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ABSTRACT

A great number of misconceptions in diverse subject areas as well as across age levels have been documented and described. Photosynthesis is one of the more intensively studied areas in biology. The purpose of this research was to carefully select and define misconceptions about photosynthesis needing remedial efforts. To achieve this, a specially designed paper-and-pencil test was administered to 285 students in grades 11 and 12 who had previously completed a study of photosynthesis just prior to the test. Analyzed in this paper were the results of the limiting factor activities, and items which tested the concept of the relationship between photosynthesis and respiration. It was found that even though these students were familiar with the concept of limiting factors, they had trouble applying it in everyday life; the students' understanding of the latter concept was as a gas exchange rather than as a biochemical process. Recommendations for the production of remedial materials are provided. A list of 21 references is included. (CW)

DETAILED ANALYSIS OF MISCONCEPTIONS AS A BASIS FOR DEVELOPING REMEDIAL INSTRUCTION: THE CASE OF PHOTOSYNTHESIS

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INTRODUCTION

A great number of misconceptions (alternative frameworks), in diverse subject areas as well as across age levels, have been documented and described (For review: Duit, 1987). Photosynthesis is one of the more intensively researched topics in biology learning (Arnold & Simpson 1980, Wandersee 1983, Smith & Anderson 1984, Bell 1985, Haslam & Treagust 1987, Stavi, Eisen & Yaakobi 1987, Eisen & Stavi 1988, Barker & Carr 1989a). It appears that time has come to move ahead and develop strategies which will help students overcome these barriers to understanding.

The description of misconceptions is a very important starting point. Such descriptions are the products of diagnostic studies which are usually based on interviewing a small number of students followed by paper and pencil test which can be administered to large samples. Analysis of students' responses to such instruments yields the percentage of students selecting a particular distractor (on a multiple choice item) or giving an answer (in response to an open question) which can be categorized as a misconception. Based on these percentages conclusions as to the type and frequency of misconceptions are drawn.

This type of work has already lead to the development of remedial material for use in middle or junior highschool classrooms (Arnold & Simpson 1980, Roth & Anderson 1985, Eisen & Stavi 1989, Barker & Carr 1989b), and 1st year university students. (Bishop, Roth & Anderson 1985).

In our work about understanding photosynthesis we felt the need to get a better insight into students' ideas about photosynthesis before embarking on the development of remedial materials. s seemed to be especially important since our target population consisted of 11th and 12th grade high school students who specialized in biology. One might expect them to hold a rich repertoire of ideas about photosynthesis which they had consrtructed in previous years. Some of these ideas may not be in line with accepted scientific notions. We thus tried to follow a process of carefully selecting and defining those misconceptions which we should concentrate our remedial efforts on. This process is the focus of the present study.

PURPOSE

The process of selecting and defining misconceptions about photosynthesis was aimed at answering the following questions:

a: what fraction of students hold a particular misconception?

b: what is the nature of this misconception?

c: how deeply is the misconception rooted?

d: can we identify the source of the misconception?

Answers to these questions are expected to result in a better understanding of the potential of particular misconceptions to function as a barrier to meaningful learning of the topic as a whole. This kind of understanding can then guide the development of remedial materials and/or effective instructional strategies.

METHOD

Instrument

We chose to seek answers to these questions by using a specially designed paper and pencil test. Items for the test were selected on the basis of the following criteria:

a. they deal with previously identified misconceptions;

b. they require understading (not just recall) of important principles;

c. the distractors, on the multiple choice items, had been shown (on large scale national tests) to draw a substantial number of students' responses indicating the existence of a common misconception.

For each identified misconception several items were included in the test. The items differed in format (multiple choice, multiple choice + justification, open ended, sentence forming) and in the cognitive demand required from the student. The use of various formats is needed since misconceptions are sometimes revealed in one situation but not in another (Eylon et al, 1987). Justifications to multiple choice items have been shown to be useful in uncovering students' ideas and misconceptions (Amir, Frankl & Tamir, 1987). In the sentence forming task students are instructed to form a sentence that connects two concepts. The sentence should reflect the link and relationship between the two concepts and the student is encouraged to use

additional concepts if she\he thinks it helps to clarify the relationship. Sentence forming tasks are not time consuming and the propositions included in each sentence can "give evidence of idiosyncratic concept meaning possesed by the student" (Novak, 1978).

