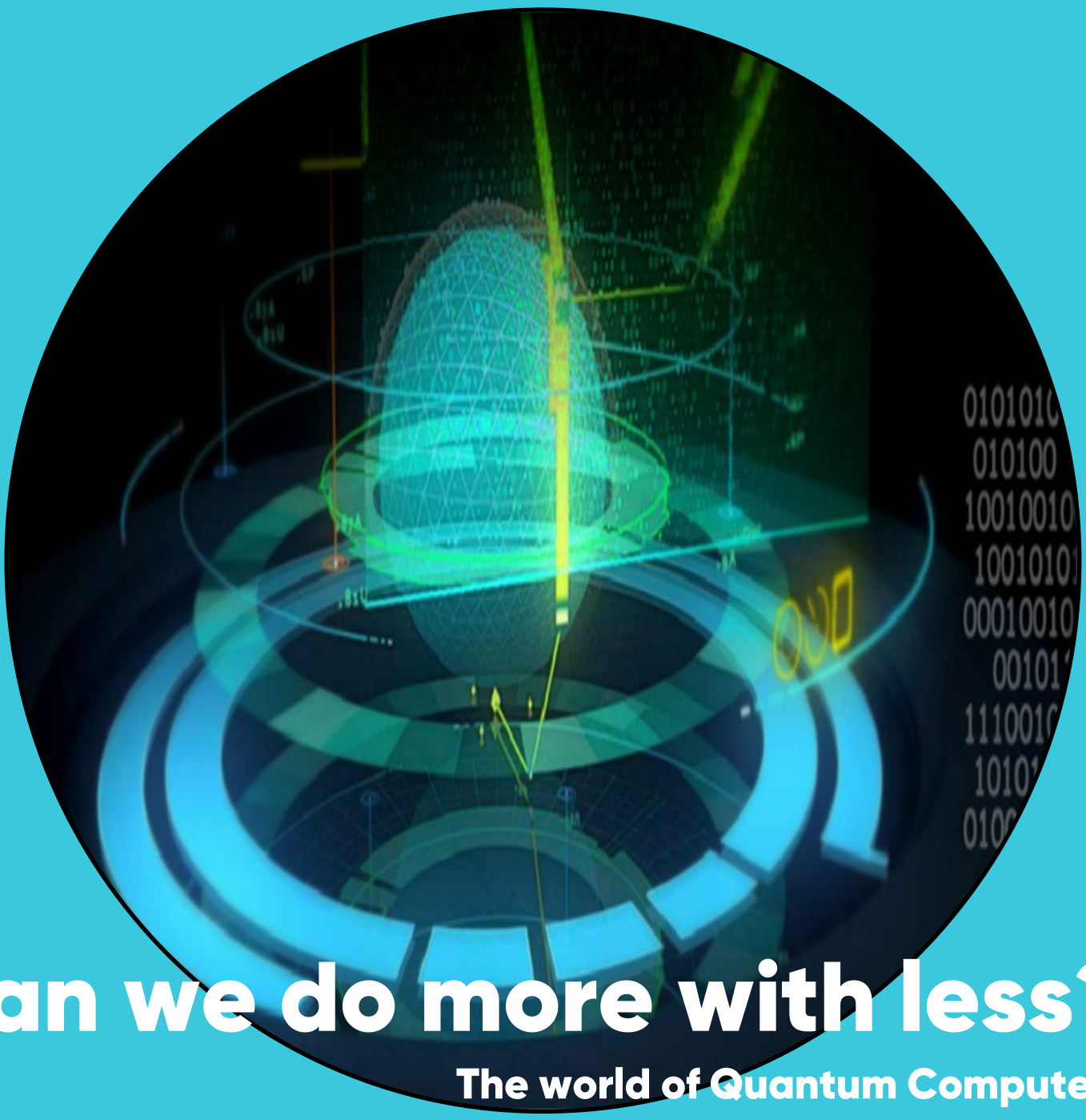

Can we do more with less?

