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INVESTIGATING GRADE 10 LEARNERS' ACHIEVEMENTS IN PHOTOSYNTHESIS USING CONCEPTUAL CHANGE MODEL

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Abstract. *Challenges in the learning photosynthesis topic may arise from misconceptions. This study investigated Grade 10 learners' achievements in photosynthesis using the Conceptual Change Model (CCM) to minimize misconceptions and to develop understanding of photosynthesis in rural high schools in South Africa. A quasi-experimental design was used with a sample of 78 Grade 10 learners: 39 Experimental Group (EG) and 39, Control Group (CG). Achievement test, learning materials and a questionnaire were used to collect data. Data were analysed using descriptive statistics, t-test, Analysis of covariance (ANCOVA) and Pearson correlation. Results from post-tests show that EG taught using the CCM exhibited higher achievements than the CG taught using traditional approach. ANCOVA show that there were significant differences in performance between pre- and post-test of the EG. Performance and attitudes correlation was (r = 0.89) for EG and (r = 0.33) for CG, suggesting that CCM positively influenced learners' attitudes towards Life Sciences.*

Key words: *achievement, attitude, conceptual change, misconceptions.*

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Introduction

Photosynthesis is one of the difficult concepts taught in high school biology (Russel et al., 2004; Koba & Tweed, 2009). In South Africa it was taught in grade 12 in the old 550 Curriculum and is currently taught in Grade 10 in the Curriculum Assessment Policy Statements (CAPS). Generally, learners start with the basics of photosynthesis in the lower primary school and expand on it in the senior phase. It is a topic that forms the basis of plant study in high school. It is an important topic for a learner intending to study botany at tertiary level (Russel et al., 2004). Photosynthesis presents a conceptual problem since molecules involved are invisible to the naked eyes and visualising the process remains a mystery (Parker et al., 2012; Svandova, 2013). The actual results of photosynthesis are hard to analyse since plants grow at seemingly slow rates. The difficulty is also compounded by lack of resources in some schools. This is true in schools where there are no laboratory equipment for practical work to provide hands-on teaching and also large classes pose challenges in schools. In addition, there are conceptual challenges surrounding the understanding of photosynthesis. These challenges may emanate from misconceptions associated with the breadth and complexity of the topic.

Misconceptions often persist in learners' understanding of photosynthesis even after being confronted in a traditional lesson (Haslam & Treagust, 1987; Lonergan, 2000; Ebert-May et al., 2003; Parker et al., 2012; Svandova, 2013). For teaching to be effective, educators need to know various misconceptions in advance and look out for new ones in their classes. Knowledge of misconceptions may assist educators to prepare interventions to minimize the learning barriers created by misconceptions. In the learning process, learners construct meaning and they may alter their views and adapt new stances. This change of stances constitutes the constructivist theory of learning (Hershey, 2004). Educators need to understand the concepts themselves in order to avoid reinforcing the existing misconceptions. A selective and effective use of intervention would minimize misconceptions in the Life Sciences classes. This study, therefore, proposed the use of the Conceptual Change Model (CCM) approach to address learners' misconceptions about photosynthesis.

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Literature Review

Educators play a very significant role in the realization of acceptable scientific concepts. The acceptable teaching methods place emphasis on the learner instead of the educator. This is vindicated in the National Curriculum Statement (NCS) in South Africa where the emphasis is on learner-centred approach, which requires learners to take responsibility for their own learning; to be active in the classroom and to participate at all levels (Department of Education, 2003). In South African schools and other parts of the globe, traditional teaching is still practiced (Broadie, 2006; Oludipe & Oludipe, 2010; Coetzee & Imenda, 2012; Kazeni & Onwu, 2013). The traditional teaching method is where educator-centred approaches dominate the teaching process. In the traditional teaching method educator-centred approaches dominate the teaching process. The educator gives information mainly through lectures to passive learners. Learners work individually on assignments and cooperative work is often discouraged (Xiaoyan, 2003; Tan, 2011). On the other hand, learner-centred teaching methods shift the focus of activity from the educator to the learners. These methods include *active learning* in which learners solve problems, answer questions, formulate questions of their own, discuss, explain, debate, or brainstorm during class. C*ooperative learning* is where learners work in teams on problems and projects under conditions that assure both positive interdependence and individual accountability. I*nductive teaching and learning* is where learners are first presented with challenges (questions or problems) and then learn the course material in the context in order address challenges. Thus, in learner-centred approaches, the role of an educator and learner should be compatible with the constructivist learning theory (Xiaoyan, 2003; Friesen, 2011). Constructivists believe that the knowledge which learners discover by themselves is more enduring than the knowledge transmitted to them by the educator. Constructivism recognizes that learning is a cognitive process involving construction and reconstruction of ideas. Constructivism recognizes that the learner is a meaning-maker rather than a passive recipient of factual knowledge (Coetzee & Imenda, 2012). Fundamentally, the constructivist approach to teaching recognizes that the conditions that inspire conceptual change are internally induced (Duit, 1996). Inducing this change necessitates a shift of ownership from the educator to the learners.