Sample

The test was administerd to 285 students in eleven 11th or 12th grade classes who had completed the study of photosynthesis in the couple of weeks prior to the test.

Data analysis

Analysis of responses involved two main steps:

a. determining frequency distribution of responses to each item.

b. carrying out cross analysis of students' responses to different items relating to the same concept(s).

RESULTS AND DISCUSSION

Two examples will be presented in detail to illustrate our approach: the first deals with the concept of a limiting factor whereas the second deals with photosynthesis and respiration.

Example 1: The "Limiting Factor" concept

Two items were used as follows:

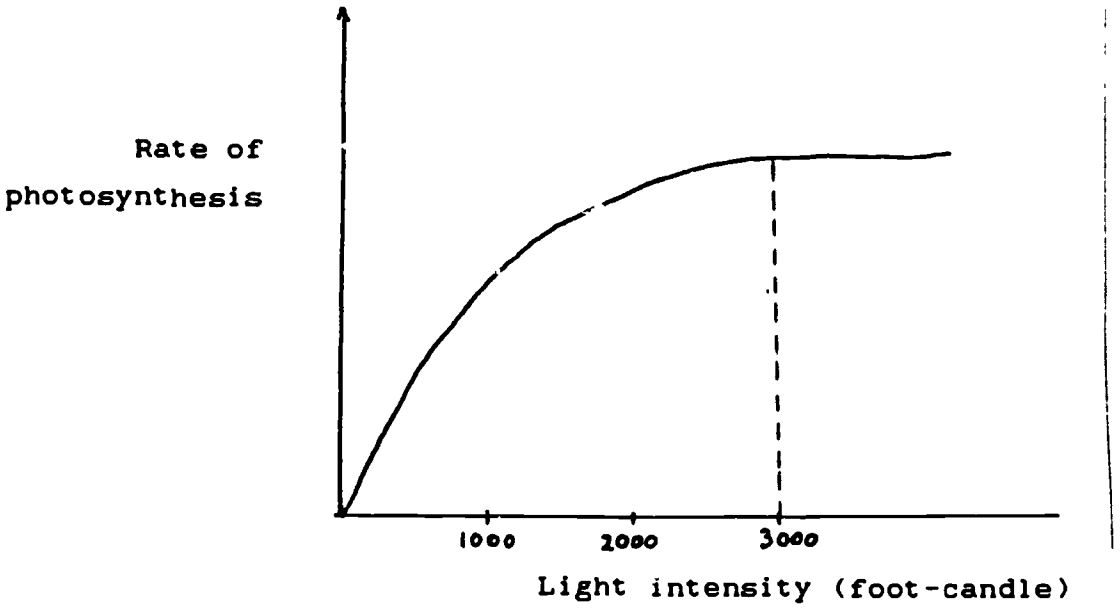
A. Multiple choice + justification (Figure 1).

It may be observed that the item requires comprehension and analysis. The fact that 98% of the students chose either answer c or d shows that practically all the students realized (correctly) that the item deals with the concept of limiting factor. This should not be surprising since a graph similar to the one used here is often presented in textbooks as an illustration of the concept. Yet 17% still chose the distractor represneting the misconception that light is the limiting factor at high light intensities.

These students clearly possess a misconception which was already

described (Amir & Tamir, 1989) namely: A factor operates as limiting when the rate of the process in question does not increase even though the intensity or the amount of that factor is increasing.

Figure 1: Limiting factor: Multiple choice item and distribution of responses (in percentages, N=285) .



The graph shows the result of an experiment in which the rate of photosynthesis was measured at different light intensities.
By examining the rate of photosynthesis it may be inferred that at light intensities higher than 3000 foot-candles:

a. photosynthesis has ceased. [1%]
b. the rate continues to increase with the increase in light intensity. [1%]
c. light has become the limiting factor. [17%]
d. another factor acts as a limiting factor [81%]

Give a brief justification for your choice.