The world of Quantum Computers

Key Stage 4 Programme

Pupil Name	Name
Handbook Designed by	Tominiyi Olupitan

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1			
2			
3			
4			
5			
6 (Feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1		
Tutorial 2		
Tutorial 3		
Tutorial 4		
Tutorial 5		

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 19 July	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

The Brilliant Club KS4 Programme – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at AS-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

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Course Rationale

The (classical) computers we use today have made tremendous impact in advancing almost every aspect of everyday life. As new technology surfaces, the computer technology is pushed further. Computers are made smaller, yet more powerful. The first-ever-made computer which can occupy a whole room will do much less than a recent smartphone. This has called for a new era of computing which perhaps could be built around tackling difficult problems that cannot be tackled by classical computers.

In this course, we will explore the world of quantum computing and discuss the motivation for the ongoing research in quantum computing, how it compares classical computers, the mathematics behind quantum computers and their diverse applications and mind boggling performances such as advanced drug development, enhanced encryption security e.t.c .

Students will learn some quantum computing concepts and its physical consequence, explore independent research and skills in poster presentations. Through these, students will be exposed to the university style tutorials and assessment.

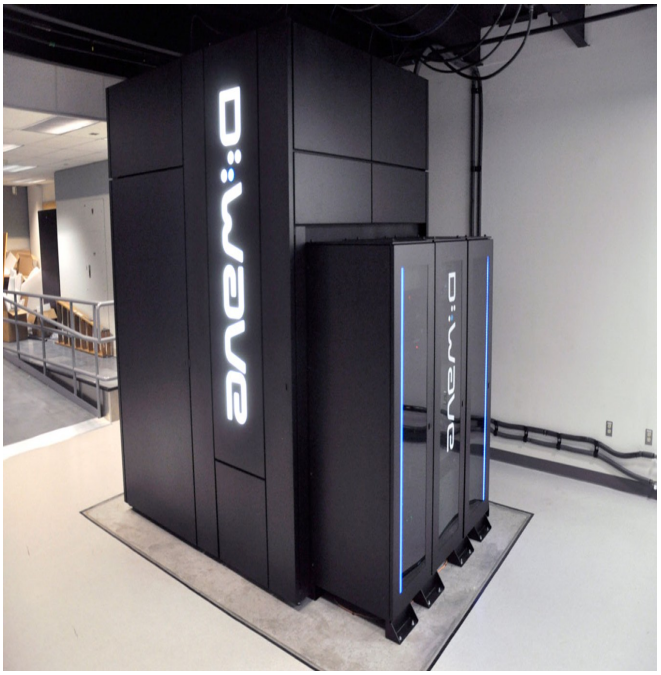


Figure 1: D-WAVE X2 Quantum computer

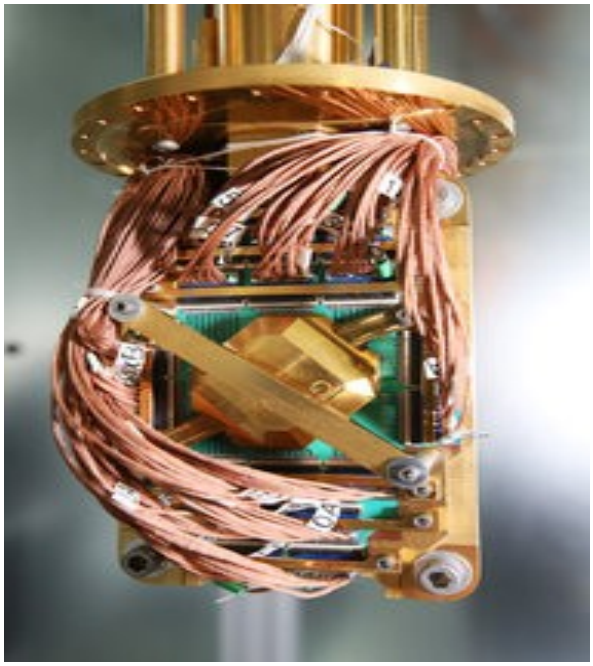


Figure 2. The processor of a quantum computer at D-Wave Systems' lab in Burnaby, British Columbia