High school learners have misconceptions of ideas regarding definition and purpose of photosynthesis, nutrition of plants, chlorophyll, the role of water (Ekici et al., 2007), classification of living things, ecology, cells and continuity and change (Driver, et al., 1994). Learners hold many ideas about scientific concepts before instruction which may be in conflict with the accepted scientific ideas (Grayson, 1995; Koba & Tweed, 2009; Svandova, 2013). Among these are misconceptions that arise from misinterpreted experiences, undifferentiated concepts, and those from instruction as well as textbooks (Stepans, 1994; Koba & Tweed, 2009). If the above mentioned misconceptions are ignored, effective learning of science concepts might not take place (Grayson, 1995; Ekici et al., 2007; Parker et al., 2012).

From the classroom experience of the first author, it was noticed that learners had misconceptions on the flow of energy during photosynthesis. For instance, learners believed that plants get their food from the soil, citing fertilizers placed in the soil for improved food production. The learners thought that photosynthesis occurs only during the day and plants respire at night. They believed that the simple conversion of carbon dioxide and water to carbohydrate and oxygen was all that was needed for the process of photosynthesis. Learners also, believed that plants are green because they absorb green light from the sun (Pers. Obs.). To them, these misconceptions are common sense of what they experience and acquire through the mass media, books and other forms of instruction (Stepans, 1994). Misconceptions are widely spread, deeply rooted and are often hard to change (Driver et al., 1986; Ekici et al., 2007; Deshmukh, 2012). According to Wichmann et al. (2003), learners are likely to resist giving up an existing concept in favour of a new concept. It is necessary to explore ways in which learners develop a better understanding of the photosynthesis process. Hewson (1992), Tanner and Allen (2005) and Svandova (2013) posit that learning may involve changing a person's conception. To achieve this outcome, CCM is used to broaden learners' knowledge and to provide educators with alternative ways of teaching Life Sciences in a meaningful way.

The development of the teaching approach of the CCM is a culmination of work by many science educators and researchers of education such as Eaton, Anderson and Smith (1993), Chih-Chiang and Jeng-Fung (2012), and Hadjiachilleos, Valanides and Angeli (2013). Two major components of the CCM were advanced by Hewson (1992). The first of these components is the condition that should be met (or no longer met) in order for a person to experience conceptual change. The extent to which the conception meets the standards is whether a new conception is 1) intelligible (knowing what it means), 2) plausible (believing it to be true) and 3) fruitful (finding it useful), termed the status of a person's conception. The second component is the person's conceptual ecology that provides the context in which the conceptual change occurs. Learners use their existing knowledge (i.e. their conceptual ecology) to determine whether different conditions are met, that is, whether a new conception is intelligible, plausible and fruitful (Hewson, 1992). If the new conception meets all the three standards, learning proceeds without difficulty. However, the new conception may conflict with the existing conceptions and in that case it cannot become plausible or fruitful until the learner becomes dissatisfied with the old conceptions.

A few studies reported that learners with meaningful learning approaches accomplished more than those with rote learning approaches (BouJaoude & Guiliano, 1994; BouJaoude et al, 2004; Cavallo, 1996; Cavallo & Schafer, 1994). A study by Mandrikas et al. (2013) shows that difficulties in scientific conceptual knowledge abound as a result of superficial scientific knowledge and may lead to formation of misconceptions. In an earlier study, BouJaoude (1992) reported that rote learning does not encourage understanding and leads to more misconceptions concerning chemistry concepts than meaningful learning approaches. Similarly, the work of Cavallo and Schafer (1994) demonstrated that learners with meaningful learning approaches developed more meaningful understanding of genetics concepts than those with rote learning approaches. Altogether, studies focusing on the learning approaches have suggested that there is a statistically significant association between learning approaches and learners' achievement in science. The curriculum in South Africa emphasises the implementation of learner-based teaching strategies in the teaching of Life Sciences. This kind of learning can occur when educators provide experiences that acknowledge and directly challenge naïve conceptions.

