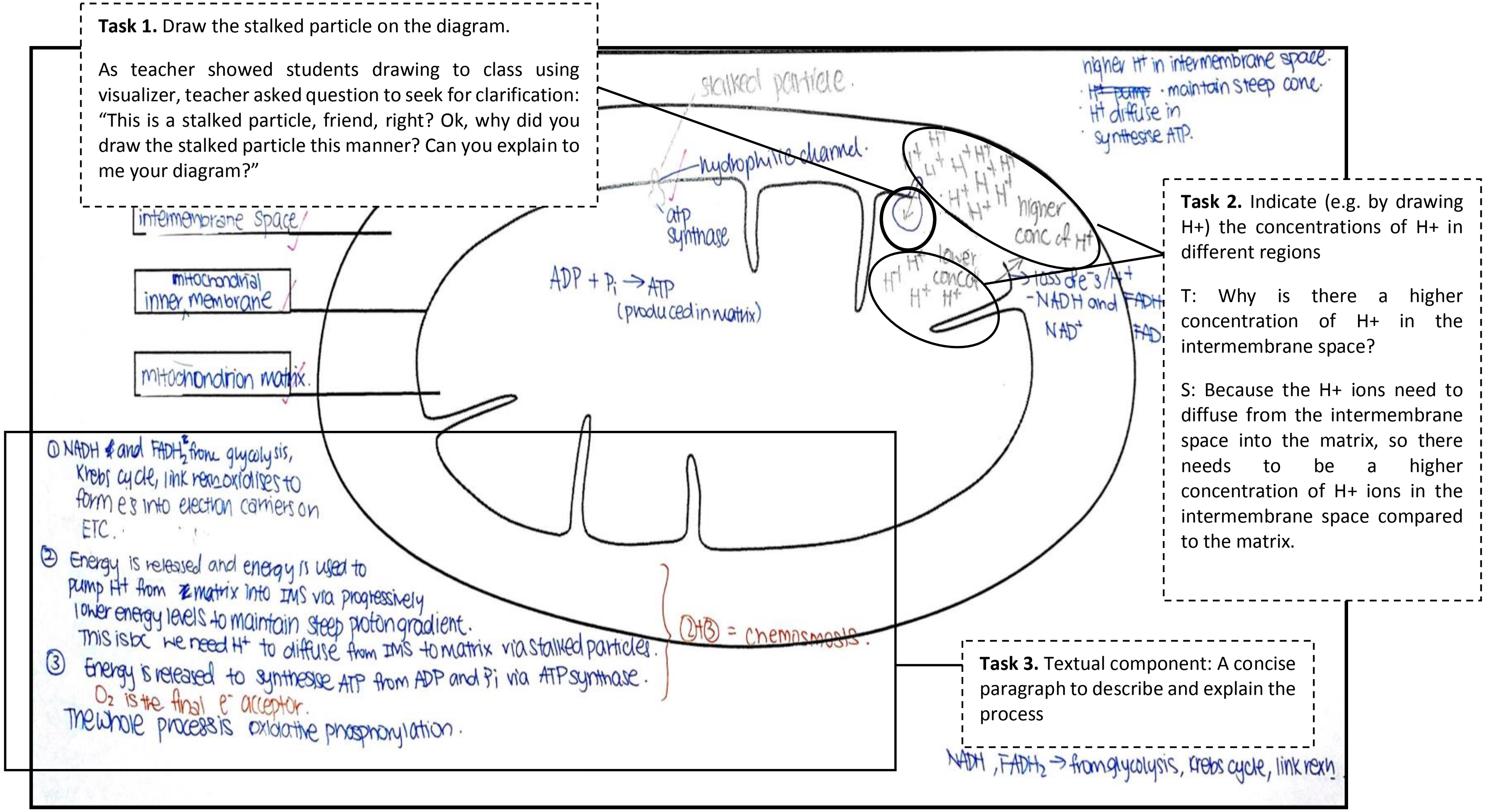

Figure 2. Student's worksheet with clear labelling and annotations to describe and explain the concept of chemiosmosis after the intervention lesson. Teacher; S: Student

Table 2

Improvement score for the Post-test for students in the experimental group

Improvement Score	**All H2**		**Teacher A**		**Teacher B**		**Teacher C**	
t-Test: Paired Two Samples For Mean	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Mean	8.15	10.09	7.33	9.97	12.50	12.50	4.41	7.68
Variance	18.28	14.66	10.53	10.04	3.65	7.47	7.48	16.31
Observations	53	53	18	18	18	18	17	17
Pearson Correlation	0.74		0.74		0.30		0.75	
df	52		17		17		16	
t Stat	-4.83		-4.84		0.00		-5.04	
P(T<=*t*) one-tail	0.00		0.00		0.50		0.00	
t Critical one-tail	1.67		1.74		1.74		1.75	
Effect Size (Cohen's *d*)	2.25		3.07		0.00		3.76	

In order to evaluate the effectiveness of the intervention lesson (Talk Moves and Concept Sketch), the same test (without explaining nor revealing the answers) was administered as the post-test after the lesson was conducted. A *t*-test was used to check the difference in the mean scores between the post-test of the experimental group and control group and it is statistically significant ($t(125) = -2.05$, $p = 0.02 < 0.05$). The experimental group has a higher mean post-test score ($M = 10.09$) than the control group ($M = 8.55$), with a small effect size, Cohen's $d = 0.37$ (using pooled *SD*) (Table 3). However, this was contributed mainly by Teacher A's classes.