Had we been satisfied with this result our conclusion should have been that the students in our sample reached on the average, a high level of mastery regarding the concept of limiting factor.

Unfortunately the analysis of the justifications revealed that the level of understanding is significantly lower (Table 1).

Table 1: Distribution of justifications by level (in percentages, N=279)

Level	All N=279	Correct choice (d) N=226	Misconception (c) N=48
Incorrect: light is limiting at high light intensities	18	7	67
partial: the graph levels off at high light intensity *	27	26	31
correct:	55	67	2

* This is a description of the graph but not a complete justification.

From the results in Table 1 it can be seen that only 55% (rather than 81%) actually understand the concept. A correct justification had to include at least one of the following: a. which factor might be the limiting factor. b: adding (or increasing) the limiting factor will bring about an increase in the rate. An example:

"If increasing the light does not bring an increase in the rate it means that another factor such as CO_2 is the limiting factor. Adding it will increase the rate".

Whereas nearly all those who have chosen the distractor failed to give a correct justification, about a quarter of those who did make a correct choice gave only a partial explanation of their choice. It is interesting to note that a justification based on the description of the graph (partial) was given by a similar proportion of both groups of students. The justifications given by the students who chose answer c showed the tenacity of the misconception regarding the limiting factor:

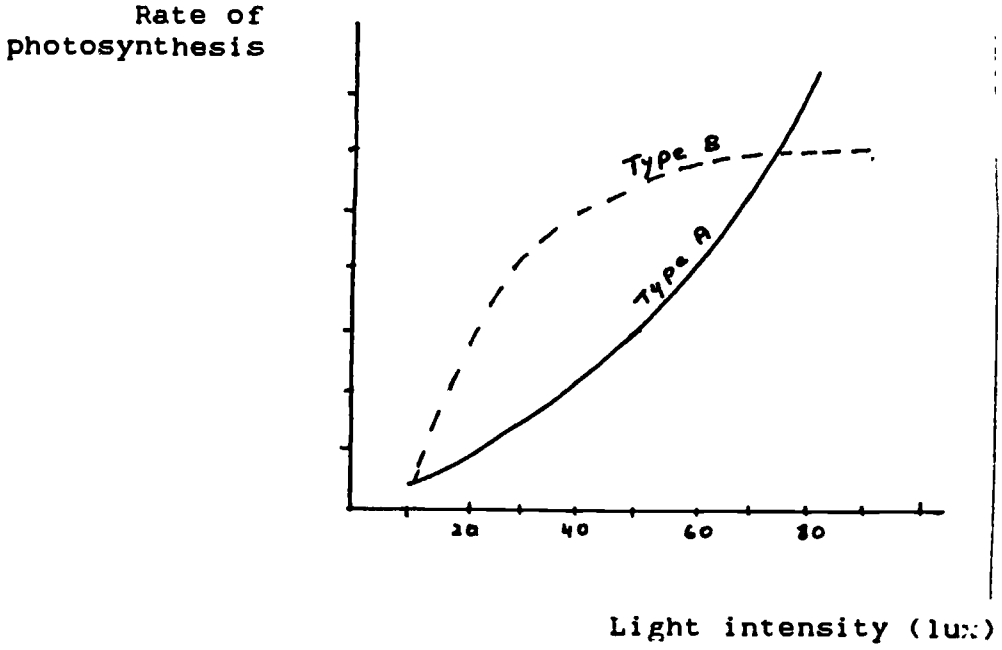
"When the rate of photosynthesis does not increase any more (above 3000 foot-candle) light is the limiting factor".

B. An open ended item

An open ended item, based on a graph was also used to assess understanding of the concept limiting factor (Figure 2). This item requires graph analysis and application. The results pertaining to this item are presented in Table 2.

Figure 2: Limiting factor: open ended item.

The graph below shows the effect of increasing light intesities on the rate of photosynthesis in two types of clover.



Is light intensity of 70 lux the limiting factor -
- for type A? - Explain.
- for type B? - explain.