Tekkaya and Balci (2003) carried out a study that aimed at determining the misconceptions of high school learners regarding the concept of photosynthesis and respiration in plants. These researchers observed that most of the learners had the idea that "photosynthesis is a gas alteration process, energy is produced after photosynthesis and photosynthesis is the reverse of respiration" which is scientifically invalid. Likewise, in Turkey, Cepni and colleagues' (2006) studied cognitive development, misconceptions and attitude of learners about the photosynthesis concept. They concluded that making use of Computer Assisted Instruction Material (CAIM) was very crucial for attaining the application and comprehension levels of cognition in teaching photosynthesis. However, they observed that CAIM did not substantially change the misconception of learners about photosynthesis. Kose *et al*. (2006) investigated the effect of concept changing texts for reducing the misconceptions of pre-service educators on photosynthesis and respiration in plants. These authors observed that most pre-service educators had misconceptions about photosynthesis and respiration in plants. They concluded that concept changing texts were efficient in the comprehension of photosynthesis and respiration in plants as well as in reducing misconceptions of pre-service educators. It is observable from these studies that despite the fact that they investigated misconceptions in science education, the CCM approach and its effect on performance in photosynthesis in high school learners in a rural setting did not aim to remedy the problem therein, hence a need for the current study.

The purpose of this study was to compare Grade 10 learners' achievements in photosynthesis using the CCM approach and those obtained using traditional teaching approach. CCM was used in order to minimize the established misconceptions and to develop a broad and deep understanding of photosynthesis process in high school context in Mpumalanga province, South Africa. The study also endeavoured to identify learners' attitudes towards science at the end of the teaching approach. CCM approach is seen as an alternative approach to teach learners about photosynthesis. This approach incorporates experiential learning and recognizes learners' prior knowledge of the concept under study.

Research Questions

This study aimed to answer this main question: what are the achievements of Grade 10 learners' in photosynthesis as core knowledge? In order to answer the main question, the study addressed the following four sub-questions: 1) Are there any significant differences in achievements between the post-test of control and experimental groups?; 2) Are there any significant differences between the experimental group's pre-test and post-test achievements? 3) What are learners attitudes towards Life Sciences before and after using CCM and traditional teaching approaches?; 4) Is there any correlation between performance and attitudes of EG as well as the CG?

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Methodology of Research

Research Design

A quasi-experimental design was used with non-equivalent pre-test, post-test control group (Campbell et al., 1963). Of the two groups, one was designated as the experimental group (EG) and the other the control group (CG).

Sample of Research

The sample comprised a total of 78 Grade 10 Life Sciences learners from two neighbouring high schools in Nkangala Region of Mpumalanga Province, South Africa. The schools were selected because they were all situated in the same rural region, which meant that the participants were likely to have been exposed to similar socio-economic conditions and were probably familiar with the traditional practices found in that particular socio-cultural environment. The sample was drawn by a purposive sampling technique from two separate schools: one Life Sciences class of 39 learners (8 boys and 31 girls) and the other, Life Sciences class of 39 learners (14 boys and 25 girls). The age of the respondents ranged between 13-15 years. One class formed the EG which was taught using CCM, while another class formed the CG and was taught through traditional approach.

Instrument and Procedures

Three types of instruments were used in this study: achievement test (AT), a questionnaire and learning materials for both the control and experimental groups. The AT which was used as both pre- and post-tests consisted of 11 questions: 5 true or false questions, five multiple choice questions and one structured question. The pre-test was administered before the intervention to identify learners' pre-existing misconceptions about photosynthesis. After the intervention, the same pre-test was used as a post-test except that the item numbering in the post test was different from pre-test to avoid recognition of items. Post-test was used to explore learners' concepts associated with photosynthesis in order to determine how their understanding had changed due to the CCM intervention. Both tests covered most aspects of photosynthesis investigated in the two groups.

