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A Review on Plant Science Education in Singapore

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Abstract

Plants are fundamental to the existence of our green planet, but the understanding of plants and the willingness to understand them is deficient. Teachers, students and curriculum developers are mindful of the lack of knowledge and ability to notice plants in our environment. In Singapore we are facing a paradox in plant science education. Known as a garden city, and having a hybrid of an orchid as our national flower, many of our citizens ironically remain blind to what are growing and cultivated around them. Our pupils are not able to name the common plant species. They would prefer to dwell in the air-conditioned comfort of their homes and learn through the computer or the television rather than to have a walk in the forest. Further, our educators merely set limited plant contents in Biology syllabus, and teachers are reluctant to bring plants to the classroom.

In this review, we reflect plant science education in Singapore based on the current syllabus at the primary, secondary and junior college levels. We also list a few case studies of specific terms in plant science using various science textbooks and questions from national exams to allow a greater understanding on how plant science is taught and tested. Finally we propose suggestions to improve plant science education in Singapore.

Keywords: Plant Science; Science Education; Syllabus; Singapore
Introduction

Science education in Singapore is designed with scientific inquiry as the core. The goal of science education in Singapore is to equip and prepare students to become effective citizens that are able to function in a technologically driven society. Scientific inquiry is based on three domains of (a) knowledge, understanding and application, (b) skills and processes, and (c) ethics and attitudes (Fig. 1).

Fig. 1. Scientific inquiry is based on 3 domains (Primary Science Syllabus, Science Curriculum Framework, MOE CPDD, pg. 1).

Science education is offered to students in primary schools, secondary schools and junior colleges. The primary science syllabus is divided into the lower block (primary three and primary four) and upper block (primary five and primary six). To graduate from primary school, all students will sit for the Primary School Leaving Examination (PSLE). Science is one of the examinable subjects for the PSLE. All secondary school students are required to study general science while in lower secondary, and will have a choice to pursue either biology, chemistry or physics at the upper secondary school level. Depending on the stream the student is in, the student will then sit for their national exams at the O, N(A) or N(T) level.
during their graduating year. Science is not compulsory at the junior college level, and students who choose to study science will have a choice of taking a pure science subject at either a H1 or H2 level.

With the structure of the Singapore science education as the context, the goal of this paper is to review plant science education through the different stages of science education in Singapore. The science syllabus at the primary, secondary and junior college level will be reviewed to determine the depth and scope in which plant science education is taught in schools. Additionally, the review of various science textbooks and questions from national exams will allow a greater understanding on how plant science is taught to students and tested in Singapore.

**Review Method**

The science syllabuses that are reviewed in this paper are the PSLE science syllabus, O-level Biology syllabus and A-level H2 Biology syllabus. Although at the secondary level, Biology is also available at the N-levels as Science Biology, and at the O-levels as Science Biology, the O-level Biology syllabus has been chosen to be reviewed in this paper as the syllabus requirements are the most comprehensive and covers the largest range of topics at the Secondary level. Similarly, at the junior college level, the Biology syllabus is available at a H1 and H2 level. The A-level Biology syllabus chosen to be reviewed is the one at the H2 level as it is the more comprehensive syllabus of the two.

National examination questions that have been chosen to be presented in this paper include PSLE questions, O-level Biology and A-level H2 Biology taken from ten year series (TYS) books. The TYS PSLE questions do not include the year in which the questions were set, thus the year is not cited for the questions presented. The O-level and A-level questions cited in the paper have been taken from examinations papers from the last ten years (2004-2013).
As the SPA practicals that are tested during the O-levels and A-levels are highly confidential in nature. The practicals that are covered in this paper refer to the experiments that are typically conducted in the science laboratories for practice and further understanding of the topics that are taught in the classrooms.

**Primary Science Syllabus**

The aims of the primary school science are many. They include stimulating interest and curiosity about the environment, learning basic scientific terms and concepts, developing skills, habits of mind and an attitude necessary for scientific inquiry, learning to use scientific knowledge and methods to make personal decisions and appreciating how science influences people and their environment.

The primary science syllabus comprises of five main themes, (a) diversity, (b) cycles, (c) systems, (d) interactions, and (e) energy. Plant science is covered in three out of the five themes in the upper primary science syllabus – cycles, systems, and energy. For each theme, the learning outcomes include three domains of knowledge, understanding and application, skills and processes, and ethics and attitudes.

Under the theme of Cycles, *plant reproduction* is covered. And under the domain of knowledge, understanding and application, students are expected to recognize the processes in the sexual reproduction of flowering plants, including pollination, fertilisation (seed production), seed dispersal and germination.
(Primary Science Syllabus, MOE CPDD, pg 21)

Under the theme of Systems, two main plant topics are covered - transport in plants and cell systems.

With regard to the topic on transport in plants, under knowledge, understanding and application, students are expected to be able to identify and state the function of the leaves, stems and roots of a plant; additionally they are also expected to identify and state the parts of the plant transport system (including phloem and xylem).

(Primary Science Syllabus, MOE CPDD, pg. 24)
With regard to topic of cell systems, students are expected to identify and state the different cell organelles (cell wall, chloroplast) that are found in a typical plant cell, and to state the differences between a typical plant and animal cell.