As may be seen in Table 2 only 42% of the total sample gave a correct answer. Others revealed the same misconcepton represented by option c of the multiple choice item described above.

Table 2: Distribution of responses to the open ended question about limiting factor (in percentages, N= 282)

Level	All* N=282	Choices made in the multiple choice item: Correct choice (d) N=229	Misconception (c) N=48
Incorrect: Type B is limited by 70 lux.	56	47	96
Partial: Type A, no explanation	2	2	0
Correct: type A + correct explanation	42	41	4

Examples of incorrect answers:

"At 70 lux light is limiting to type B since the rate does not increase any more".

"70 lux is not limiting to type A because the rate of photosynthesis continues to rise and does not decrease".

Examples of correct answers:

" Light intensity of 70 lux is limiting the rate of photosynthesis for species A because this species produced more sugar when the light intensity had been increased".

" For species A the answer is "yes" since we can see that the rate of photosynthesis increases further with the increase in light intensity".

It may be concluded that although many students can identify a correct statement about a limiting factor, about half of them do not fully understand the concept. Many students believe that a limiting factor is inhibiting or slowing down the process when its amount or intensity is high rather than at minimum.

This misconception can be a barrier to understanding how environmental conditions affect photosynthesis. Moreover, although the concept is taught mainly in connection with photosynthesis it has important applications in many other biological areas such as nutrient requirerments or biochemical processes (e.g. enzymatic reactions).

Example 2: Photosynthesis and Respiration

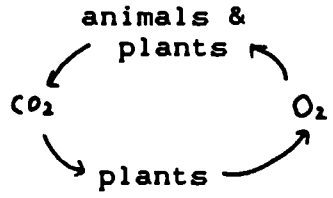
Photosynthesis and respiration are two fundamental processes in material cycling and energy flow in the biosphere. In order to understand how an organism, an ecosystem or the biosphere functions - one has to understand the difference between the two processes, their common features and the inter-relationship between them.
The confusion and misunderstandings regarding photosynthesis and respiration are well documented (Wandersee 1983, Anderson 1984, Haslam & Treagust 1987, Eisen & Stavi 1988).
Two items were used in our study to investigate students' understanding of the relationship between the two processes.

A: Multiple Choice + justification (Figure 3).

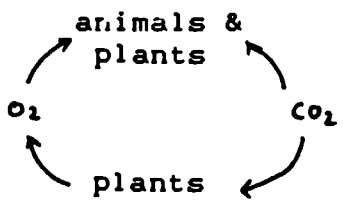
Figure 3: Photosynthesis & respiration: multiple choice item and distribution of responses (in percentages, N=285)

Which of the following drawings shows the cycling of carbon dioxide and oxygen in nature?

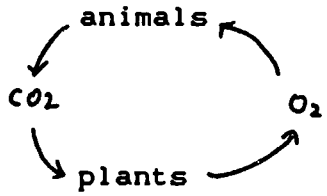
a. [63%]



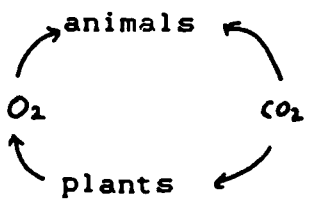
b. [1%]



c. [35%]



d. [1%]



Give a brief justification for your choice.

The nearly complete avoidance of the two obviously incorrect options (b & d) shows that the choices were non-random.
Answer c differs from answer a by a very important feature: in c plants neither take oxygen in nor give CO_2 out, namely plants do not respire. Do students who opt for c realy think tha' this is the case? The analysis of the justifications clearly supports such a conclusion (Table 3).

Table 3: Analysis of justifications to multiple choice item: distribution of responses by levels (in percent, N=282)

Level	All N=282	Correct choice (a) N=177	Misconception (c) N=99
Incorrect: plants do not respire	47	20	93
Partial: correct description of gas exchanges	10	13	6
Correct: plants respire and photosynthesize	43	67	1

Ninety three percent of those who chose option c do not realize that plants respire. The same is true for 20% of those who chose the correct answer. It may be concluded that only 43% (rather than 63% who chose the correct answer) fully understand that whereas photosynthesis is carried out only by plants respiration occurs in both animals and plants.