Table 3

Effectiveness of intervention lesson (First data collection)

Effectiveness of intervention lesson	**All H2**		**Teacher A**		**Teacher B**		**Teacher C**	
t-Test: Two-Sample Assuming Equal Variances	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*
Mean	8.55	10.09	5.55	9.97	12.26	12.50	7.87	7.68
Variance	19.76	14.66	13.87	10.04	15.12	7.47	15.02	16.31
Observations	74	53	21	18	19	18	15	17
Pooled Variance	17.64		12.11		11.41		15.71	
df	125		37		35		30	
t Stat	-2.05		-3.96		-0.21		0.14	
P(T<=*t*) one-tail	0.02		0.00		0.42		0.45	
t Critical one-tail	1.66		1.69		1.69		1.70	
Effect Size (Cohen's d*)*	0.37		1.27		0.07		-0.05	

Short-Term and Long-Term Retention Rate

In order to evaluate the short-term and long-term effectiveness of the intervention lesson, the test and examination scores were tracked and analysed (Tables 4, 5, and 6). The conceptual understanding was assessed through various assessments administered one month (test), two months (examination) and six months (test) after the experimental lesson. The total marks allocated for this concept in the various tests were between six and nine. The results suggested that students were unable to retain the concept within the first month and second months (Tables 4 and 5).

Table 4

Retention rate after one month based on test result (Second data collection)

Average of 2016 Test 3 Q2 (7 marks)	All H2		Teacher A		Teacher B		Teacher C	
t-Test: Two-Sample Assuming Equal Variances	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*
Mean	2.03	2.48	1.98	2.83	2.29	2.53	2.50	2.06
Variance	1.90	1.44	1.81	1.24	2.29	1.57	1.96	1.37
Observations	74.00	53.00	21.00	18.00	19.00	18.00	15.00	17.00
Pooled Variance	1.71		1.55		1.94		1.65	
df	125		37		35		30	
t Stat	-1.90		-2.15		-0.52		0.97	
P(T<=t) one-tail	0.03		0.02		0.30		0.17	
t Critical one-tail	1.66		1.69		1.69		1.70	

Table 5

Retention rate after two months based on examination result (Third data collection)

Average of 2016 MYA Q3 (6 marks)	All H2		Teacher A		Teacher B		Teacher C	
t-Test: Two-Sample Assuming Equal Variances	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*
Mean	3.52	3.50	3.67	3.75	3.71	3.44	3.53	3.29
Variance	0.93	0.87	1.06	0.65	0.76	1.06	0.87	0.88
Observations	74.00	53.00	21.00	18.00	19.00	18.00	15.00	17.00
Pooled Variance	0.90		0.87		0.90		0.88	
df	125		37		35		30	
t Stat	0.12		-0.28		0.85		0.72	
P(T<=t) one-tail	0.45		0.39		0.20		0.24	
t Critical one-tail	1.66		1.69		1.69		1.70	

The difference in the test scores six months after the lesson between the experimental group and control group seemed to be statistically significant ($t(125) = -2.63$, $p = 0.00 < 0.05$). The experimental group had a higher mean post-test score ($M = 1.61$) than the control group ($M = 1.11$) (Table 6).

Table 6

Retention rate after six months based on test result (Fourth data collection)

Average of 2017 JC2 Revision Test Q1 (9 marks)	All H2		Teacher A		Teacher B		Teacher C	
t-Test: Two-Sample Assuming Equal Variances	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*	*Ctrl*	*Expt*
Mean	1.11	1.61	1.19	1.86	0.89	1.56	1.33	1.41
Variance	1.00	1.34	1.26	1.91	0.38	0.70	1.67	1.48
Observations	74.00	53.00	21.00	18.00	19.00	18.00	15.00	17.00
Pooled Variance	1.14		1.56		0.54		1.57	
df	125.0		37.00		35.00		30.00	
t Stat	-2.63		-1.67		-2.75		-0.18	
P(T<=*t*) one-tail	0.00		0.05		0.00		0.43	
t Critical one-tail	1.66		1.69		1.69		1.70	

However, the difference seemed to be contributed solely by Teacher B's classes. The great variation observed between the experimental and control classes for each teacher could be due to the low discriminatory power of the scores, which were out of only a total of nine marks for the testing of the concept of chemiosmosis.

Discussion

The comparison between the pre- and post-test scores of the students (Table 2) provided evidence that the intervention lesson had been effective. On average, there was an improvement of 1.94 marks in the post-test scores. However, a closer analysis of the data suggested that the trend was not observed for all the students in the experimental group. The mean post-test scores were higher than the mean pre-test scores for students in Teacher A and Teacher C classes, with mean improvements of 2.64 and 3.27 marks respectively, but there was no observed improvement in the post-test scores for students in Teacher B's class.

The improvement in the mean post-test score was most evident in Teacher A's class. It could be due to the type of Talk Moves conducted during the intervention lesson. It was observed that Teacher A used 'Consolidating discussion point' more extensively compared to Teachers B and C (Table 7). It was also noted that Teacher A, who had more experience, had the highest frequency of 'Deepening individual students' reasoning' while Teacher C with the least experience had the highest occurrence of 'Voicing and clarifying students' ideas' (Table 7). It was possible that students required more frequent consolidation of ideas during the lesson to build up their understanding of the concept.

To evaluate the effectiveness of the lesson on a long term basis, the students were tested on the same concept at three other time points (Figure 1). However, a positive effect from the lesson was not observed consistently across the experimental groups at the different data collection points. The time lapse between the lesson and the final assessment point was six months, thus other factors such as the students' academic ability, level of motivation and their preparedness for the test could have contributed to the results. Another factor that could have resulted in the great variation in the results obtained was the low discriminatory power of the test scores which were between six and nine marks. However, due to the constraints of the assessment topics and test rigour, it was not possible to administer a test that was solely on one topic or to allocate more marks for the concept taught in the intervention lesson.