In order to determine learners' attitudes, a questionnaire of 16 items on a 5-point Likert Scale ranging from 1 (strongly agree) to 5 (strongly disagree) was used in addition to the pre- and post-tests (Hake, 2001; Randler, 2006). This study was conducted over a period of six weeks. To alter learners' misconceptions, six stages of the CCM were used. The independent variable was the intervention and the dependent variable was learners' understanding measured by pre- and post-test scores. The EG was taught using the CCM approach, while the CG was taught using the traditional approach. Educator facilitated learners' activities in the EG through the first six stages of the CCM. Learners were allowed to make presentations in groups and submitted worksheets of their activities. The educator evaluated each group based on their presentations and worksheets. In the CG, where the traditional approach was utilized, the textbook method; whole class discussion and lectures were employed for instructional purposes.

Data Analysis

Data collected were analysed using SPSS Version 18. Descriptive statistics were used to obtain the difference between means, standard deviations of the scores for each group on each dependent variable. The means for the EG which received CCM instructional approach were used to determine whether they performed better than their CG counterparts who received traditional teaching approach. The differences in achievements of the EG and CG were verified using t-tests ($p < 0.05$) Dugard & Todman, 1995). ANCOVA was used to compare group means of post-test scores between the EG and the CG. ANCOVA using pre-test as covariate statistically controlled for the differences of the pre-test so that post differences would not be due to initial differences prior to treatment. Data from attitude questionnaire were reduced from five to three groups: Disagree, not sure and agree. In each group a mean percentages score was calculated. Pearson correlation was calculated between performance and pooled data for attitudes.

Results of Research

Learners' prior knowledge and misconceptions were identified from the pre-test. The independent t-test analysis showed that there was no statistically significant difference between pre-test achievement scores of the CG (Mean = 2.51, SD = 1.46) and the EG (Mean = 2.94, SD = 1.56) (t = -1.27, df = 76, $p > 0.05$). There was a significant difference between the post-test achievement scores of the CG (Mean = 4.23, SD= 1.71) and EG (Mean = 7.33,df =76, SD = 3.94; t = -4.509, df = 76, $p < 0.05$). The mean score of the EG was 7.33 which was higher than the CG mean score of 4.23. There was a significant difference between the pre-test and post-test scores in the EG (t = -6.46; $p < 0.05$). The mean pre-test scores were 2.94 and the mean post-test score was 7.33. Conversely, there were no significant differences between pre-test and post-test for the CG ($p < 0.05$). The results of ANCOVA are summarized in Table 1.

Table 1. ANCOVA summary of pre-test and post-test for EG.

Source	SS	df	F	p
Pre-test	23.57	1	2.82	0.09
Post-test	125.14	1	14.65	0.00
Error	657.79			

Key: SS= Sum of Squares; df= Degrees of freedom; F= F-ratio to determine whether the variances in two independent samples are equal; p= probability at 0.05.

The results of ANCOVA in Table 1 show that there was a statistically significant difference in performance between the pre- and post-test of EG.

During lesson presentation and classroom discussion with learners the following misconceptions were identified: plants get their food from the environment rather than manufacturing it internally and soil supplies most of the raw materials for photosynthesis. Water and minerals are food for plants and soil is the plant's food which is the reason why people put food (fertilizer) in the soil for plants to eat. These misconceptions were found in 80% of learners in the class. Figure 1 further summarizes the comparison of the results as mean scores of pre-test and post-test.

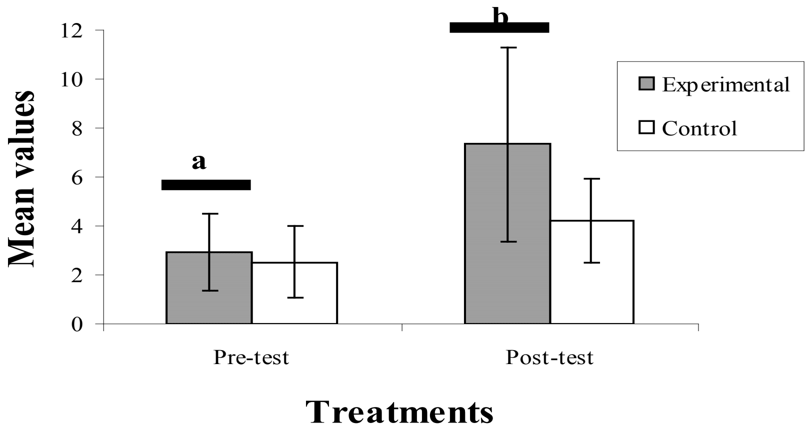

Figure 1: Summary of Pre and Post-test Results.

