Singapore Examinations and Assessment Board

Singapore–Cambridge Secondary Education Certificate (2027)

G3 Biotechnology (Syllabus K375)

CONTENTS

INTRODUCTION

Biotechnology is a multi-disciplinary science that engages knowledge in biology and technological applications to improve human lives and the environment. This syllabus allows students to develop a range of interests in biotechnology and provides the foundation for further studies in biotechnology and related fields.

Students will be introduced to the principles and applications of various areas of biotechnology. They will gain an understanding of gene technology, microbial biotechnology, animal cell culture and plant biotechnology. The subject will also encompass the applications of biotechnology in the fields of forensic science, medicine and the environment.

This subject is suitable for upper secondary school students with no prior knowledge in biotechnology.

AIMS

The aims are to:

1. equip students with fundamental knowledge in biotechnology to enable them to understand its applications,

2. provide experiential learning opportunities for students to conduct hands-on experiments, projects and research in the many areas of biotechnology, and

3. equip students with an understanding of recent advances in biotechnology and its ethical and social implications.

ASSESSMENT OBJECTIVES

A Knowledge with Understanding (30%)

Students should be able to demonstrate knowledge and understanding in relation to:

1. scientific phenomena, facts, laws, definitions, concepts, theories

2. scientific vocabulary, terminology, conventions (including symbols, quantities and units)

3. scientific instruments and apparatus used in biotechnology, including techniques of operation and aspects of safety

4. scientific quantities and their determination

5. biotechnological applications with their ethical, social and environmental implications.

The subject content defines the factual materials that candidates may be required to recall and explain. Questions testing the objectives above will often begin with one of the following words: *define, state, name, describe, explain* or *outline*. (See the *Glossary of Terms*)

B Handling Information and Solving Problems (40%)

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to:

1. locate, select, organise, and present information from a variety of sources
2. translate information from one form to another
3. manipulate numerical and other data
4. interpret, critique, analyse and evaluate data to solve problems
5. use information to identify patterns, report trends and draw inferences
6. present reasoned explanations for phenomena, patterns and relationships
7. make predictions and propose hypotheses
8. solve problems.

These *Assessment Objectives* cannot be precisely specified in the subject content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives may begin with one of the following words: *discuss*, *predict, suggest, calculate* or *determine*. (See the *Glossary of Terms*)

C Experimental Skills and Investigations (30%)

Students should able to:

1. follow a sequence of instructions
2. use techniques, apparatus and materials
3. make and record observations, measurements and estimates
4. interpret and evaluate observations and experimental results
5. plan investigations, select techniques, apparatus and materials
6. evaluate methods and suggest possible improvements.

Weighting Of Assessment Objectives

Theory Papers (Papers 1 and 2)

A Knowledge with Understanding, approximately **45%** of the marks.

B Handling Information and Solving Problems, approximately **55%** of the marks.

Structured Project (Paper 3)

C Experimental Skills and Investigations, **100%** of the marks.

USE OF CALCULATORS

An approved calculator may be used in all papers.

SCHEME OF ASSESSMENT

Candidates are required to enter for Papers 1, 2 and 3.

Paper	Type of Paper	Duration	Marks	Weighting
1	Multiple Choice	45 min	30	20%
2	Structured Questions	1 h 45 min	80	50%
3	Structured Project	15 h	100	30%

Paper 1

This written paper consists of 30 compulsory multiple choice questions with 4 options.

Paper 2

This paper consists of a variable number of structured questions. Candidates must answer all the questions.

Paper 3

This structured project is carried out over a period of 15 hours in Secondary 4. It comprises three interrelated components and assesses appropriate aspects of objectives C1 to C6.

a) The Project Plan (15 marks)
Candidates will have 3 hours to prepare their experimental plans and timeline in their logbooks.

b) Experimental Skills (45 marks)
Candidates will have 3 scheduled laboratory sessions to carry out their experiments and record their procedures in their logbooks.

c) Report (40 marks)
Candidates will report on the results, analyse their data, and evaluate the planning and design of their experiments.

