APPENDIX

Table 1.
The four types of research that may take place when computer science and biology come together (Bentley, 2002).

	Research Type	Initiator	Focus of Research	Significance of Research	Additional
1	Biology-driven Research	Biologist	Modelling or processing data of real biological systems	Mostly significant to biology but not computer science	Requires skills of a computer scientist or mathematician for accurate results
2	Computing-driven Research	Computer Scientist	Improve existing algorithms or create new ones	More significant to the field of computer science than biology	Biological knowledge of processes provided by Biologists aids the development of new computational techniques
3	Parallel Biology and Computing-driven Research	Either Biologist or Computer Scientist	Either started off as a Type 1 or 2 project before developing the two separate fields in parallel	Benefit both biology and computer science equally	Seen as a two in one project where the two fields are still developed distinctly on their own
	Combined Biology and Computer-driven Research	Digital Biologist*	Focus is embedded in both Type 1 and 2 projects which can produce interesting results otherwise impossible without the collaboration	Benefit both biology and computer science equally	Uncommon form of research and difficult to merge the two fields

Footnotes: A digital biologist is defined as an individual who has expertise in one field and knowledge in the other. For example, a biologist with expertise in computing or a computer scientist with biological knowledge.

Table 2.
Examples of efforts in incorporating computing or computational skills into pre-university curriculum in a sample of countries across the world.

Country	Description of Teaching Methods and Content	Context	Primary	Secondary
Australia (Falkner et al., 2014)	Focus on digital technologies to develop computational thinking skills, digital competence and programming knowledge	Recognised both as a subject of its own and integrated across subjects such as English, mathematics, science, humanities, arts, physical education nationally but implementation can differ across schools.	Compulsory	Compulsory
New Zealand (Bell et al., 2014)	Focus on programming and computer science as an independent subject	Progression with programming occurs across three years in secondary school, with an emphasis on learning text-based programming in the end.	Not mentioned	Elective
Sweden (Heintz et al., 2017)	Focus on digital competence and understanding of digital technology through programming	Integrated into mathematics, technology, and social sciences at national primary level to address computational thinking skills, programming skills and digital competence respectively, whereas programming is offered as an elective in secondary school.	Compulsory	Elective
Singapore (Kong et al., 2017; Seow et al., 2019)	Focus on programming to foster computational thinking skills	Leverages on programming electives to provide the opportunity for students to be interested at it and decision to offer the elective is dependent on schools' interest by opting in.	Elective	Elective
South Korea (So et al., 2020)	Focus on computer science principles and concepts	Standalone national curriculum named as informatics to cover digital literacy, computational thinking, and programming through textbooks.	Compulsory	Elective
Taiwan (So et al., 2020)	Focus on computational thinking skills	Integrated into national primary level through other subjects such as mathematics and exists as a standalone.	Compulsory	Compulsory

Table 3**.** Examples of current topics within Singapore Pre-University Biology curriculum that match with CT cornerstones and the bridge between them, to build towards the **Bio-CT** curriculum. (Continued on the next page).

Pre-University Bio-CT Topics	Goals and objectives in biological domain	Examples of bridging CT in the biological context	CT cornerstones covered
Cell Structures and Organelles	Interpret drawings or micrographs of cell structures and organelles (e.g. organelles such as centrioles or rough and smooth ER). Outline and describe the respective functions of cell structures and organelles.	Cells have hierarchical organization and compartmentalisation in the form of structures and organelles. This is akin to the modular organisation of a computer.	Decomposition Abstraction
Membranes and Transport	Understand fluid-mosaic model and the role of constituent biomolecules in cell membranes. Visualize and describe the different movement of molecules across membranes.	In trafficking, a molecule undergoes maturation step-by-step before it is released from the cell. Error checks exist. Likewise, a computer programme must also run sequentially, and error checks prevent an erroneous program from continuing to run.	Algorithms Logic
DNA Structure and Replication	Identify the different structures of DNA (helical, double-stranded, complementary base-pairing, correct bases) and the role of DNA/ RNA. Integrate these properties in understanding the process of DNA replication and its relevance to the end-replication problem.	DNA exist as Nature's hard drives. Each unit of information has a defined location. Similarly, computer drives can be copied and checks exist to ensure the integrity of the copying in both domains.	Abstraction Patterns Logic
Stem Cells	Recognise that a stem cell has infinite potential and can become any matured cell.	The capacity of a stem cell is akin to a computer with no software and no data. They can differentiate into any specialised cells with changes in their genetic expression. Such configuration differences can also be seen in computers that serve	Abstraction

		different functions. For example, a computer for gaming and one for office use are configured differently.	
Eukaryotic Gene Expression	Understanding how the information on DNA can be used to synthesise polypeptides (from transcription to translation).	The transcription machinery functions as a complex modular computer which needs to be self-assembled and transform one input into another. Throughout the process, error checks exist to counter any misincorporation event in an erroneous transcription. In addition, pattern recognition is also a critical aspect of how genes are recognised for initiating transcription.	Algorithm Logic Decomposition Patterns
Organisation of Eukaryotic Genomes	Identify the different portions on DNA such as coding and non-coding regions (introns, centromeres, telomeres, promoters, enhancers, and silencers).	The genome consists of all the genetic instructions necessary for an organism, with each having their own distinct roles and purpose. Likewise, each part of a computer has a defined design and location, and interactions of the parts define the function.	Decomposition Ab straction

Table 4
Examples of current topics within Singapore Pre-University Biology curriculum that match with CT cornerstones and the bridge between them, to build towards the Bio-CT curriculum.