Table 7

Frequency of Talk Move focus areas used during the intervention lesson by different teachers

Focus area	**Frequency (%)**		
	Teacher A	**Teacher B**	**Teacher C**
1. Voicing and clarifying students' ideas	33	57	48
2. Listening closely to other students	3	5	2
3. Deepening individual students' reasoning	22	16	14
4. Engaging with each other's reasoning	8	18	34
5. Consolidating discussion points	33	3	2

Students' feedback

The feedback from students from the experimental group was gathered using Google forms. The quantitative results showed that the intervention was effective. The student survey findings showed that 87% of the respondents indicated that the lesson was effective in helping them understand the concept of chemiosmosis. Out of 44 responses, 84% of the respondents indicated that the concept sketching helped in their recall of the concept; 65% found that ‘teacher questioning’ (Talk Moves) helped in their recall of the concept. Only 11.3 % (five students) preferred learning through reading their notes and only 4.5% (two students) could not follow the lesson – possibly due to the different learning style of the students (e.g. reading, kinaesthetic).

Interestingly, 50% of the respondents indicated that they had attempted to draw their own diagrams of the mitochondria to help them remember the concept of chemiosmosis during revision. While this is not a large number, the teachers were encouraged by this response from the students as it indicated that students found the method (Concept Sketch) useful and were willing to adopt the method during their revision. The teachers hoped that students would be able to apply Concept Sketch to learning other concepts to help them visualize and concretize relationships between various Biology concepts.

Teachers’ feedback

The teachers who took part in this study thought that the use of Talk Moves allowed students to actively participate in productive classroom conversation and was a deliberate attempt to make students’ thinking visible. The use of the Concept Sketch provided a platform to start the classroom talk and a tool for students who were visual learners to articulate ideas, identify and arrange key concepts, and see how these ideas and concepts were connected. An example of a student’s worksheet after the intervention is shown in Figure 2. Teachers were encouraged to hear that 50% of the students from the experimental groups adopted the Concept Sketch during their revision.

The teachers worked as a team to develop the lesson plan and the lesson materials. A large proportion of the time was spent on crafting the questions to ensure the questions asked would lead students to the correct conceptual understanding via the visual-verbal-textual links.

However, during the planning stage, teachers noted that it was very hard to pre-empt students’ answers, which might affect how teachers could respond meaningfully to students’ answers. Given a similar set of questions in the lesson plan, all teachers knew the objectives of each question and the main aim of the lesson. However, in actual practice, students’ responses varied widely and teachers needed to react on the spot to bring students back to the planned learning outcomes. Thus, the intervention lesson hinged largely on teachers’ facilitation skills, content mastery and questioning skills.

A potential solution to narrow the scope of students’ responses and to increase the effectiveness of the intervention lesson was to ensure students revised the contents before the lesson. With prior revision, students would have been more familiar with the biological terms used during the classroom talks, and would have been able to respond more appropriately to the scaffolding questions.

Another valuable take-away from this study was that the pedagogical tools used provided a platform to surface misconceptions in students’ initial understandings of the concepts, thus allowing teachers to address these misconceptions early. An example of how a misconception was picked up and addressed during Teacher C’s lesson is shown in Figure 3. Using the visualizer, Teacher C presented a piece of student work, in which, the stalked particle was drawn incorrectly. Teacher C facilitated a four-minute classroom discussion using various prompts such as ‘Engaging with each other’s’ reasoning’, ‘Voicing and clarifying students’ ideas’ and ‘Deepening individual students’ reasoning’ to clear up the misconception.

Speaker	Script	Comment
Teacher	Ok… Everyone, have you drawn. Attempted the question? Let’s look at your friends’ answers. First thing first. Now. How should a stalked particle look like, class? Do you remember your lecture, how does it look like? How many components of a stalked particle do you think there are?	

Speaker	Script	Comment
Student 1	There are two	
Student 2	There is protein and ATP synthase	
Teacher	There is protein and ATP synthase. Let's look at Student 4's answer [Teacher took Student 4's drawing and flashed it on screen]. Ok, over here. Do you think this is... what do you think of her answer? What do you think of her drawing? What is lacking, Student 2?	Engaging with each other's reasoning
Student 2	protein channel, hydrophilic channel	
Teacher	Lacking the protein channel, hydrophobic channel.	
Student 1	Isn't there supposed to be a tip to the stalked particle where it contains ATP synthase?	
Teacher	So what I hear from you, Student 1, there should be a tip.	
Student 1	Ya… there should be	
Teacher	Student 3, what do you think about the answer? If there is a tip of ATP synthase, where do you think this should be? Student 1, can you answer? Where do you think is this tip that she is talking about, Student 3?	Listening closely to other students
Student 3	In the inter membrane space	
Teacher	In the intermembrane space. K. so now thank you Student 4. Let's look at Student 5's answer. What do you all think about her drawing now? Student 5, can you explain to us what is the difference between your answer and Student 4's answer?	Deepening individual students' reasoning Students were uncertain how to draw the stalked particle.
Student 5	Got the...ya...embedded to inter membrane... inter membrane	
Teacher	Embedded to inter membrane. Student 6, what can you tell me about her structure as compared to Student 4's? What is the biggest difference?	Engaging with each other's reasoning
Student 6	Yes. There is protruding thing	Students seemed to have misconception about which part is the stalked particle.
Teacher	Yes. There is protruding thing. And protruding thing. Student 7, what do you think that protruding thing is? What is the function of protruding thing?	Deepening individual students' reasoning
Student 7	As a stalked particle	
Teacher	As a stalked particle… k… so you are telling me that only that protruding part...K...can I check which is the protruding part you are talking about? Is it this or this? Ok… sorry… one or two?	Deepening individual students' reasoning
Student 7	This one	
Teacher	One? This is the one here, smaller one, two is the bigger one.	Deepening individual students' reasoning
Class	One! One! One! One! One! One!	