(Refer to Appendix A for *Assessment Scheme for Structured Project*)

CONTENT STRUCTURE

The key areas are:

S/N	Scope
1.	Introduction to Cells and Biomolecules
2.	Gene Technology
3.	Microbial Biotechnology
4.	Animal Cell Culture
5.	Plant Biotechnology
6.	Biotechnology Applications

SUBJECT CONTENT

1. Introduction to Cells and Biomolecules

Content

- The Cell
- Biomolecules

Learning Outcomes

Candidates should be able to:

(a) identify bacteria as typical prokaryotic cells and state functions of their cellular structures: surface structures (flagella, pili, fimbriae), glycocalyx, cell wall, cell membrane, ribosomes, cytoplasm, plasmids, nucleoid and endospore

(b) identify cellular structures (including organelles) of plant and animal cells as typical eukaryotic cells and state their functions: cell membrane, cell wall, cytoplasm, cell vacuoles, nucleus, smooth and rough endoplasmic reticulum, mitochondria, chloroplasts, Golgi body and ribosomes

(c) compare the structures of typical bacteria, animal and plant cells

(d) describe the structures and properties of the following biomolecules: proteins, nucleic acids (DNA and RNA), carbohydrates and lipids

(e) explain how the structures and properties of the biomolecules identified above are related to their roles in living organisms

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

2. Gene Technology

Content

- DNA to RNA, RNA to Proteins
- Recombinant DNA Technology
- Genomics and Genome Projects

Learning Outcomes

Candidates should be able to:

(a) outline the relationships between DNA, genes, chromosomes and genome

(b) state the rule of complementary base pairing and outline its importance in the transfer of genetic information from
   i. DNA to DNA (semi-conservative replication)
   ii. DNA to RNA
   iii. RNA to proteins (names of enzymes are not required)

(c) describe sequence mutation from errors in DNA replication, leading to variation

(d) describe the use of plasmids in biotechnology:
   i. identify features of plasmids such as multiple cloning sites (MCS) containing specific recognition sites for restriction enzymes, origin of replication and selection markers (e.g. antibiotic resistance gene and the *lacZ* gene) and their use in cloning genes
   ii. production of recombinant cells with new traits (such as the production of recombinant proteins)

(e) outline the principles and process of cloning a recombinant DNA molecule:
   i. digestion of DNA and plasmid using restriction enzymes
   ii. ligation, transformation and selection of recombinant cells

(f) explain how DNA is amplified using polymerase chain reaction (PCR)

(g) explain how agarose gel electrophoresis is used to analyse DNA fragments

(h) outline the principles and process of purification of recombinant proteins using size- exclusion chromatography

(i) explain how polyacrylamide gel electrophoresis (SDS-PAGE) is used to analyse proteins

(j) use spectrophotometry to determine
   i. the quantity and quality of nucleic acids (DNA and RNA)
   ii. the quantity of proteins

(k) describe genome projects (e.g. the Human Genome Project), and their applications to disease diagnosis, personalised medicine and agriculture.

(l) discuss the social and ethical implications from applications of genome projects (e.g. the Human Genome Project)

(m) state the use of model organisms in understanding the human genome

(n) state the use of bioinformatics tools in the analysis of biological data (e.g. BLAST, Entrez, PDB, Genbank)

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

3. Microbial Biotechnology

Content

- Bacterial Growth
- Tests to Characterise Bacteria and Microbiological Procedures
- Applications of Microbial Biotechnology

Learning Outcomes

Candidates should be able to:

(a) describe the stages of the bacterial growth curve in culture

(b) classify bacteria based on
  i. morphology
  ii. nutrient requirements and nutritional types

(c) state the effect of the following environmental conditions on the growth of bacteria:
  i. temperature
  ii. pH
  iii. oxygen requirement