(Primary Science Syllabus, MOE CPDD, pg. 26)

Lastly, under the theme of Energy, the topic of photosynthesis is taught. Students are not expected to write out the equation of photosynthesis, however, they are expected to know the requirements of photosynthesis, and that it is a process that converts solar energy into chemical energy (sugar).
In summary for the primary school syllabus, the main topics covered under plant science education are cell systems in plants, reproduction in plants, transport in plants and nutrition in plants. At the primary school level, the requirements of the syllabus are not extremely specific and do not expect students to learn many facts or processes in great detail. Instead it gives room for the student to explore the various topics mostly by observing various phenomena related to the topic to ensure better learning and understanding.

Secondary Science Syllabus

Similar to the aims of the primary science syllabus, the secondary science syllabus also aims to develop students to further increase their knowledge with understanding; additionally secondary school students are also expected to able to learn how to handle and process information to solve problems and develop their experimental skills and investigations to a greater degree.

Unlike the five themes in the primary science syllabus, the secondary science syllabus (O-level pure Biology) comprises of four themes (a) principles of biology, (b) maintenance and regulation of life processes, (c) continuity of life, and (d) man and his environment; with 16 topics classified based on the four themes. Plant science can be found in three out of the four themes, with four topics in total covering some information on plants.

Under the theme of Principles of Biology, the topic of cell structure and organisation covers plant cells in greater depth – in addition to knowing organelles specific to typical plant cells, students are also expected to identify these organelles in SEM images. In primary school, students were expected to know the structure of typical plant cells, while secondary school O level biology students are also expected to know two examples of specialised plant
cells and how they are adapted to carry out their function – the root hair cell and xylem vessel.

1. **Cell Structure and Organisation**

**Content**
- Plant and Animal Cells
- Specialised Cells, Tissues and Organs

**Learning Outcomes**
Candidates should be able to:

(a) Identify cell structures (including organelles) of typical plant and animal cells from diagrams, photomicrographs and as seen under the light microscope using prepared slides and fresh material treated with an appropriate temporary staining technique:
- chloroplasts
- cell surface membrane
- cell wall
- cytoplasm
- cell vacuoles (large, sap-filled in plant cells, small, temporary in animal cells)
- nucleus

(b) Identify the following membrane systems and organelles from diagrams and electron micrographs:
- endoplasmic reticulum
- mitochondria
- Golgi body
- ribosomes

(c) State the functions of the membrane systems and organelles identified above

(d) Compare the structure of typical animal and plant cells

(e) State, in simple terms, the relationship between cell function and cell structure for the following:
- absorption – root hair cells
- conduction and support – xylem vessels
- transport of oxygen – red blood cells

(f) Differentiate cell, tissue, organ and organ system

*Use the knowledge gained in this section in new situations or to solve related problems.*

(O-level Biology Syllabus 5158, MOE CPDD, pg. 7)

There are two topics that fall under the theme of Maintenance and Regulation of Life Processes, *nutrition in plants* and *transport in plants*.

With regard to nutrition in plants, knowledge obtained from primary school science would include the various components required for photosynthesis – in O level biology, this prior
knowledge is further built upon, where students are expected to use these various components of photosynthesis and write down the equation for photosynthesis (both the word and chemical equation). Additionally, students are also expected to understand and explain the concept of limiting factors and describe how a particular factor may affect the rate of photosynthesis in a plant. Under this topic, students are also taught the structure and cross section of a dicotyledonous plant. For the O-levels, students are not expected to know details of the light dependent and light independent reactions of photosynthesis.

5. Nutrition in Plants

Content
- Leaf Structure
- Photosynthesis

Learning Outcomes
Candidates should be able to:

(a) identify and label the cellular and tissue structure of a dicotyledonous leaf, as seen in transverse section using the light microscope and describe the significance of these features in terms of their functions, such as the
- distribution of chloroplasts in photosynthesis
- stomata and mesophyll cells in gaseous exchange
- vascular bundles in transport

(b) state the equation, in words and symbols, for photosynthesis

(c) describe the intake of carbon dioxide and water by plants

(d) state that chlorophyll traps light energy and converts it into chemical energy for the formation of carbohydrates and their subsequent uses

(e) investigate and discuss the effects of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis (e.g. in submerged aquatic plant)

(f) discuss light intensity, carbon dioxide concentration and temperature as limiting factors on the rate of photosynthesis

Use the knowledge gained in this section in new situations or to solve related problems.

(O-level Biology Syllabus 5158, MOE CPDD, pg. 10)

Previously in primary school, students were taught to identify and state the function of leaves, stems and roots – building upon this, O-level students are expected to also be able to identify these plant organs based on cross sections diagrams or images provided. Further,
primary school students were only taught the function of the xylem and phloem; in addition to knowing the function, O-level students are expected to identify the positions of xylem and phloem tissue in various cross sections of different organs. The movement of various substances due to transpiration pull and translocation are also taught in detail.

6. Transport in Flowering Plants

Content
- Water and Ion Uptake
- Transpiration and Translocation

Learning Outcomes
Candidates should be able to:

(a) identify the positions and explain the functions of xylem vessels, phloem (sieve tube elements and companion cells) in sections of a herbaceous dicotyledonous leaf and stem, using the light microscope

(b) relate the structure and functions of root hairs to their surface area, and to water and ion uptake

(c) explain the movement of water between plant cells, and between them and the environment in terms of water potential. (Calculations on water potential are not required.)