B: Sentence forming task.
The task was presented as follows:
"Write a sentence that will clarify in the best way you can, the relationship between the two concepts photosynthesis and respiration. You may include other relevant concepts in your sentence." The first step in the analysis of the sentences was to assign them to one of three levels: incorrect, partial, correct.
The results are presented in Table 4.

Table 4: Sentence forming task: distribution of responses by levels (in percentages. N= 261*)

Level	All N=261	Correct choice (a) N=162	misconception (c) N=93
Incorrect	25	22	29
Partial	20	19	23
Correct	55	59	48

* Because of technical reasons not all students completed this task.

An interesting result emerged from the analysis of the sentences. About half of those who chose the distractor were able to write a correct sentence linking photosynthesis and respiration. This required a closer look at the content of the sentences.

A sub-sample of 180 sentences was content analyzed. This analysis yielded 3 categories of sentences which appeared more frequently than others (see Table 5):

1. Photosynthesis is the respiration of plants
2. Photosynthesis is the opposite of respiration.
3. Photosynthesis and respiration are complemetary processes.

Table 5: Content analysis of sentences linking photosynthesis and respiration (in percent, N=180)

Category	All N=180	Choices made in the multiple choice item: Correct choice (a) N=119	Misconception (c) N=57
1. Incorrect: photosynthesis = repiration of plants	12	6	23
2. Opposite processes	21	20	23
3. Complementary processes in nature	41	44	33
Others: correct	10	11	9
Others: incorrect	17	19	12

Whereas the sentences in category 1 are clearly incorrect, category 2 represents correct but partial understanding. Based on the overall chemical equation, photosynthesis and respiration appear as opposites. However, the location, enzymes involved and intermediate reactions are completely different.

A sentence was categorized as including the idea of complementarity only if it was made clear that the products of one processes are used in the other. Examples:

"The CO_2 released by respiration is used in photosynthesis".

"Light energy is converted into chemical energy by photosynthesis and later released through respiration".

Students who merely stated that in respiration oxygen is consumed and in photosyntheis oxygen is produced - their sentences were categorized as "opposites". Sentences that stated that respiration goes on day and night while photosynthesis is carried out during the day only were also categorized as "opposites".

Although these "opposites" are considerd to be correct, in our cpinion such sentences reveal less understanding than the ones categorized as complememtary.

From the analysis we see that relatively more sentences in category 1 were written by students who had indicated by their choice to the multiple choice item that "plants do not respire " (χ^2=10.0 P<0.01)*.

It seems that there is a substantial difference in the level of understanding between those who chose the correct answer in the multiple choice item and those who chose the distractor. More of the first group understand the complementarity between the fundamental life processes and considerably fewer of them hold the resilient misconception in category 1.

[* based on the frequencies in the 6 cells marked by a frame (Table 5)].

CONCLUSION

As might have been expected, students at the 11th or 12th grade level are familiar with the concept of a limiting factor. However even though they recognize a correct definition they have difficulty in applying the concept. Providing more opportunities to apply the concept in biological as well as in daily life situations might be helpful in overcoming this deficiency and achieving better understanding. Two examples of paper and pencil activities designed to achieve this goal are given in Appendix I.

The misconception regarding photosynthesis and respiration stems from a different source. The kind of gases exchanged in photosynthesis and respiration are well known to the students. This leads many students to perceive both processes solely as gas exchange events, and not as complex biochemical processes with the resulting misconception that photosynthesis is the respiration of plants. Here the remedial treatment should work to achieve a "progressive differetiation" (Ausubel, 1968) of both concepts in order to show the many ways the processes are linked to each other (through material cycles and energy flow) and to stress the idea of respiration as a universal process common to most living organisms. The "compensation point" phenomenon is the focus of one activity dealing with photosynthesis and respiration in plants (Appendix II).

Our goal is to go beyond the phase of describing common misconceptions about photosynthesis and base the development of remedial material on a detailed analysis of misconceptions. The main features of these materials are:

1. Report for the teacher regarding the nature of the misconceptions he\she is expected to find among his\her students.
2. An updated theoretical discussion of the concepts involved.
3. Suggestions for activities such as invitations to inquiry (Schwab, 1963) concept maps, relevant short articles and graph analysis tasks.