Speaker	Script	Comment
Teacher	One. So what I hear right is, you are saying is that only that part is called the stalked particle.	Voicing and clarifying students' ideas
Student 1	No. the whole thing is called stalked particle but one contains ATP synthase.	
Teacher	One contains ATP synthase. Student 8, do you agree with what Student 1 said? There is narrow portion, this portion here contains the ATP synthase.	Engaging with each other's reasoning
Teacher	Let's take a step back, class? K…just now you guys mention that ATP synthase consists of two proteins each side (??), correct? ... maybe now you start thinking, you know one portion consists of which enzyme?	Voicing and clarifying students' ideas
Class	ATP synthase	
Teacher	What do you think the other portion of the protein?	Voicing and clarifying students' ideas
Class	Channel protein allows the H+ ions diffuse	

Figure 3. Use of Talk Moves to clarify a misconception that surfaced during the intervention lesson.

Conclusion

In conclusion, the results of this study showed that Concept Sketch and Talk Moves are two effective tools that, when used concurrently, are beneficial in helping A-Level students deepen their conceptual understanding in Biology. However, the effectiveness of these tools might be dependent on the teachers' adaptive capacity during the lesson and the students' preparedness. Future studies can focus on expanding the application of both tools to other abstract concepts and encourage more students to pick up the skill of Concept Sketch to help them prepare summary notes during revision and link up concepts between different topics. However, as a large amount of classroom time needs to be invested in conducting the intervention, teachers also need to consider if lessons of this nature are sustainable throughout the A-Level Biology course, which is a complex, abstract and, yet, content-driven subject.

Acknowledgement

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Appendix I: Lesson plan for the intervention lesson

Lesson plan

Level: JC1 students (CG 19, 20, 23/16, H1)

Subject: H2/H1 Biology

Duration of lesson: 40 minutes

Lesson objectives:

1. To review concepts under chemiosmosis
2. To provide scaffolding through the use of Talk Moves

Lesson prerequisite:

1. Attended lecture on Respiration
2. Already completed Pre-test

Duration /min	**Objective**	**Activity**
10		1. Distribute worksheet 1 to students
10	Start questioning about stalked particle because this is the most prominent feature of the mitochondria and it allows teachers to ask Why questions (eg. Focus Area (FA) 3 - Probe for reasoning/	**Questions** 1. Label the different regions of the mitochondria: a. Outer membrane b. Inner membrane

10	evidence; Challenge students' statement/ assumption). This helps to scaffold students' understanding of why things work in a certain way. Scaffold questions step-by-step.	c. Matrix d. Intermembrane space [Teacher quickly scans through students' worksheet, checks that all answers are correct. Teacher to reveal answers.] 2. Draw the stalked particle on the diagram. [Teacher to walk around and identify a student who drew correctly and a student who drew wrongly. Teacher to invite both students to draw on write-board / show live scripts. Teacher to ask students to explain the orientation of stalked particles] **[FA1, Talk move: Seek Clarification – e.g. Why is the stalked particle drawn this way?]** **[FA1, Talk move: Revoice for verification –** *So you're saying that…/I wonder whether you mean]* Answers obtained from students need to include: i. Hydrophilic channel protein, flow of H+ ii. ATP synthase iii. ADP + Pi in matrix 3. Indicate (e.g. by drawing H+) the concentrations of H+ in different regions i. Ans: More H+ in the intermembrane space ii. Use visualizer with live script to project the wrong answer and ask another student with the correct answer **[FA4, Talk move: Elicit students' views on other students' idea - Why do you think your classmates have drawn it this way?] Would you also draw it in this way?** **Challenging student's contribution: Is that the only way to represent it? / Did anyone use a different**

10		**approach?** **[FA3, Talk move: Challenging assumption - What makes you say so?]** 4. Draw arrows to indicate directions of flow of H+ i. Ans: 1. Arrows from intermembrane space to matrix through stalked particles. 2. Arrows from matrix to intermembrane space. **[FA1, Talk move: Seek clarification – e.g. why is the flow in this direction?]** **[FA3, Talk move: Probe for reasoning – Why does H+ need to accumulate in the intermembrane space.]** Ans: There is higher H+ conc in the intermembrane space, thus H+ will flow into the matrix thru the stalked particle. **[FA4, Talk move: Seek clarification – e.g. How is the higher H+ concentration in the intermembrane space achieved?]** Ans: Proton pump in inner membrane to pump H+/ actively transport from matrix to intermembrane space, using energy from electron transfer in ETC. **[FA 4, Talk move: Build on others' contribution]: Where did the electron come from?** Ans: NADH, $FADH_2$ **[FA3, Talk move: Probe for reasoning] Where did the NADH and $FADH_2$ come from?** Ans: Glycolysis, Krebs cycle, Link Rxn **[FA4, Talk move: Elicit students' view on other students' ideas - using the explanation provided, is the drawing complete?]**

		Ans: No, need to draw 1 more arrow (arrow 2) **[FA 4, Talk move: Build on others' contribution - Guide student to build on the diagram. E.g. Are there supposed to be more arrows? What is the direction of the arrow?]**
10	**Conclusion**	**[FA5, Talk move: Get students to consolidate and summarise – e.g. How can we bring all these together? Which step should we start with to describe the process of chemiosmosis?]** Guide students to describe chemiosmosis in the following sequence: 1. The energy released from electron transport is used to actively transport protons (H^+) from the mitochondrial matrix, through the inner mitochondrial membrane, into the intermembrane space. 2. This creates a proton gradient across the inner mitochondrial membrane (High H^+ concentration in intermembrane space, low H^+ concentration in the matrix). The proton gradient is a source of potential energy for the synthesis of ATP. 3. The stalked particles on the inner mitochondrial membrane project into the matrix of the mitochondrion. Each stalked particle is a protein complex which consists of a hydrophilic protein channel, and an enzyme component, ATP synthase. 4. As hydrogen ions diffuse down its concentration gradient from the intermembrane space to the matrix of the mitochondrion through the protein channel of the stalked particle, the energy released is coupled to ATP synthesis, a process catalysed by ATP synthase. This is known as chemiosmosis.