The range of post test scores for the CG was from 0 to 7 with a mean of 4.23, for the EG values from ranged 1 to 15 with a mean of 7.33 (Figure 1). By comparing the means of the post-test scores, this study, found that learners in the EG (Mean = 7.33 ± 3.94) gained more than their CG counterparts (Mean = 4.23 ± 1.71). Attitudes of both EG and CG gathered from the questionnaire are presented in Table 2.

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Table 2. Showing mean % of Likert results regarding learners' attitudes in EG towards CCM and in CG towards traditional teaching approach.

Group	Strongly disagree and Disagree (Mean %)	Not sure (Mean %)	Strongly agree and Agree (Mean %)
Experimental Group (EG)	9.27	10.36	80.36
Control Group (CG)	60.55	23.45	15.91

The vast majority of learners from EG agreed (80.36%) showing that their attitudes towards science were positive. On the other hand, in the attitude questions, more learners from CG were not sure either to agree or to disagree (23.45%) compared to EG (10.36%) (Table 2). The results from Pearson correlation of performance and attitudes was ($r(38) = 0.89$) for the EG when compared to ($r(38) = 0.33$) for the CG.

Discussion

The purpose of this study was to compare Grade 10 learners' achievements in photosynthesis using the CCM approach with those obtained using traditional teaching approach. During lesson presentation and classroom discussion with learners the following misconceptions were identified as: plants get their food from the environment rather than manufacturing it internally; and soil supplies most of the raw materials for photosynthesis and these findings were consistent with Driver, et al., (1994). Water and minerals were cited as food for plants which was in agreement with Ekici et. al., (2007). Also, soil was the plant's food which is the reason why people put food (fertilizer) in the soil for plants to eat. These findings suggest that indeed learners have misconceptions on photosynthesis. The pre-test results showed that 80% of learners in the class had similar misconceptions. This suggested that Grade 10 learners' understanding of photosynthesis was similar in both the EG and CG. This was vindicated by the findings from the pre-test where there was no significant differences between EG and CG (t-test, $p< 0.05$).

After six weeks of teaching using different methods: CCM and traditional approach, the EG scores in Achievement Test (AT) were higher than those of CG. This is not surprising because the use of CCM affords learners the opportunity to exchange ideas through discussion and presentations. Through this process, learners find out that their views are less interesting and at times are at odds with the acceptable scientific views. This often results in dissatisfaction with the old views and learners look for new ways that are acceptable, plausible and intelligible (Hewson, 1992). Our findings show that learners from EG taught using the CCM achieved higher post-test scores than the CG taught through the traditional approach and these findings are in agreement with Smith et al. (1993) and Kose et al. (2006). These researchers found that post-test results for learners taught using CCM approach performed better than those taught using traditional methods. This further corroborates the study of Cibik et al. (2008) who investigated the effect of CCM approach with pre-service science educators at Gazi University in Turkey. Thus, after instruction using CCM our results show that conceptual change instruction addressed learners' misconceptions and produced significantly great achievement in understanding concepts of photosynthesis.

The academic achievements from post-test results of EG using ANCOVA reveal that there was a significant difference (Table 1) confirming that indeed the CCM approach resulted in such differences. The academic achievements of the EG using the CCM approach achieved higher post-test results than the CG using the traditional approach (Figure 1) suggesting that the two groups achieved different gains from different teaching approaches. Also, group work and demonstrative experiments based on the CCM approach seemed to be very effective in eliminating misconceptions in the EG. This suggests that learners improve their performance when they are actively engaged in hands-on activities (Oludipe & Oludipe, 2010). Thus, the underlying reason is that CCM addresses misconceptions between scientific information and existing information and seemed to be context-based (Kazeni & Onwu, 2013).

It seemed clear that the CCM approach employed during the intervention (treatment) in this study had a significant positive impact on the learners' understanding of the concept of photosynthesis and their attitudes towards Life Sciences. The high positive attitudes exhibited by the EG (80.36%) (Table 2) suggest that learners from EG found the CCM approach useful in helping them to understand concepts and to think out-of-the-box because it challenged their thinking process. The CCM approach is viewed positively by learners who describe it as enjoyable, interactive, relevant and practical. They liked the CCM approach because it encouraged them to discuss issues with the educator and among themselves. Consequently, through CCM approach learners developed interpersonal skills. This is in agreement with Barraket's (2005) study which concluded that the use of learner-centred techniques facilitated a strong social context for learning. Both the learner-centred teaching used by Barraket (2005) and that of the CCM process used in this study encouraged active and experiential engagement of learners with the subject matter. Therefore, CCM approach has the potential to be effective in terms of learner satisfaction and class performance as demonstrated in this study (Table 2).