(d) outline the pathway by which water is transported from the roots to the leaves through the xylem vessels

(e) define the term transpiration and explain that transpiration is a consequence of gaseous exchange in plants

(O-level Biology Syllabus 5158, MOE CPDD, pg. 10)

Lastly, under the theme of Continuity of Life, reproduction in plants is covered. Unlike the primary science syllabus, the O-level biology syllabus focuses largely on the structure of flowers, pollination and fertilisation (excluding details on formation of endosperm) – what is not included in the syllabus (unlike the one in primary science) is seed dispersal and germination of seeds. In this aspect, there are different foci for primary science and secondary science. The O-level syllabus stops abruptly once fertilisation takes place, and does not expect students to know details of embryo development, seed dispersal and germination. Adding on to the typical structure of flowers that is part of the primary science syllabus, O-
level biology students are now expected to differentiate flowers adapted for insect pollination and flowers adapted for wind pollination.

12. REPRODUCTION

Content
- Asexual Reproduction
- Sexual Reproduction in Plants
- Sexual Reproduction in Humans
- Sexually Transmitted Diseases

Learning Outcomes

Candidates should be able to:

(a) define asexual reproduction as the process resulting in the production of genetically identical offspring from one parent

(b) define sexual reproduction as the process involving the fusion of nuclei to form a zygote and the production of genetically dissimilar offspring

(c) identify and draw, using a hand lens if necessary, the sepals, petals, stamens and carpels of one, locally available, named, insect-pollinated, dicotyledonous flower, and examine the pollen grains under a microscope

(d) state the functions of the sepals, petals, anthers and carpels

(e) use a hand lens to identify and describe the stamens and stigmas of one, locally available, named, wind-pollinated flower, and examine the pollen grains using a microscope

(f) outline the process of pollination and distinguish between self-pollination and cross-pollination

(g) compare, using fresh specimens, an insect-pollinated and a wind-pollinated flower

(h) describe the growth of the pollen tube and its entry into the ovule followed by fertilisation (production of endosperm and details of development are not required)

(O-level Biology Syllabus 5158, MOE CPDD, pg. 13)

Junior College Science Syllabus

Unlike science in primary and secondary school, science education is not compulsory for all students. Similar to the O-level Biology syllabus, there is a strong focus on experimental work, and an even stronger focus on recent developments in biology. The focus of biology at A-levels is to learn about how life works at the cellular and molecular level, unlike O-level biology, where the focus is on how life works at the physiological level.
Biology at the Junior College level is offered at the H1 and H2 level, with the H2 level being more comprehensive, covering a larger number of topics in greater detail as compared to H1 biology. The syllabus discussed in this paper will cover the H2 syllabus. The H2 biology syllabus, unlike the primary and secondary syllabus, is not organised into different themes. Instead, the H2 syllabus simply comprises of seven core topics and two application topics. Out of a total of nine topics, plant education is only covered in two (core) topics, Cellular Functions and Cellular Physiology and Biochemistry.

The topic of plant cells is covered under Cellular Functions in the syllabus. The syllabus requirements of H2 biology are very similar to that of O-level biology. Students are studying the same organelles studied at O-levels in greater detail, and are now also expected to identify organelles based on Transmission Electron Microscope (TEM) images.

1 Cellular Functions

Content

- Detailed structure of typical animal and plant cells, as seen under the electron microscope

Learning Outcomes

Candidates should be able to:

(a) Describe and interpret drawings and photographs of typical animal and plant cells as seen under the electron microscope, recognising the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus. (Knowledge of the principles of TEM and SEM are not required.) (For practical assessment, students may be required to operate a light microscope, mount slides and use a graticule.)

(b) Outline the functions of the membrane systems and organelles listed in (a).

(A-level H2 Biology Syllabus 9648, MOE CPDD, pg. 12)

Nutrition in plants (photosynthesis) is covered under the topic of Cellular Physiology and Biochemistry. The topic of nutrition in plants is also part of the primary and secondary science syllabus. At the H2 level, students are now expected to learn about details of the light dependent and light independent reactions of photosynthesis – this was not covered
previously at the O-level syllabus. Similar to the O-level syllabus, students are expected to identify limiting factors of photosynthesis and explain how the factor affects the rate of photosynthesis. Unlike what was covered at the O-levels, students do not learn about the structure of the leaf.

4 Cellular Physiology and Biochemistry

Content

- Photosynthesis as an energy-trapping process

Learning Outcomes

Candidates should be able to:

(a) With reference to the chloroplast structure, explain the light dependent reactions of photosynthesis (no biochemical details are needed but will include the outline of cyclic and non-cyclic light dependent reactions and the transfer of energy for the subsequent manufacturing of carbohydrates from carbon dioxide).

(b) Outline the three phases of the Calvin cycle: (i) CO₂ uptake (ii) carbon reduction and (iii) ribulose bisphosphate (RuBP) regeneration and indicate the roles of ATP and NADP in the process.

(c) Discuss limiting factors in photosynthesis and carry out investigations on the effects of limiting factors, such as light intensity, CO₂ concentration and temperature, on the rate of photosynthesis.