Appendix II: Pre- and Post-test paper

Temasek Junior College
H2/ H1 Biology
JC 1/ IP Year 5 2016

RESPIRATION POP QUIZ

(Duration: 15 mins)

Name: ____ **CG: __________/16**

Date: ______________________ **Score: ____/15.5**

The following statements describe the process of oxidative phosphorylation. However, the statements are not arranged in the correct sequence.

Task A: Fill in the blanks to complete the statements below. (Note: the underlined words are the answers)

1. are passed along a series of electron carriers of decreasing energy levels found in the inner mitochondrial membrane
2. as H^+ diffuse down the concentration gradient from the intermembrane space into the matrix of the mitochondrion
3. electrons from NADH and $FADH_2$ generated from glycolysis, link reaction and Krebs Cycle
4. oxidation of 1 molecule of NADH yields 3 ATP and 1 molecule of $FADH_2$ yields 2 ATP.
5. oxygen is the final electron acceptor.
6. the energy released from the flow of electrons down the electron transport chain by a series of redox reactions is used to actively transport protons (H^+) from the mitochondrial matrix, through the inner mitochondrial membrane into the intermembrane space.
7. the energy released is coupled to ATP synthesis catalyzed by ATP synthase.
8. this creates a steep proton gradient across the inner mitochondrial membrane.
9. this process is known as chemiosmosis.
10. through the protein channel of the stalked particle.

Task B: Rearrange the statements in the correct order.

Correct order of statements: ____

ANS: 3, 1, 5, 6, 8, 2, 10, 7, 9, 4 OR 3, 1, 5, 6, 8, 2, 10, 7, 4, 9

Appendix III: Worksheet used in conducting the intervention lesson

Temasek Junior College

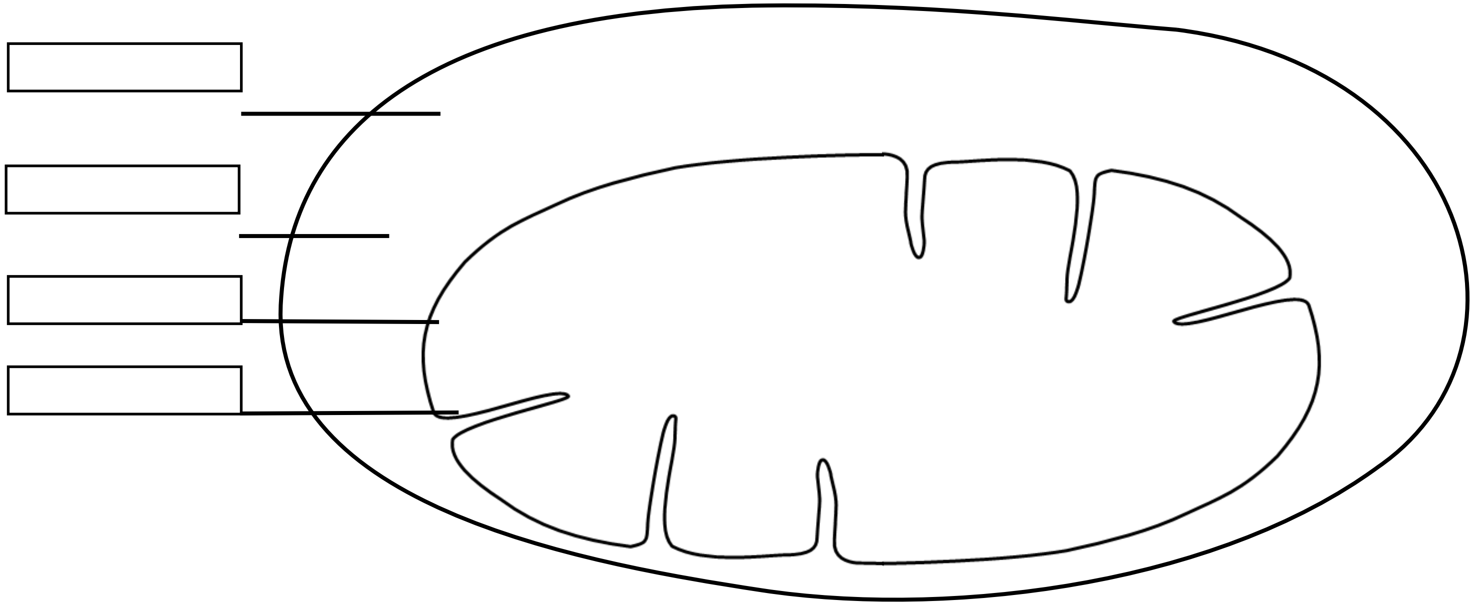
H2/ H1 Biology

JC 1/ IP Year 5 2016

RESPIRATION LESSON ACTIVITY

Name: ____________________________________ **CG:** __________/16

Date: ____________________



Appendix IV: Test Question and Answers for data collection

Temasek Junior College
H2/ H1 Biology
JC 1/ IP Year 5 2016

TOPICAL TEST 3: PHOTOSYNTHESIS, RESPIRATION, CELL CYCLE
(Duration: 45 mins)

Name: ______________________________ **CG:** ________/16

Date: ____________________ **Score:** ______/30

2. A student mixed up solutions containing membranous vesicles derived from a thylakoid and mitochondrial membrane. In these vesicles, the orientation of the ATP synthase enzymes is preserved as they were found in the cell. Fig. 2.1 below shows the various experimental systems that were prepared in order to identify them.