The high percentage scores on the positive side of the Likert scale suggests that learners from EG responded positively to the CCM approach. It can be concluded that CCM approach positively influenced learners' conceptual understanding of photosynthesis. These results are compatible with results of other studies like Smith et al. (1993) and Kose et al. (2006) who found that learners in classes where educators used CCM approach performed better in post-tests than those learners who were taught using traditional methods.

In the traditional teaching approach, the low positive attitude (15.91%) together with the high percentage scores on the disagreeing of the Likert scale (attitude 60.45%) (Table 2) suggest that learners in the traditional teaching approach had negative attitudes towards Life Sciences. Furthermore, the academic achievements from post-test results of EG and the CG reveal that there was a significant difference between the two groups. The post-test results of the EG was higher than the CG. These results are not surprising because learners from CG were not active when compared to EG. These findings are in agreement with Kazeni and Onwu (2013) who found that context-based teaching that included active learning was better than the traditional teaching approach. The high Pearson's correlation between achievement and attitudes for EG as opposed to low correlation for CG suggests that good performance may lead to positive attitudes towards learning a specific subject or topic. These findings are in agreement with those of Yenilmez, et al. (2006), Ali and Awan (2013); and Gbore (2013). Also, similar findings have been reported in Mathematics (Mubeen, Saeed & Arif, 2013).

Conclusions and Recommendations

Learners come to science classrooms with misconceptions. These misconceptions are at variance with scientific conceptions and resist efforts by educators to change them. The traditional teaching approach may not be ineffective in changing learners' non-scientific ideas. The CCM, in this study, was effective in influencing learners' attitude as well as in improving their performance in the study of photosynthesis.

It is recommended that educators change their mode of presenting lessons by adopting CCM for improved academic achievement. Educators should play the role of facilitators and strive to give learners opportunities that will challenge their misconceptions. CCM inspires a reform in the approach to Life Sciences teaching, thus, the paradigm shift from the traditional approach to the constructivist approach where CCM can be used.

It is proposed that further research should investigate the effect of CCM in public schools in rural and urban areas of South Africa. Also, the effect of CCM on teaching of other Life Sciences concepts other than photosynthesis should be investigated.

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Appendix

ACHIEVEMENT-TEST

Question 1 (5 marks)

1.1 Use either **TRUE** or **FALSE** in responding to statements below:
1.2 Plants get food from soil. People put food (fertilizers) in the soil for plants to eat.
1.3 Plant growth material (mass) comes from soil.
1.4 Plants breathe in carbon dioxide and drink water.
1.5 Sunlight, carbon dioxide, water and minerals (fertilizers) are food for plants.
1.6 Plants manufacture their food internally.

Question 2 (5 marks)

Multiple-choice questions

Various possibilities are suggested as answers to the following questions. Indicate the correct answer.

2.1 Photosynthesis takes place in …
A: Autotrophic organisms B: Primary consumers C: Decomposers D: Heterotrophic organisms

2.2 Which of the following is **not** needed for photosynthesis to occur?
A: Water B: Oxygen C: Chlorophyll D: Carbon dioxide

2.3 Photosynthesis is process in which plants produce …
A: Carbohydrates and oxygen B: Sugar and carbon dioxide C: Starch and carbon dioxide D: Chlorophyll and radiant energy

2.4 Which of the following atmospheric gases will disappear first if all chlorophyll containing plants were to be removed from earth?
A: Nitrogen B: Carbon dioxide C: Oxygen D: Water vapour

2.5 For photosynthesis to occur, a plant requires …
A: Water, oxygen, light and chlorophyll B: Chlorophyll, light, carbon dioxide and oxygen C: Carbon dioxide, light, chlorophyll and water D: light, darkness, oxygen and carbon dioxide

Question 3 (5 marks)

3.1 In the seventeenth century John Baptista Van Helmont carried out one of the first experiments relating to the synthesis of food in plants. He placed *200lb* (*±90kg*) dried earth in a vessel in which he planted a *5 lb (±2,25kg)* willow tree. He covered the opening of the vessel with an iron plate to prevent dust from entering and he watered the soil with rainwater. After five years he found that the willow tree weighed *169lb (±73,5kg)* and the soil has lost *20oz (±0,56g)*. Explain what lead to the increase in body mass of the plant.
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