Pre-University Bio-CT Topics	Goals and objectives in biological domain	Examples of bridging CT in the biological context	CT cornerstones covered
Control of Eukaryotic Gene Expression	Understand that prokaryotic gene expression is regulated by regulatory genes and simple operons (*lac* and *trp*) Understand that eukaryotic gene expression is regulated spatially and temporally at various levels (chromatin level, transcriptional, post-transcriptional, translational, post-translational levels). Differentiate between prokaryotic and eukaryotic gene expression.	Systems control is effectively a function of regulatory networks where there is sequence, and logical controls regulating one step to the next.	Abstraction Decompositio nLogic
Cell and Nuclear Division	Visualise and describe the main stages and events that occur during mitosis and meiosis. Identify the significance of mitotic and meiotic cell cycle. Describe the behaviour of chromosomes.	While computers do not "physically reproduce", coordinating the cloning and correct reproduction of data across different servers and computers is also complex and sequential.	Algorithms Logic Abstraction Decompositio n
Molecular Basis of Cancer	Describe the multi-step process in cancer development. Recognise the roles of mutations and other causative factors that increase chances of cancerous growth.	A cancer cell is akin to a computer whose BIOS has been corrupted and/or a virus has attacked. Such can cause information processing to be error prone. In a similar vein, replication in a biological system can also experience such fault, resulting in wrong instructions being generated. Additionally, cancer often	Abstraction Logic Decompositio nPatterns

	Understand and draw parallels to the mutations in p53 & ras genes with uncontrolled cell division and consequent cancer progression.	creates novel rewiring in genetic networks, and this can cause new modules of function. Some of these rewiring also creates interesting patterns of connectivity which are of interest for developing effective treatments.	
Genetics of Viruses	Describe the structure and organisation of viral genomes. Illustration the reproductive cycles of bacteriophages, enveloped viruses, and retroviruses. Understand how variation in viral genomes arises.	Viruses with RNA as their genetic material may be modelled in this topic as basic building blocks of bases A, G, C, U (abstraction). RNA folding is a complicated problem necessitating modular decomposition. Basic rules of base pairing may be translated into logical procedures (algorithms). Finding stable folded structures is an optimisation problem (algorithms, logic). Inferring functions from patterns and exceptions (patterns, logic) is the overarching biological problem.	Abstraction Logic Decompositio nPatterns Algorithms

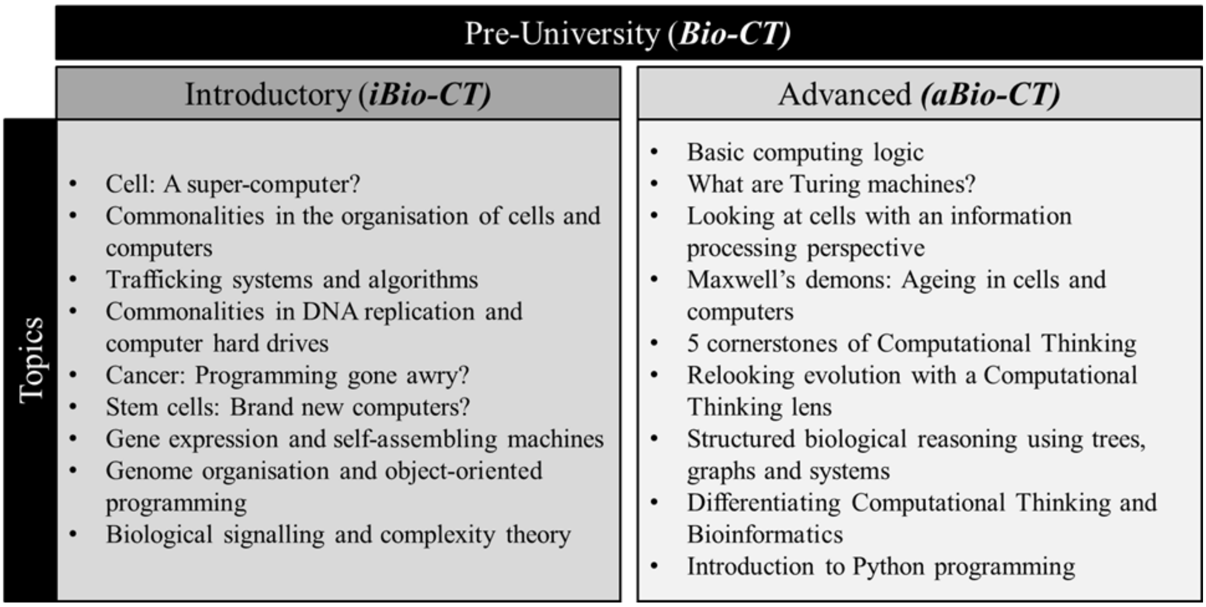

Figure 1. Proposed Pre-University Curriculum Topics within iBio-CT and aBio-CT