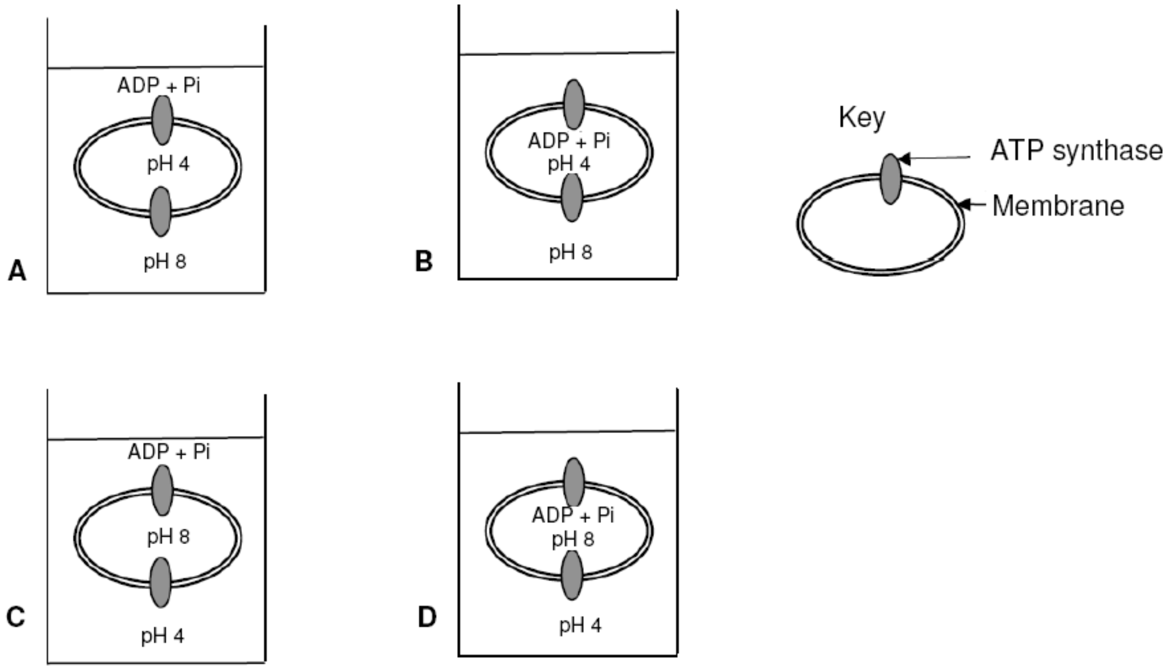


Fig. 2.1

(a) With reference to Fig. 2.1,
explain why the stalked particle is required for the transport of H^+ across membrane; [2]

Answer:

1. The charged H^+
2. is unable to cross the hydrophobic core of the phospholipid bilayer/ The membrane is impermeable to H^+.
3. Therefore, ATPase/ stalked particle/ ATP synthase is a channel protein/ acts as an H^+ ion channel

4. to allow H^+ to diffuse down the electrochemical/ concentration gradient.

(b) state which experimental system contained vesicles derived from a thylakoid membrane and explain how you arrived at this conclusion; [3]

Answer:

1. **Experimental system A.**
2. **The pH inside the lumen of the thylakoid/ thylakoid space is lower (pH 4) than its surrounding (pH 8) due to a higher concentration of H^+ than in the stroma**
3. **This is because the flow of electrons down the electron transport chain of PS II and PS I provides the energy to pump H^+ from the stroma, across the thylakoid membrane, into the thylakoid space.**
4. **In addition, photolysis of water also results in the accumulation of H^+ in the thylakoid space.**
5. **The thylakoid membrane is impermeable to H^+, as a result H^+ accumulate in the thylakoid space.**
6. **H^+ will diffuse through the stalked particles and ATP will be synthesized using the ADP and P_i found outside/ in the stroma.**

Molecule **P** forms a pore in the phospholipid bilayer of mitochondria as shown in the Fig. 2.2.

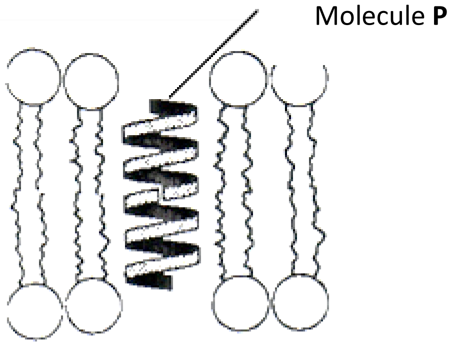


Fig. 2.2

(c) Explain how the presence of molecule P might affect the synthesis of ATP in isolated mitochondria. [2]

Answer:

1. **The pore may allow H^+ to diffuse through down a concentration gradient,**
2. **thus preventing the generation of a steep proton gradient.**
3. **Therefore, NO/ less energy is provided for chemiosmosis.**
4. **Hence, ATP synthesis CANNOT occur/ the rate of ATP synthesis drops.**