(d) outline the tests used to characterise bacteria:
  i. Gram stain
  ii. biochemical tests
  iii. antibiotics susceptibility tests

(e) state the effects of antibiotics (e.g. cell wall inhibitor, DNA and protein synthesis inhibitor, alteration of cell membrane) on bacteria

(f) outline and perform basic microbiological procedures:
  i. preparation of agar and broth cultures
  ii. serial dilution and determination of bacteria density
  iii. determination of culture purity

(g) discuss the applications of bacteria in
  i. food (e.g. fermentation, probiotics)
  ii. industry (e.g. production of enzymes)
  iii. agriculture (e.g. nitrogen fixation)

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

4. Animal Cell Culture

Content

- Types of Animal Cell Cultures
- Cell Culture Medium
- Growth and Maintenance of Cells in Culture

Learning Outcomes

Candidates should be able to:

(a) define the following in terms of *in vitro* culture of animal cells:
  i. primary cell culture
  ii. cell lines (adherent and suspension cell lines)
  iii. subculture

(b) state the uses of the following equipment and materials used in animal cell culture: biological safety cabinet, cell culture incubator, inverted microscope, haemocytometer, liquid nitrogen (for cryopreservation) and vessels for cell culture (e.g. Petri dish, flask, bioreactor)

(c) outline the functions of various components of the cell culture medium: water, amino acids, carbohydrates, serum, antibiotics, sodium bicarbonate and pH indicator (e.g. phenol red)

(d) perform calculations to prepare cell culture reagents using the concepts of
  i. molarity (moles of solute/litre of solution) and relative molecular mass of chemicals
  ii. percent concentration (%w/v, %v/v)
  iii. dilution of stock solutions
  iv. $C_1V_1 = C_2V_2$ where C refers to concentration of a solution and V refers to the volume

(e) describe the following cell culture techniques and procedures that are used in subculturing cells:
  i. trypsinisation
  ii. determination of cell density and viability
  iii. calculation of seeding density

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

5. Plant Biotechnology

Content

- Plant Tissue Culture
- Genetically Engineered Plants

Learning Outcomes

Candidates should be able to:

(a) explain the concept of cell totipotency and morphogenesis in plant tissue culture

(b) state the different types of plant tissue cultures and their applications

(c) outline the types of sterilisation techniques (e.g. autoclaving, filtration, gamma- irradiation and chemical sterilisation) and their uses

(d) describe the effects of the following on plant tissue cultures:
   i. culture conditions (e.g. light, temperature)
   ii. growth medium (e.g. macronutrients, micronutrients, carbon source, auxins, cytokinins)

(e) outline and perform the various stages of micropropagation of plants, including the preparation of media with different plant growth regulators

(f) outline the method of plant transformation using *Agrobacterium* with transferred DNA (T-DNA) from the tumour inducing (Ti) plasmid

(g) state the applications of plant genetic engineering and discuss ethical and social issues regarding genetically-modified crops with respect to
   i. crop improvement e.g. BT gene
   ii. enhanced nutritional quality
   iii. molecular farming

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

6. Biotechnology Applications

Content

- Molecular Diagnostics
- Transgenic Animals and their Applications
- Biologics
- Environmental Biotechnology

Learning Outcomes

Candidates should be able to:

(a) describe DNA profiling using short tandem repeats (STRs) in forensic science and paternity testing

(b) outline the applications of PCR in disease diagnostics

(c) describe the process of gene transfer into animal cells using microinjection

(d) list types of transgenic animals (mice, livestock and fish) and state their uses (understanding human diseases, production of pharmaceutical products and scientific research)

(e) define *biologics* as biological products synthesised by living organisms through biotechnology methods

(f) compare the production of biologics in bacteria and animal cells in terms of
  i. ease of production
  ii. functionality of the biologic (e.g. protein folding, post-translational modification)