(A-level H2 Biology Syllabus 9648, MOE CPDD, pg. 17)

Overview of Plant Science Education in Science Syllabus

After reviewing the primary, secondary and junior college science syllabus, it can be summarised that there are four main topics that are covered – plant cells, nutrition in plants, transport in plants and reproduction in plants. The four topics are organised quite well, with basic facts and knowledge taught at the primary school level, and later refined and delved deeper into at the secondary school level. At the junior college level, only plant cells and nutrition in plants are included in the syllabus – transport in plants and reproduction in plants are not included as they are not in line with the theme of studying how life works at the cellular and molecular level.
The next section of the paper covers how these plant topics are taught and tested traditionally in the classroom and during the national examinations, by reviewing a number of commonly used textbook sources and examination questions from ten-year series (TYS) books.

### How Plants Are Taught and Tested in Singapore Schools

In this section key diagrams or details are taken from commonly used textbooks to compare the amount of detail that is currently being taught at each academic level, questions from the national exams (PSLE, O-levels and A-levels) or various workbooks are also occasionally included to show the level of difficulty in the assessment of various concepts, and the various types of laboratory practicals that are used in classrooms to supplement what is being taught in theory are reviewed. Comparisons are organised according to the topics that are taught in order to compare the continuity of the facts that are being taught.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Primary PSLE Science</th>
<th>Secondary O-level Biology</th>
<th>Junior College H2 Biology</th>
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<tr>
<td>Plant cells</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Nutrition in Plants</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transport in Plants</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Reproduction in Plants</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
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Primary school science textbooks that are commonly used in schools are “i-Science” by Panpac education, and “My Pals are Here!” by Marshall Cavendish. One of the most popular textbook used by secondary schools for O-level biology is “Biology Matters” by Marshall Cavendish. As for Junior College biology, there is no fixed or popular textbook that is being
used for the topics that are related to plant science; instead university level Biology textbooks are used as references to supplement what is being taught in the classroom.

Various questions from the PSLE, O-level and A-level exams are also reviewed in this paper. The sources of these questions come from various TYS books that are published annually containing examination questions from the past 10 years of national exams. There are many different publishers that produce TYS books. Analysing questions from the national exams will give an indication of the difficulty level of the particular exam and what knowledge and information a student is expected to possess while taking the examination.

1. Plant Cells

Textbooks at the primary level

Students at the primary level are normally taught the organelles of the cell that can be viewed directly under the light microscope — cell membrane, cytoplasm and nucleus. Organelles that are specific to the plant cell are also taught — the cell wall and chloroplasts. Other organelles like the various membrane systems (golgi bodies, endoplasmic reticulum) that can only be seen under an electron microscope are not taught at the primary school level (Fig. 2).
Fig. 2. Plant cells taught in the i-Science textbook at Primary Five (Ho, 2004 pg. 26)

Textbooks at the O-level biology level

The diagram below is taken from the textbook “Biology Matters” on the topic of plant cells. In addition to the organelles that have been taught in primary school, students are expected to know organelles of the plant cell that can be observed under electron micrographs, including various membrane-bound organelles like the endoplasmic reticulum, golgi bodies and vesicles (Fig. 3 left). Additionally, the textbook also introduces specialised plant cells and tissues like the xylem vessel and root hair cell; descriptions are given on how the cells are structurally adapted to carry out their specific function, but no details are given on the developmental formation of the specialised cells in the plant (Fig. 3 right).

![Diagram of a plant cell](image1)

Fig. 3. Left: Diagram of a plant cell. Right: Specialised plant cells of xylem vessels and root hair cells. Both diagrams and tables from Lam & Lam (2007), with the left adapted from pg. 23 Fig. 2.16, and right adapted from pg. 25 Table 2.2.

Textbooks at the Junior College level
Organelles like the endoplasmic reticulum, golgi bodies and vesicles previously introduced at the secondary school level, where their basic functions were taught, are now covered more in detail – the function of how these organelles are related to protein synthesis are covered in greater detail. The structure of chloroplasts are also covered in greater detail – previously at O-levels, students identified chloroplasts simply as the organelles containing the green pigment chlorophyll, will now learn the various parts of the chloroplast (e.g. stroma, thylakoid, lamellae etc).

Assessment at the primary level

Students are generally tested on identifying and stating the basic function of simple organelles, and also tested on the basic differences between plant and animal cells. Generally questions on this topic are rather straight forward and do not require high amounts of analysis of data in the question given (Fig. 4).

(a) From the above information, identify the plant cell and the animal cell.

Plant cell: ____________________________
Animal cell: ____________________________

(b) A certain part of the plant cell is not found in the animal cell.
(i) Name this part: ____________________________

(ii) What is the function of this part? ____________________________

Where are cells X, Y and Z likely to be found?

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<th></th>
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<th>cell Y</th>
<th>cell Z</th>
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<td>leaf</td>
<td>root</td>
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<td>root</td>
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<tr>
<td>(4)</td>
<td>root</td>
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Fig. 4. PSLE questions on the topic of plant cells.
**Assessment at the secondary level**

The assessment of plant cells at the secondary school level is still relatively straightforward. Many examination questions still include the identifying and stating of the function of cell organelles, and also identifying and stating the differences between plant and animal cells. Additionally, questions on specialised plant cells are tested, and these questions are also usually straightforward (Fig. 5).

1. **The diagrams show two cells as seen using a light microscope.**
   - Which label is correct for both cells?
     - A. cell sap
     - B. chloroplast
     - C. cytoplasm
     - D. membrane

   Fig. 5. MCQ questions on plant cells are direct and require little analysis. Both questions obtained from O-level Biology Paper (left: 2009/P1/Q1, right: 2008/P1/Q1).