Mark Scheme Table

	Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Subject knowledge	Knowledge and Understanding (Poster and essay)	• All content included is relevant to quantum computing and to the specific question • Good understanding of key concepts of quantum computing.. • Scientific terms are defined and used accurately throughout • Clear justification on how the content included is related to the specific issues that are the focus of the assignment. • Pupil's poster are informative and understandable to a	• Most of the content included is relevant to quantum computing and to the specific question. • Good understanding of the key concepts of quantum computing • Scientific terms are used accurately but not always clearly defined. • Adequate justification on how the content included is related to the specific issues that are the focus of the assignment. • Pupil's poster are informative and makes sense	• Some of the content included is relevant to quantum computing and to the specific question. • Good understanding on the key concepts of quantum computing but occasional confusion on others. • Scientific terms are used mostly accurately with occasional confusion and often not defined. • Some justification on how the content included is related to the specific issues that are the focus of the assignment
Critical Thinking	Research and Evidence	• Inclusion of rich sources of research findings, data, quotations or other sourced material beyond what was in the tutorial • Evidence of further reading beyond materials provided which were used in an appropriate context	• Inclusion of adequate sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas • Evidence of further reading beyond materials provided	• Inclusion of some sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas • Limited evidence of further reading beyond materials provided

Written Communication	Communication and Presentation (Poster and essay)	• Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment • The introduction clearly outlines how the essay/report will deal with the issues • The conclusion summarises all the main points clearly and concisely • Writing is well balanced with appropriate diagrams and pictures. • All sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment • The introduction adequately describes how the essay/report will deal with the issues • The conclusion summarises most of the main points clearly • Writing is well balanced with diagrams and pictures. • Most sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure • The introduction mentions how the essay/report will deal with the issues • The conclusion summarises some of the main points clearly • Poster not well structured, and clear to follow. • Some sources are referenced correctly in the agreed format with occasional errors
	Language and Style	• No spelling, grammar or punctuation errors • Units and significant figures are presented accurately throughout • Writing style consistently clear, appropriate for scientific documents and easy to follow • Accurate and consistent use of technical language and vocabulary	• Minimal spelling, grammar or punctuation errors • Units and significant figures are presented accurately throughout • Writing style mostly clear, appropriate for scientific documents and easy to follow • Some attempts of using technical language and vocab alary, but not always accurate	• Some spelling, grammar or punctuation errors • Units and significant figures are presented accurately throughout with occasional errors • Writing style moderately clear, appropriate for scientific documents and easy to follow • Use of simple language and vocabulary effectively but struggles to use

Glossary of Keywords

Word	Definition	In a sentence

Tutorial 1 – Why quantum computers?