(g) outline the production of biologics using
  i. recombinant bacteria
  ii. recombinant Chinese hamster ovary (CHO) cells

(h) describe bioremediation as the use of living organisms (microbes and plants) to alleviate environmental problems, including
  i. bacteria that digest oil
  ii. waste treatment through decomposition
  iii. plants that extract heavy metals from the environment

(i) outline the process of alcohol fermentation and describe its application in the production of biofuels

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

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

The following list illustrates the common symbols and units that will be used in Biotechnology and the question papers and is not meant to be exhaustive. Some of the units used, such as for volume and concentration, may differ from those used in Biology and Chemistry.

Quantity	***Symbol***	***Unit***
length	l	µm, mm, cm, m
area	*A*	cm^2, m^2
volume	*V*	µl, ml, L
mass	*m*	µg, mg, g, kg
concentration	*C*	µM, mM, M, %v/v, %w/v
time	*t*	s, min, h, d
pH	pH	-

GLOSSARY OF TERMS USED IN BIOTECHNOLOGY PAPERS

This glossary provides a description of the meanings of the terms which the candidates may encounter in the exam papers. It is to be used a guide and it is neither exhaustive nor definitive. Candidates should appreciate that the meaning of a term must depend in part on its context.

1. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.

2. *Comment* is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.

3. *Compare* requires candidates to provide both similarities and differences between things or concepts.

4. *Deduce* is used in a similar way as predict except that some supporting statement is required, e.g. reference to a law/principle, or the necessary reasoning is to be included in the answer.

5. *Define* (*the term(s)* …) is intended literally. Only a formal statement or equivalent paraphrase being required.

6. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.

7. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula e.g. relative molecular mass.

8. *Discuss* requires candidates to give a critical account of the points involved in the topic.

9. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about the points of principle and about the values of quantities not otherwise included in the question.

10. *Explain* may imply reasoning or some reference to theory, depending on the context.

11. *Find* is a general term that may be variously interpreted as calculate, measure, determine etc.

12. *List* requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should not be exceeded.

13. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or mass, using a balance.

14. *Outline* implies brevity, i.e. restricting the answer to giving essentials.

15. *Predict* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted from an early part of the question.

16. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value.

    In diagrams, sketch implies that a simple, freehand drawing is acceptable; nevertheless, care should be taken over proportions and the clear exposition of important details.

17. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained “by inspection”.

18. *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an ‘unknown’), or to imply that candidates are expected to apply their general knowledge to a ’novel‘ situation, one that may be formally ‘not in the syllabus’.

19. *What is meant by (the term(s) ...)* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in light of the indicated mark value.

Appendix A

ASSESSMENT SCHEME FOR STRUCTURED PROJECT

Project Plan			
Timeline	A clear timeline is shown, with experiments spread out over the project duration.	1	3
	Plan takes into account the time required for individual experiments and when the data will be collected.	1	
	Time is allocated for repeating experiments.	1	
Experimental plan / design	Appropriate tests are chosen to meet all project objectives	6	12
	Appropriate controls are included for each tests	4	
	Replicates are included	2	
Experimental Skills			
Logbook	Procedures / modifications to plan are recorded in the logbook	2	4
	Observations and results are recorded in the logbook	2	
Experimental skills	Experimental work is well organised and systematic	3	9
	Experiments are executed according to set procedures / protocols	5	
	Correct handling of equipment such as micropipettes, microscopes etc.	1	
Safety	Use of laboratory coat, gloves and personal protective equipment where appropriate (e.g. safety goggles)	1	2
	Appropriate disposal of waste (e.g. biohazard waste in autoclave bags, normal waste in appropriate waste container)	1	
Report			
	Observation of results, handling of data, evaluation and analysis of data, making inference	28	28
	Modification / evaluation / improvement of experiment	4	4
	Design of experiment (new scenario)	8	8