**Assessment at the junior college level**

As stated previously, greater detail and knowledge is required from students with regard to how protein synthesis is related to the various membrane organelles like the endoplasmic reticulum and golgi body. Students are also expected to be able to interpret images from electron microscopes (Fig. 6).
Practicals at the primary level

Depending on the primary school, some primary school students are taught how to use the light microscope, and would have examined a number of plant cells under the microscope, most typically that of the hydrilla or onion epidermal cell. However, in our experience, many of these students do not fully master the use of the light microscope and have to re-learn how to use it properly again in the secondary school. Students who undergo these practicals in primary school are usually just expected to identify the cell wall and the chloroplasts (if present) in the cell that is being examined.

Practicals at the secondary level

At the secondary level, students are usually taught how to use the light microscope during their lower secondary science classes, and again when they take Biology at the upper secondary level. The different parts and function of the parts of the microscope are taught to the students. Additionally, students typically learn how to prepare slides containing hydrilla...
cells or onion epithelial to be viewed under the microscope. Prepared slides of root, stem and leaf cross sections are occasionally given to students to view for them to practice learning how to focus and view cells at different magnifications.

Practicals at the junior college level

At the junior college level, it is assumed that students are able to competently use the light microscope and they are not taught how to use the light microscope. Instead of simply preparing and viewing the hydrilla or onion epidermal cells, students do practicals that involve more application. In order to study the function of cell membranes and their role in osmosis, students will prepare and view slides of onion epidermal cells that have been placed in solutions of different water potentials and study the changes in the structure of these cells.

2. Nutrition in Plants

Textbooks at the primary level

Students are introduced to the concept of photosynthesis and how plants "make food" by using various starting materials like carbon dioxide and water, with the aid of chlorophyll to capture the energy from sunlight. Students are also taught the importance of plants due to their ability to produce oxygen. The actual word equation is not taught to the students and they are not expected to write that out during their PSLE exams.
What is photosynthesis?

We need energy to move, think, play, watch television and even to blink our eyes. Where does this energy come from? It comes from the food we eat. Food provides us with energy.

How about plants? Do they need energy too? Why do they need energy?

Like all living things, plants need energy to carry out life processes like growing and breathing. Since plants do not eat, where does their energy come from?

I know plants get their energy from the soil, water, fertilizers and air.

Not! The soil, fertilizers, air and water do not provide plants with energy. They are not food for the plants.

Then what is food for the plants, Ptey? Where do they get their energy from?

The answer is sugar. Sugar is the food that provides plants with energy to carry out life processes.

How do plants obtain sugar?

Fig. 7. Photosynthesis being taught in the i-Science primary 5 textbook (Ho, 2004 pg. 132-133).

Textbook at the secondary level

Although details with regard to the light dependent and light independent reactions of photosynthesis are not part of the syllabus requirements. Biology textbooks still include a fair amount of information with regard to the topic. For the case of “Biology Matters” (Fig. 8 left image), in addition to showing the overall chemical equation of photosynthesis, the textbook also talks about the photolysis of water that occurs in the light dependent stage. And for the textbook “Biology Insights” (Fig. 8 right image), the textbook mentions the light dependent and light independent reactions and even has a diagrammatic image of the process. On the one hand, this is useful for the higher ability students as an introduction to the complex chemical reactions involved in photosynthesis; on the other hand, weaker students will struggle with these concepts when they study their textbooks and it may discourage them.
Fig. 8. The chemical reaction of photosynthesis being taught in two different O-level textbooks, where the light dependent and light independent stages are briefly mentioned; image on the left from Lam & Lam (2007) pg. 119, diagram on right from Tay (2007) pg. 81

Textbook at the junior college level

The typical Biology textbooks used at the university level cover photosynthesis of C₃, C₄ and CAM plants. However, at the junior college level, students are only expected to know the details of photosynthesis in C₃ plants. While most junior colleges will stick to teaching the details of C₃ plants, some of the more academically inclined junior colleges may also teach students photosynthesis details of C₄ and CAM plants.

Assessment at the primary level

Questions related to the topic of photosynthesis at the primary school level are surprisingly challenging. Students are expected to interpret graphs (Fig. 9. left image) to determine the
variable that is being investigated in the question. Questions of such difficulty can usually be found in the O-level science biology examination papers too. Although primary school students are not expected to be able to write down the equation of photosynthesis, they are still expected to know the various components of photosynthesis and are tested accordingly (Fig. 9. right image).

Assessment at the secondary level

At the secondary school level, questions related to photosynthesis are still relatively direct and do not require the students to know many details. As seen in the essay questions (Fig. 10), students are expected to know the general process of photosynthesis and the significance of photosynthesis. In addition to the details of photosynthesis, students are also expected to understand the cross section structure of a dicotyledonous leaf and are tested accordingly (Fig. 11).
Either  

(a) Describe the process of photosynthesis. 

(b) Explain why animals are dependent on photosynthesis. 

(c) Describe the effects of increasing light intensity on photosynthesis. 

[Total: 10]

Fig. 10. Essay question in the O-level exams testing on photosynthesis (2007/P2/Q8 either)

The diagram shows part of a cross-section of a leaf.

![Diagram of a leaf cross-section]

Which labelled structures convert light energy to chemical energy?