The development and selection of appropriate activities was directly based on the analysis of multi dimentional test results. Materials developed according to these lines are now being trialed in Israeli classrooms.

References

Amir, R., Frankl, D.R., Tamir, P. (1987) Justifications of answers to multiple choice items as a means for identifying misconceptions. in: Novak (Ed.) Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics (vol. 1) Cornell University, Ithaca, N.Y. (pp:15-25).

Amir, r., Tamir, P. (1989) When does a factor become a "limiting factor"? - a study of students' misconceptions. Journal of Biological Education 23:129-134.

Anderson, C.W. (1984) Overcoming critical barriers to learning in non-majors' science courses. Institute for Research on Teaching. Michigan State University.

Anderson, C.W., Sheldon, T.H., DuBay, J. (1986) The effects of instruction on college non-majors' conceptions on respiration and photosynthesis. Research rseries no. 164, Institute for Research on Teaching' Michigan State University.

Arnold, B., Simpson, M. (1980) An investigation of the development of the concept photosynthesis to S.C.E. '0' grade. Aberdeen College of Education. Aberdeen Scotland.

Ausubel, D. (1968) Educational Psychology . Holt, Rinehart & Winston. New York.

Barker, M., Carr, M. (1989a) Photosynthesis - can our pupils see the wood for the tree? Journal of Biological Education 23:41-44.

Barker, M., Carr, M. (1989b) Teaching and learning about photosynthesis. Part 2: A generative learning strategy. International Journal of Science Education 11:141-152.

Bell, B. (1985) Students' ideas about plant nutrition: What are they? Journal of Biological Education 19:213-219.

Bishop, B.A., Roth, K.J., Anderson, C.W. (1985) Respiration and Photosynthesis. A teaching module. Institute for Research on Teaching. Michigan State University.

Duit, R. (1987) Reseach on students' alternative frameworks in science- Topics, Theoretical Frameworks, Consequences for science teaching. in: Novak (Ed.) Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and

Mathematics. (vol. 1) Cornell University, Ithaca, N.Y. (pp:151-162).

Eisen, Y., Stavi, R. (1988) Students understanding of photosynthesis. The American Biology Teacher 50:208-212.

Eisen, Y., Stavi, R. (1989) Development of new science study unit following a research on students' ideas about photosynthesis: A case study. in: Adey, P. (ED.) Adolescent Development and School Science The Falmer Press. Lewes, East Sussex, England. (pp: 295-302).

Eylon, B., Ben-Zvi, R., Silberstein, J. (1987) Hierarchial task analysis- An approach for diagnosing students' conceptual difficulties. International Journal of Science Eduaction 9:187-196.

Haslam, F., Treagust, D.F. (1987) Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. Journal of Biological Education 21:203-211.

Novak, J.D. (1978) An alternative to Piagetian psychology for science and mathematics eduaction. Studies in Science Education 5:1-30.

Roth, K.J., Anderson, C.W., (1985) The Power Plant Institute for Research on Teaching. Michigan State University.

Schwab, J. (1963) The Biology Teacher Handbook. Wiley: New York

Smith, E.L., Anderson, C.W. (1984) Plants as producers: A case study of elementary science teaching. Journal of Research in Science Teaching 21:685-698.

Stavi, R., Eisen, Y., Yaakobi, D. (1987) How Israeli students aged 13-15 understand photosynthesis International Journal of Science Eduaction 9:105-115.

Wandersee, J.H. (1983) Students' misconceptions about photosynthesis: A cross age study. in: Helm & Novak (Eds.) Proceedings of the International Seminar on Misconceptions in Science and Mathematics. Cornell University, Ithaca, N.Y. (pp: 441-463).