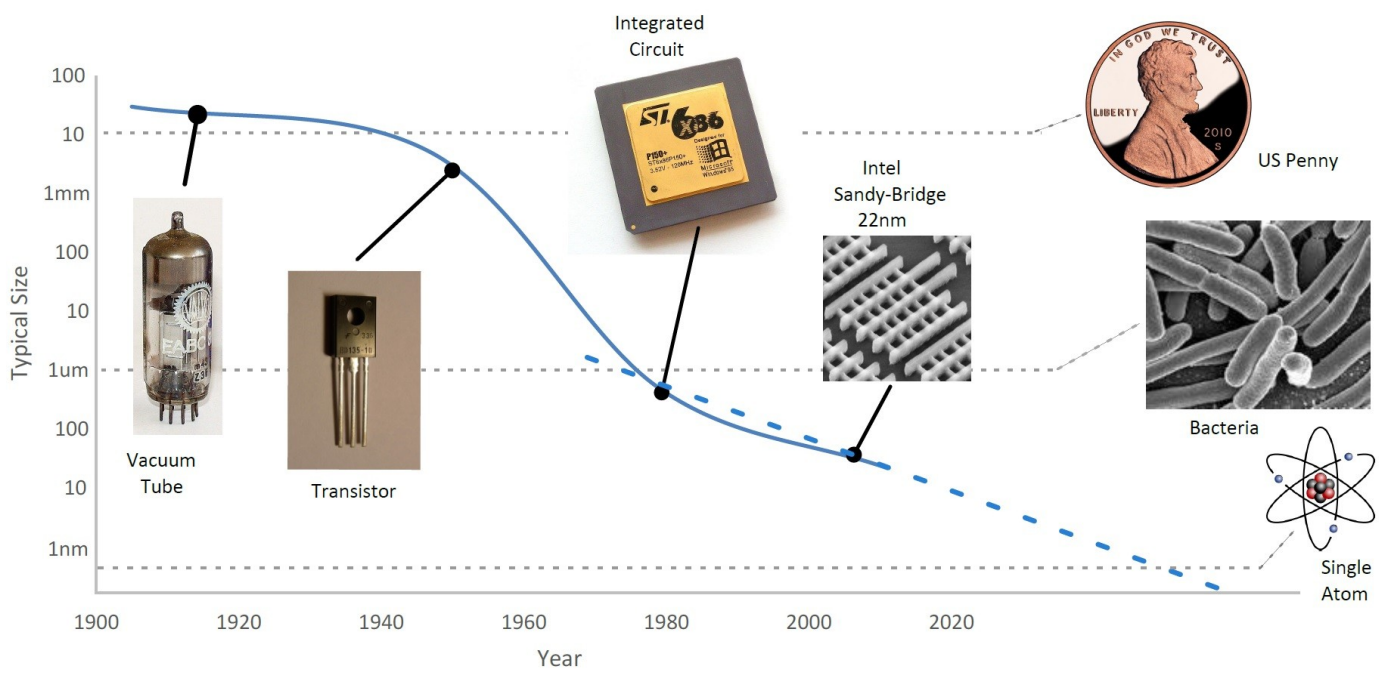
Fig 1.1 The travelling Salesman

Aims

- To understand the motivation for ongoing research in quantum computing
- To identify major differences between classical (modern day) computing and quantum computing.
- To learn how to research independently

Activity 1.1

From the graph below can you deduce how classical (modern day) computing evolved over the years?



Today's Homework

Research how classical computers compares to quantum computers.

In about 300 words, explain why we need quantum computers using what we learned in this tutorial and your own research.