A 1 and 2
B 1 and 6
C 2 and 4
D 3 and 5

Fig. 11. O-level question testing on the cross-section structure of a dicotyledonous leaf (2009/P1/Q10)

Assessment at the junior college level

Unlike the O-level syllabus, A-level students are expected to know the details of the chemical reactions that occur during the light dependent and light independent reactions and are tested accordingly (Fig. 12 and Fig. 13). Comparing the difficulty level in assessment on the topic of photosynthesis, personally the questions tested at PSLE and at O-levels are relatively similar, and involve the interpretation of various experimental setups and do not require detailed knowledge of the actually process and reactions involved in photosynthesis. This is unlike what is expected at the junior college level, where students are not only expected to understand what has been taught previously at the O-levels, they are also expected to have highly detailed knowledge of the light and dark reactions of photosynthesis.
In a series of experiments, actively photosynthesising plants were supplied with labelled reactants.

1. Water containing $^{18}$O isotope
2. Carbon dioxide containing $^{14}$C isotope
3. Carbon dioxide containing $^{13}$C isotope

Where in the chloroplast would the products of photosynthesis from these reactants be formed?

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Fig. 12. MCQ question at A-levels testing on the location of the light dependent and light independent reactions in the plant cell.

9. (a) Outline the light dependent reactions of photosynthesis.  
(b) Explain the role of membranes in the chloroplast.  
(c) Describe the effect of increasing light intensity on the rate of photosynthesis.  

[Total: 20]

Fig. 13. Essay question at A-levels, which is similar to what is tested at O-levels except students are expected to know in greater detail of the light dependent reactions and the structure of the chloroplast.

**Practicals at the primary level**

The most common practical conducted in primary schools is the iodine-starch test on leaves that have been exposed to sunlight to show the presence of starch in leaves that have undergone photosynthesis. This reinforces the concept to students that the process of photosynthesis “makes food”, however wrongly gives the impression to students that starch is the end product of photosynthesis and not glucose. However, this misconception is corrected in secondary school when students study the world and chemical equation of photosynthesis.

**Practicals at the secondary level**
There are a wide range of practicals that can be conducted at the secondary school level to teach the concept of photosynthesis. These practicals range from conducting the iodine-starch test on a variegated leaf (to show that starch is only found in regions of the leaf that contains chlorophyll), to experimental setups testing if a particular factor (for example carbon dioxide) is required for the process for photosynthesis to occur, to studying how different facts (for example light intensity) can affect the rate of photosynthesis (by counting the number of oxygen bubbles produced in a hydrilla plant). Even so, many teachers do not conduct all the practicals due to time constrains trying to complete the O level syllabus. As the SPA practical exams are chosen by the school, teachers may not feel the need to conduct the full range of these practicals especially if they are not examined during the SPA practical exam.

**Practicals at the junior college level**

Practicals that potentially can be conducted at the junior college level are very similar to those that can be conducted at the secondary level. However, due to similar reasons as stated in the secondary level, not all of these practicals may be conducted by the teachers.

### 3. Transport in Plants

**Textbook at the secondary level**

The focus of the topic in textbooks is on the cross section of the leaves, stems and roots of dicotyledonous plants – where there is a strong emphasis on identifying the position and arrangement of vascular bundles (xylem and phloem) (Fig. 14 and Fig. 15).
Fig. 14. Biology matters covers the cross section of the dicotyledonous stem and root in the chapter of transport in plants (Lam & Lam, 2007 pg. 174-175), and the cross section of the dicotyledonous leaf under the chapter on nutrition in plants (Lam & Lam, 2007 pg. 129).

Fig. 15. Biology Insights covers the cross section of the root, stem and leaf in dicotyledonous plants under the chapter on transport in plants (Tay, 2007 pg. 227 Fig. 10.3)

Assessment at the primary level
Again, the level of difficulty at the primary school level examinations is surprisingly high. Although not stated specifically in the PSLE syllabus, students are tested on the positions of the xylem and phloem in plant stems during their examinations, through the analysis of a “ringing” experiment (Fig. 16). Students are also tested on the topic of transpiration, through the analysis of an experimental setup comparing the rates of absorption of different plants in different experimental setups (Fig. 16). Such questions can also be commonly found at O-level science biology and O-level biology examination papers.

Fig. 16. PSLE questions on the topic of transport in plants.

A similar question to the “ringing” experiment tested during the PSLE science exam was also found in the Biology Matters workbook (Fig. 17). Personally, we find such questions more suited at the secondary school level, and too challenging for primary school students.
5. Part of the branch in the diagram below has been ‘ringed'. What will happen to apple Y after some time?

A. Grows bigger  
B. Shrinks in size  
C. Remains the same  
D. Same size as apple X

Hint: ‘Ringing' removes phloem tissue. Recall how phloem tissue is involved in the transport of manufactured food to other parts of the plant.

Fig. 17. Ringing experiment questions are also found in upper secondary level workbooks.

Question is from Lam et al. (2007 pg. 76 Q5)

Assessment at the secondary level

As stated previously, the focus is on the cross section images of different organs of the plants, and being able to identify the position and the contents of the xylem and phloem tissues (Fig. 18).
Practicals at the primary level

The most common practical or demonstration done in class is to place celery stalks in coloured water to show the movement of water up the xylem stem. This allows students to identify the part of the celery stem that contains the xylem and also allows them to observe the process of transpiration which draws up water through the stem.