APPENDIX I

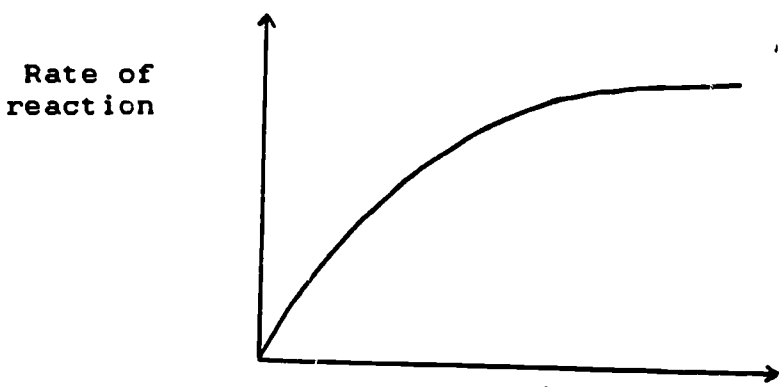
Limiting factor activities.
1: The soccer field

At the enterance of the soccer field a guard checks the tickets of the people coming to watch the game. The rate at which he manages to check the tickets is 4 tickets per minute.
On one Saturday the game was scheduled to start at 2 o'clock in the afternoon. Consider the following information and then answer the questions below:
* Betwwen 12am and 1pm 40 people passed through the gate.
* between 1pm and 2pm 240 people passed through the gate.

Questions:
a. what is the factor that limits the number of paople entering the stadium in the first hour (12am - 1pm)?
I. The swiftness of the guard at he gate.
II. The number of people arriving at the gate.
Choose one answer and explain your choice.

b. On that particular day not all the fans had gotten in before the game started. What would you suggest to improve the situation (assuming a similar situation exists every game)?
I. Add another guard from 12 am.
II. Add another guard from 1 pm.
Choose one answer and explain using the concept "limiting factor".

B. Enzymatic reactions
The graph below shows the effect of substrate concentration on the rate of enzymatic reaction.

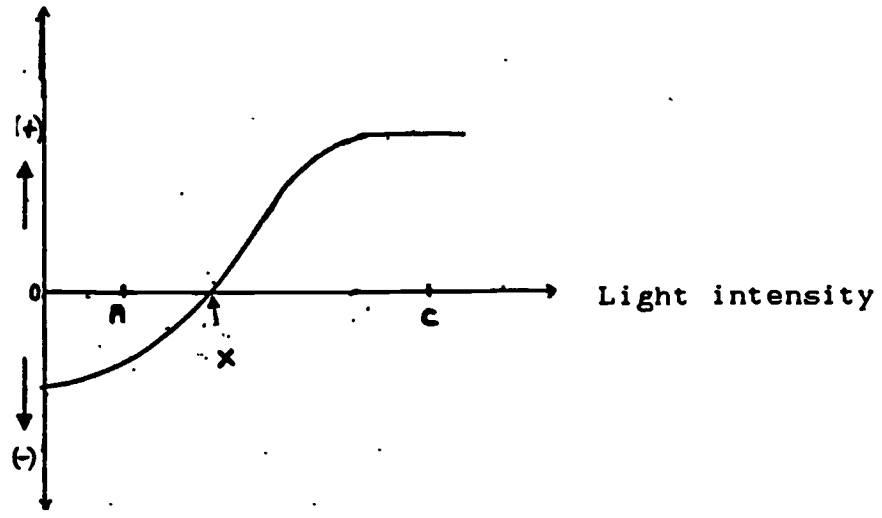


Explain the course of the graph using the concept "liming factor".

Appendix II

Photosynthesis & respiration in plants

An experimant was carried out on a plant in an enclosed chamber. The purpose of the experiment was to investigate the effect of light intensity on the O_2 concentration in the chamber. The results are shown in the graph below. Study the graph and answer the questions below:



A: Is O_2 given up by the plant at light intensity A? - Explain.
B: What happens inside the plant at light intensity X? - Explain.
C: Under which natural conditions can we expect to find a similar situation as at point X?
D: At one point of the experiment, under high light (c), "heavy" oxygen was added to the chamber. When the changes in the amount of heavy oxygen where recorded with time it was found that its amount:
   * decreased with time
   * remained unchanged.
   * increased.

Choose the best answer and explain your choice.