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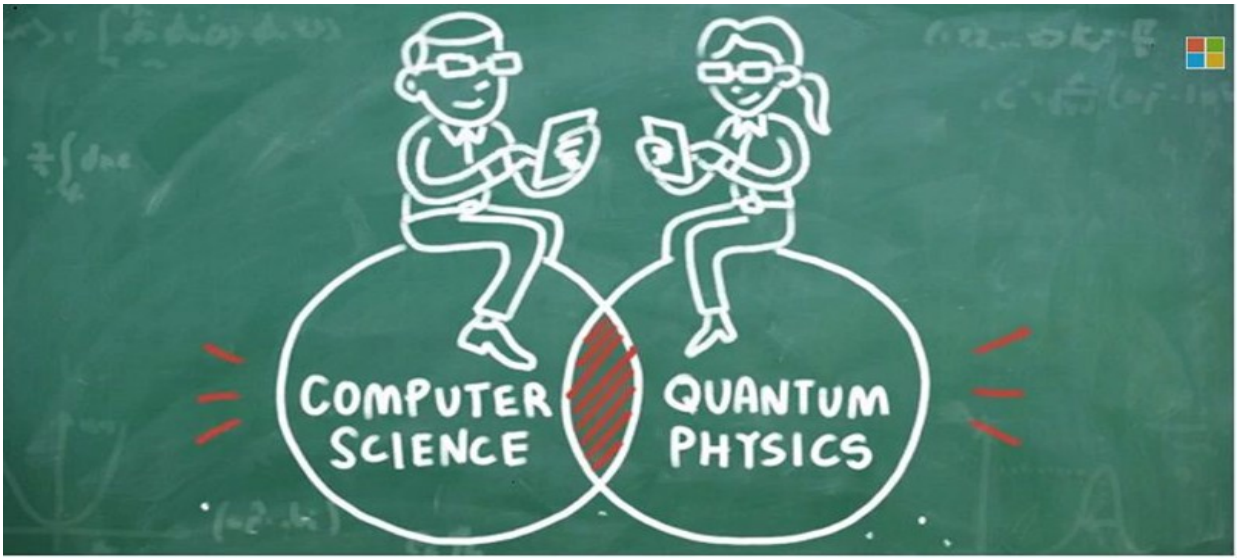
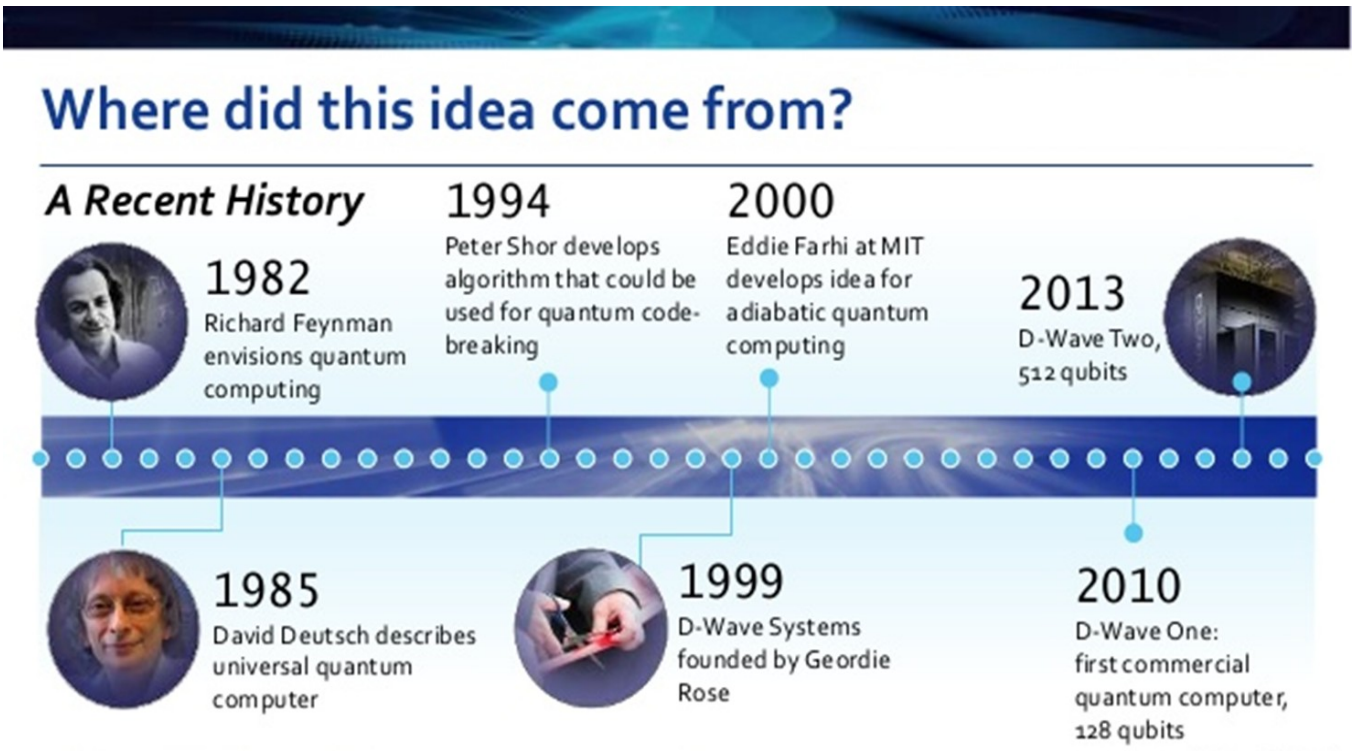
A quantum computer is a machine that performs calculations based on the laws of quantum mechanics.