Practicals at the secondary level

Besides viewing prepared slides of the cross section of roots, stems and leaves of various plants under the microscope to identify the position of vascular bundles in the different plant organs, experiments related to transpiration using a potometer can be conducted. However,
these experiments are usually not done in the laboratory as the potometer is difficult to set up. Teachers usually end up teaching the theory of transpiration and talking about the functions of the potometer without the students actually observing it or taking measurements on it real life to study the different factors that may affect the rate of transpiration in plants.

4. Reproduction in Plants

Textbooks at the primary level

Students are taught the structure of a typical flower only – in fact the structure of the flower taught to the students is similar to that of an insect pollinated flower (Fig. 19). Textbooks only mention of pollination occurring through the aid of insects, and do not mention about wind pollinated flowers. Quite a fair bit of emphasis is placed on the different methods of seed dispersal in the textbooks (Fig. 20).

Fig. 19. The structure of a typical flower is taught in i-Science at primary 5. Diagram from Ho (2004, pg. 53)
Textbook at the secondary level

Unlike the primary school syllabus, students are taught the structure of a typical flower, and also the more specific structure of both insect pollinated and wind pollinated flowers (Fig. 21). Thus students are aware that insect pollination is not the only way in which pollination of flowers can occur. Additionally, students are also taught the process of fertilisation; however they are not expected to know details of the formation and development of the endosperm (Fig. 22). Information on what happens after fertilisation is not part of the O-level biology syllabus, and is only briefly touched upon in the textbook Biology Matters – no information is given with respect to how seed dispersal occurs or the process of the actual germination of the seed.
What happens after fertilisation:
The following changes take place after fertilisation:
• The ovule develops into the seed.
• The ovary develops into the fruit.
• The zygote develops into the embryo.
• When the seed germinates, the embryo will develop into the new plant.

Fig. 22. Details given on what happens after fertilisation is minimal as they are not part of the O-level syllabus. Textbook image from Lam & Lam (2007, pg. 309).

It appears rather strange that students are expected to know the process of fertilisation, yet are not expected to know about the endosperm. This makes the teaching of the process of double fertilisation in plants considered to be somewhat out of the suggested syllabus. If the growth of the pollen tube and its function to carry the two sperm cells to the ovule is discussed, it is impossible not to talk about double fertilisation that will occur, and the subsequent formation of both the zygote and the endosperm when the sperm cells fuse with different cells inside the ovule.

Additionally, information of the structure of the pollen grain is slightly confusing and incorrect in both Biology Matters (Fig. 23 left image) and Biology Insights (Fig. 23 right image). Both textbooks show the diagram of a pollen grain containing a generative nucleus and a pollen tube nucleus, but in actual fact it is a generative cell (and not a nucleus) found within the pollen grain.
Fig. 23. Both diagrams show the growth of the pollen tube before fertilisation takes place.
Left diagram from Lam & Lam (2007, pg. 309), right diagram from Tay (2007, pg. 31).

Assessment at the primary level

As there is a strong emphasis on seed dispersal, it is not surprising that the topic is tested during the PSLE exams. If students are familiar with the various seed dispersal methods that have been discussed in the textbooks, answering such questions in the exam should be relatively straightforward for them (Fig. 24 left). Students are also expected to be familiar with the structure of a typical flower and how pollination can occur, thus they are also tested accordingly during the examinations (Fig. 24 right).
Fig. 24. PSLE questions tested on the topic of reproduction in plants.

Assessment at the secondary level

Although seed dispersal is not part of the O-level syllabus, it has been tested before during the exams (Fig. 25 right image). Under such circumstances of testing, the clause in the syllabus states that students should be able to “use the knowledge gained in this section in new situations or to solve related problems”. As the topic of seed dispersal was covered in fairly deep detail in primary school, students who are able to assess their prior knowledge should be able to answer the question fairly easily. Typically questions relating to the structure of flowers are fairly straightforward (Fig. 25 left image), that will involve the labelling of the different parts of the flowers, and occasionally students will be asked to deduce if the structure of the flower given in the question is adapted for insect or wind pollination.
Fig. 25. Left: Typical O-level question testing students on the structure of a typical flower (2011/P2/Q7). Right: Application type of question with regards to seed dispersal tested at the O-levels (2006/P1/Q35)

**Practicals at the primary level**

In order to study the life cycle of plants, most primary school students have the opportunity to germinate various types of seeds (usually green beans or red beans) and observe the growth of the plant starting from a seed. Subsequently, students may learn about flowers by visiting the science garden in their school (if available) to study the different types and structures of plants. Finally, to study seed dispersal, there usually will be a practical that has an array of different types of fruits and their methods of seed dispersal can be observed and examined by the students.
Practicals at the secondary level

As the O-level syllabus focuses on the flower as the reproductive organ of the plant. Most of the practicals on plant reproductive revolve around examining different types of flowers. As students are expected to differentiate between wind and animal pollinated flowers, students are given specimens of flowers (usually a lily and another wind pollinated flower) to be examined so that they can identify the different parts of the flower and also have the pollen grains from the flowers removed to be examined under the microscope. As germination and fruit/seed dispersal is not part of the O-level syllabus, students do not do practicals involving these 2 concepts.

5. Additional Side Topics in Molecular Biology

Although not stated specifically in the syllabus, the textbook Biology Matters has a small section on transgenic plants (Fig. 26). There is no information regarding transgenic plants in the textbook Biology Insights. In Biology Matters, an example of a transgenic plant is given, however, no details on how the transformation of DNA into plant cells is discussed or mentioned. It would be helpful to briefly describe the use of agrobacterium in the process of plant cell transformation.