Appendix V: Test Question and Answer for the third data collection

TEMASEK JUNIOR COLLEGE
MID YEAR ASSESSMENT
JC 1/ IP YEAR 5 2016

H1 & H2 BIOLOGY | **8875 & 9744**

Answer Scheme

3 Fig. 3.1 shows an electron micrograph of a mitochondrion.

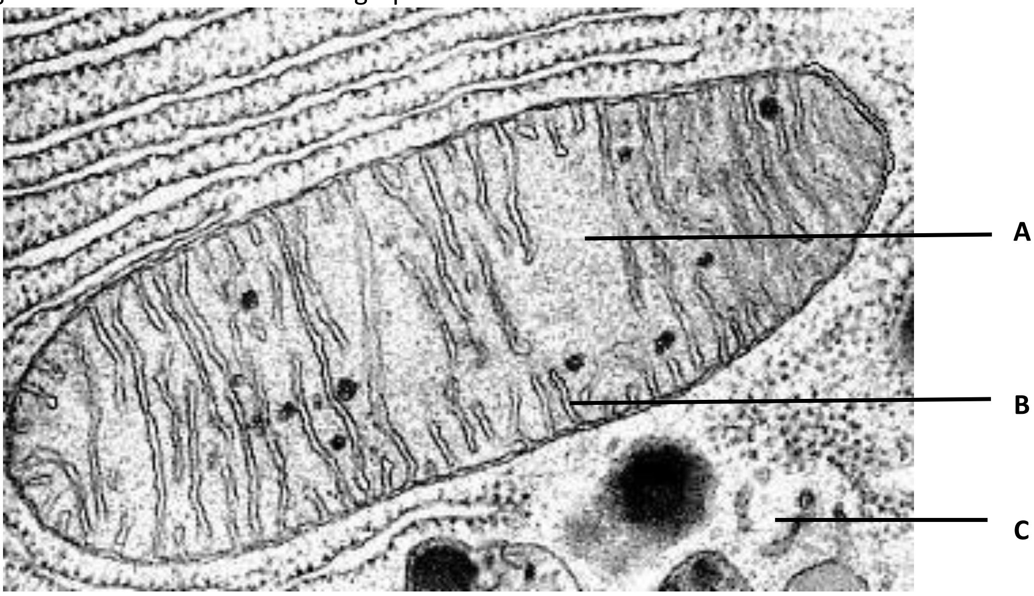


Fig. 3.1

(a) Complete the following table. [3]

Answer:

Label	Structure	Main function in respiration
A	Matrix	site of Krebs cycle
B	Crista	increase surface area for oxidative phosphorylation
C	Cytosol/ cytoplasm	site of glycolysis

(b) Explain the role of oxygen in aerobic respiration. [3]

Answer:

1) Oxygen is the final electron acceptor
2) in the electron transport chain
3) at the inner mitochondrial membrane;
4) reduced/ combine with hydrogen ions/ hydrogen/ protons/ H^+ to form water

5) **during oxidative phosphorylation**
6) **allows link reaction, Krebs cycle and oxidative phosphorylation to continue working in aerobic respiration.**

Appendix VI: Test Question and answer for the fourth data collection

Temasek Junior College
H2/ H1 Biology
JC 2/ IP Year 6 2017

REVISION TEST
(Duration: 45 mins)

Name: ______________________________ **CG:** ________/16

Date: ____________________

Score: ______/ 37 (H1); 43 (H2)

Question 1 **[9 marks] (Photosynthesis & Respiration)**

(Modified 2016 NJC H1 Paper 2)

Fig. 1.1 shows the schematic representation of a series of protein complexes found on the inner membrane of a mitochondrion in a brown adipocyte. Brown adipocytes are a type of fat cells in mammals.

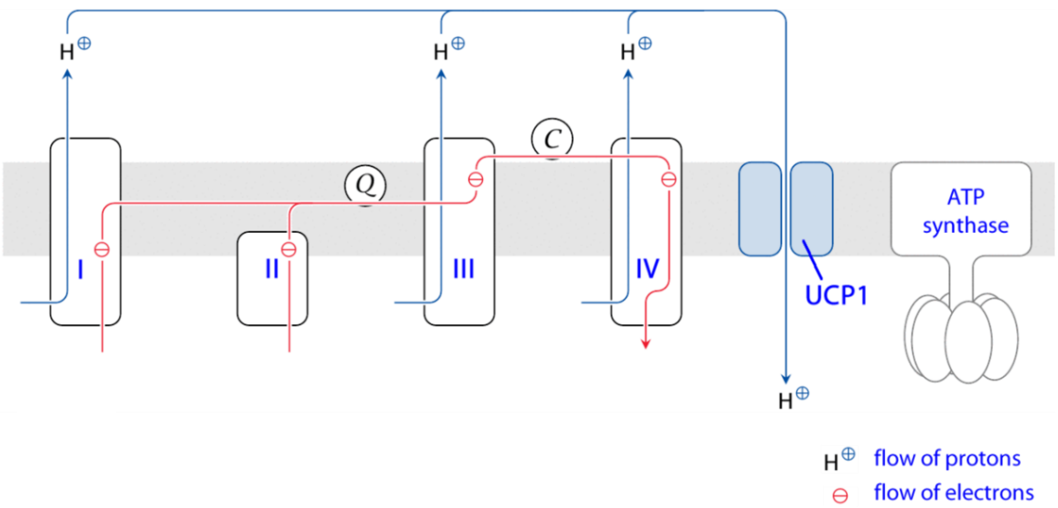


Fig. 1.1

(a) Describe the function of the inner membrane for the process shown. [2]

Answer:

1. **It acts as a boundary for the generation of the proton gradient/ H^+ ion build-up, in the inter-membrane space for chemiosmosis/ synthesis of ATP.**
2. **Allows for electron carriers and ATP synthase to be embedded for the reduction-oxidation reactions/electron transfer/electron transport/oxidative phosphorylation to take place.**

(b) Oxygen is required to sustain the process illustrated in Fig. 1.1.
With reference to the Fig. 1.1, describe the role played by oxygen. [1]

Answer:

- **Oxygen serves as the final electron acceptor, receiving electrons from complex IV to form water.**

(c) Describe **two** similarities in the production of ATP in the organelle shown and in chloroplasts. [2]

Answer:

1. **Involves flow of electron down the electron transport chain via electron carriers of progressively lower energy levels.**
2. **Requires generation of proton motive force / electrochemical / H^+ gradient across the inner membrane.**
3. **Diffusion of H^+ through ATP synthase, energy released is used for the synthesis of ATP (ref to chemiosmosis, but Reject: just chemiosmosis without description)**

(d) NADH and $FADH_2$ are used to drive ATP synthesis by ATP synthase.
Using relevant information from Fig. 1.1, suggest and explain why more ATP is produced from NADH. [2]

Answer:

1. **NADH and $FADH_2$ donates electrons to Complex I and II respectively, the energy released from transfer of electrons through the complexes**
2. **is used to pump protons across the inner membrane from the matrix to the inter-membrane space.**
3. **Since Complex I is located before Complex II, electrons from NADH will lead to more chances to pump more protons across the gradient, which powers the ATP synthase (OWTTE)**
4. **to give 3 ATP per molecule of NADH, while one molecule of $FADH_2$ produces only 2 ATP through the electron transport chain**

(e) Brown adipocytes contain a unique protein, UCP1, which is not found in mitochondria in any other cell type.
Evaluate the impact of UCP1 on the normal functioning of the process illustrated in Fig. 1.1 and suggest the physiological significance of brown adipose tissue. [2]

Answer:

1. **As UCP1 allows protons to move back into the matrix without passing through the ATP synthase, [1/2]**
2. **ATP synthesis will be reduced from NADH and $FADH_2$ /during oxidative phosphorylation [1/2]**
3. **The energy released from the spontaneous flow of protons through UCP1 is lost as heat, which helps to keep the organisms warm.**

Appendix VII: Student feedback form

[updated] Student Feedback on Review Lesson for Respiration

Please complete this form by 11th April 2017

* Required

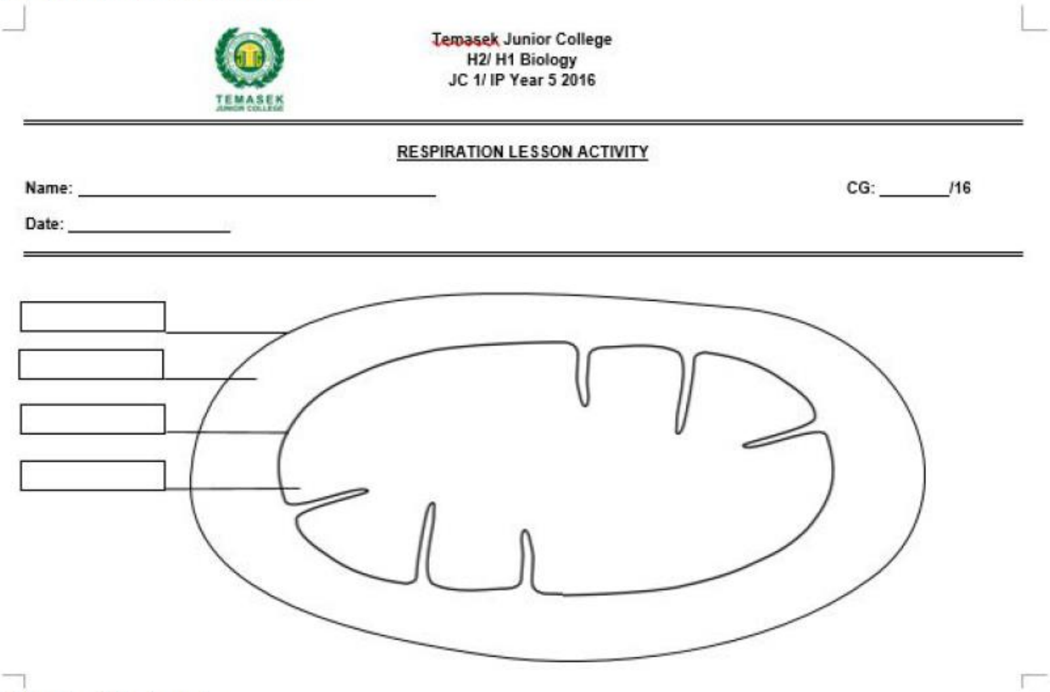
1. **Class:** *

___

2. **Name (optional):**

___

3. **Do you recall this lesson:** *



Check all that apply.

- [ ] Yes
- [ ] No

4. **1. Was this lesson activity effective in helping you learn the concept of chemiosmosis?** *

Check all that apply.

- [ ] Yes, please answer Question a.
- [ ] No, please answer Question b.

5. **a) Which part of the lesson was useful? [can choose more than 1]**
Check all that apply.

- [ ] Drawing and annotations on the diagram
- [ ] Tutor questioning [e.g. orientation of ATPase on the membrane, how did H+ accumulate in the inner membrane space etc]
- [ ] Tutor showing classmates scripts on the projector
- [ ] Other reasons that this was an effective lesson:
- [ ] Other: ______________________

6. **b) If this lesson activity was not useful in helping you learn the concept, what is the reason? Please tick in the boxes if the statement applies to you [can choose more than one]:**
Check all that apply.

- [ ] I have no idea what the tutor was talking about during the lesson.
- [ ] I learnt the concept of chemiosmosis by reading the lecture notes many times.
- [ ] I learnt the concept only after tutor repeated it few times in class (during tutorial, review of tests).
- [ ] Other reasons that this lesson was not effective:
- [ ] Other: ______________________

7. **2. When you were studying for Topical test 3, Promos and/or revision test (JC2), did you recall any of the following to help you remember the concept of chemiosmosis? [can choose more than 1]** *
Check all that apply.

- [ ] Drawing and annotations on the diagram
- [ ] Tutor questioning [e.g. orientation of ATPase on the membrane, how did H+ accumulate in the inner membrane space etc]
- [ ] Tutor showing classmates scripts on the projector

8. **3. Did you attempt to draw your own diagram of the mitochondria to help you remember the concept of chemiosmosis during revision?** *
Check all that apply.

- [ ] Yes
- [ ] No

Appendix VIII: Teacher Feedback Questions

Post-lesson reflections (individual) and discussion (team)

- Post lesson reflection questions:
  1. Which parts of the lessons went well? Why?
  2. Which parts of the lessons can be improved? Why? In what way can they be improved?

- Overall feedback for the ELIS project (through discussions as a project team):
  1. What are some pros and cons of this project?
  2. What are some key take-aways/learning points from this project?
  3. How can we use “Talk moves” or “Concept Sketch” in other tutorials or other lessons?