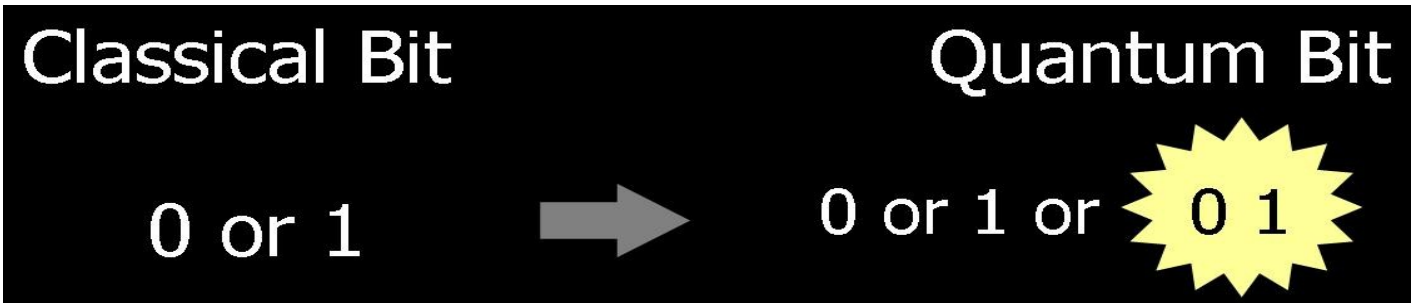




Tutorial 2– Computer Logic– Moving from bits to qubits

Activity 2.0

How do computers process information (integers, words, and graphics)?

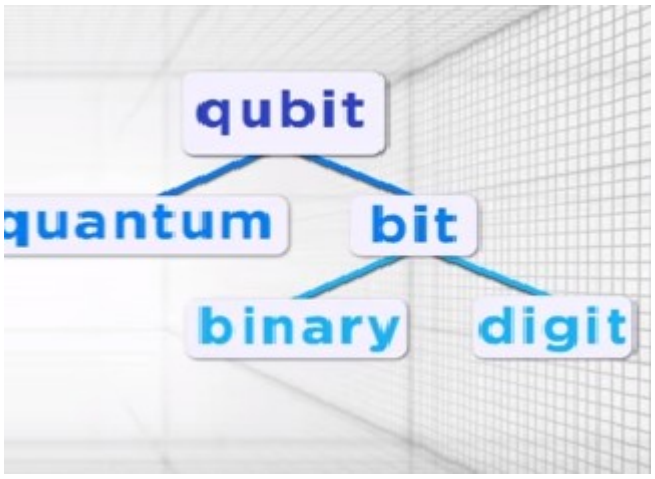


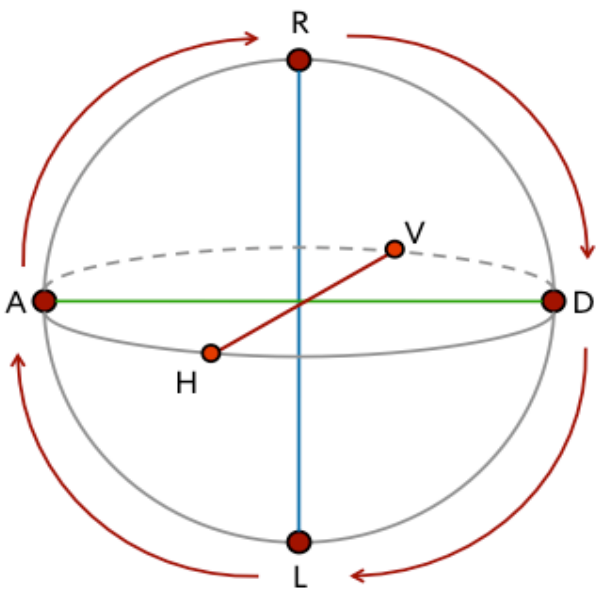
In Qubit format, 1 "qubit" or quantum bit can represent both 0 and 1 simultaneously.