So far, no questions regarding the transformation of plant cells and how transgenic plants are produce have been tested in the O-levels.
Transferring foreign genes into plants

A gene may also be inserted into a crop plant which makes it resistant to herbicides. This allows weeds to be killed by herbicides without affecting the crop plant. The plant which has acquired the foreign gene is a transgenic plant.

Fig. 20.13 (Both these types of corn were exposed to insect pests. The normal corn was eaten. The genetically engineered corn shows little damage.)

For example, a weak solution of cyanamide kills weeds, but it also causes some damage to tobacco plants. A soil fungus, M. verrucaria, has a gene which produces an enzyme, cyanamide hydratase. This enzyme converts cyanamide to urea, which is harmless to tobacco plants. This gene can be inserted into the tobacco plant. This not only makes the plant resistant to the herbicide, but the urea formed also provides a source of nitrogen for plant growth.

Fig. 26. Creation of transgenic plants covered in Lam & Lam (2007, pg. 393).

Suggestions for Improvement

There are a number of concepts that tend to be presented in the textbooks in a confusing manner. With regards to the O-level syllabus for example, are xylem vessels considered specialised cells or specialised tissues? The syllabus describes them as xylem vessels, but the learning outcome is to be able to describe the relationship between cell function and cell structure. Similarly, in Biology Matters, the structure of the xylem vessel is categorised under cell structure. Thus is there a need to differentiated between a xylem cell, xylem tissue and xylem vessel?

Additionally, it is very common for a number of workbooks to test students on cell structure in the manner below, like what is done in the Biology Matters workbook. It is wrong to use a protozoa cell and ask students to attempt to classify it as either a plant or animal cell based on the present of certain organelles that are present in the protozoan.
Instead, students should be taught that not all cells can be classified into two categories (plant and animal cells) only as this is wrong and tends to perpetuate the misconception (Fig. 27).

The diagram below shows the structure of a water organism. The organism may be classified as

A. plant due to the presence of contractile vacuoles
B. plant due to the presence of an eyespot
C. plant due to the presence of chloroplasts
D. animal due to the presence of a nucleus

Fig. 27. Commonly asked question in various workbooks, which requires to students to classify a protozoa as an animal or plant cell based on the organelles found in the cell. Question from Lam et al. (2007, pg. 5 Q9).

In the primary and secondary syllabus, the focus of the vascular bundle arrangement seems to be that of dicotyledonous plants. Through the testing of the “ringing” experiments (in both PSLE and secondary school workbook questions), and the study of the cross-section of various plant organs, students are only taught the structure and arrange of vascular bundles of that of dicotyledonous plants. In Biology Matters, there is no mention of monocotyledonous plants and the arrangement of their vascular bundles in different organs at all. It may cause students to have the misconception that all flowering plants have the same arrangement of vascular bundles in all their organs as that of dicotyledonous plants only.

Both the primary and secondary syllabus also places a strong emphasis on flowering plants. With regard to the topic of reproduction in plants, students are only taught about how
flowering plants are able to reproduce. There is no mention in the textbooks at all about the lower non-flowering plants like the ferns, liverworts and mosses.

As stated previously, the formation of the endosperm is not required to be known in the secondary school syllabus; however students are expected to know that there are two sperm cells in the pollen tube, which makes it very hard to reconcile what the second sperm fuses with, if the endosperm is not brought into the picture.

**Continuity Issue**

Generally, there is good continuity between the plant science topics from primary school to secondary school to junior college. The four plant science topics that are covered in primary school are revisited again in secondary school but in greater detail. Out of the four plant science topics covered in secondary school, two of these topics are selected to be taught in greater detail in the A-level syllabus.

However, there are some minor gaps in continuity. Not all subtopics taught in plant reproduction in primary school are covered in secondary school – seed dispersal and germination are not covered. Obviously the topic of transport in plants and reproduction in plants are not covered at all in the junior college syllabus, thus students knowledge on these topics stops at the secondary school level.

**Concluding Remarks**

Plant science education, although is part of the syllabus for all academic levels in the science syllabus in Singapore, tends to make up only a small proportion of the whole syllabus. Topics that are covered also tend to be limited in scope, and tend to focus on flowering dicotyledonous plants.
In general, plant science topics are not as popular as animal science topics among both students and teachers. Students in general, tend to be uncomfortable and may occasionally show less interest in studying plant science as compared to the animal sciences, thus teachers may have more trouble trying to engage and interest students during their classes. Part of the lack of interest in students may stem from the fact that plants do not appear to "move" and perhaps tend to look very similar from their point of view, or even due to the fact that plants appear to be very different from humans and animals, thus giving them the false impression of plants being uninteresting or boring.

The current plant science syllabus in Singapore is generally geared towards teaching students about the various physiological ways in which plants function to survive, especially at the primary and secondary level. Unfortunately, most teachers are probably more confident in teaching animal science topics perhaps due to their own experiences as being unengaged during their plant science lessons as students, or even having less knowledge with regards to plants as compared to animals. Ultimately, it is important to create a syllabus that not only arouses the interest of the students, but is also representative of what plants are about; and if plant science education is taught properly to students, many would not feel so disinterested or unengaged during class.

References


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