Hence with 3 qubits of data, the quantum computer can store all the 8 possible combiinations of 0 and 1 simultaneously. As a result, 3 Qubit based quantum computer does calculations 8 times faster compared to 3-bit conventional computer.

To represent n quantum states requires 2^n classical bits

All single-qubit states can be represented as points on a sphere.

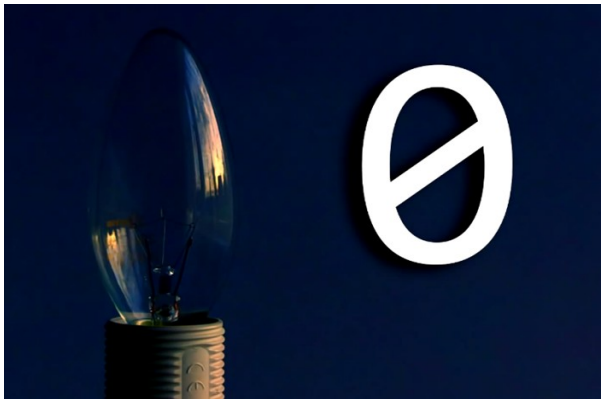




Important Summary of a qubit

- All single-qubit states correspond to a point on or inside a sphere.
- Every axis corresponds to a single quantum measurement, and every measurement changes the state of the qubit to match the result of the measurement.
- Qubits can be changed by rotating them around an axis.

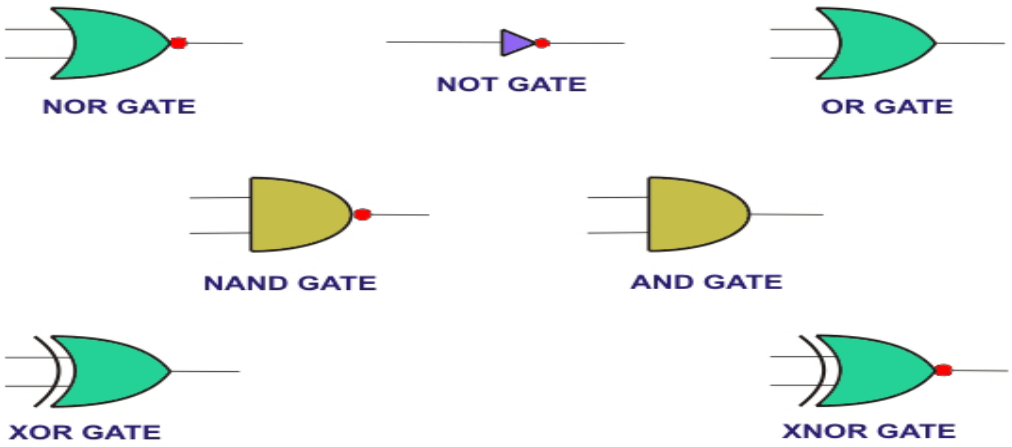
A classical computer performs operations using bits which can be either zero or one.



In contrast quantum computer uses quantum bits or qubits and they can be both zero and one at the same time .

Logic gates

Logic gates perform 'logical operation on one or more binary inputs (bits) and produces a single binary output. Combination of logic gates form a circuit. Electronic circuits are physical systems that lend themselves well to the representation of binary numbers (bits).



Logic gates are essential parts of all computer systems. They are electronic components of essential circuits used in processors, memory and almost all hardware components of a computer system.

Apart from the NOT gate, all gates take two wires as input and output a single wire. Each wire can either have current running through it (treated as a 1) or not (treated as a 0).

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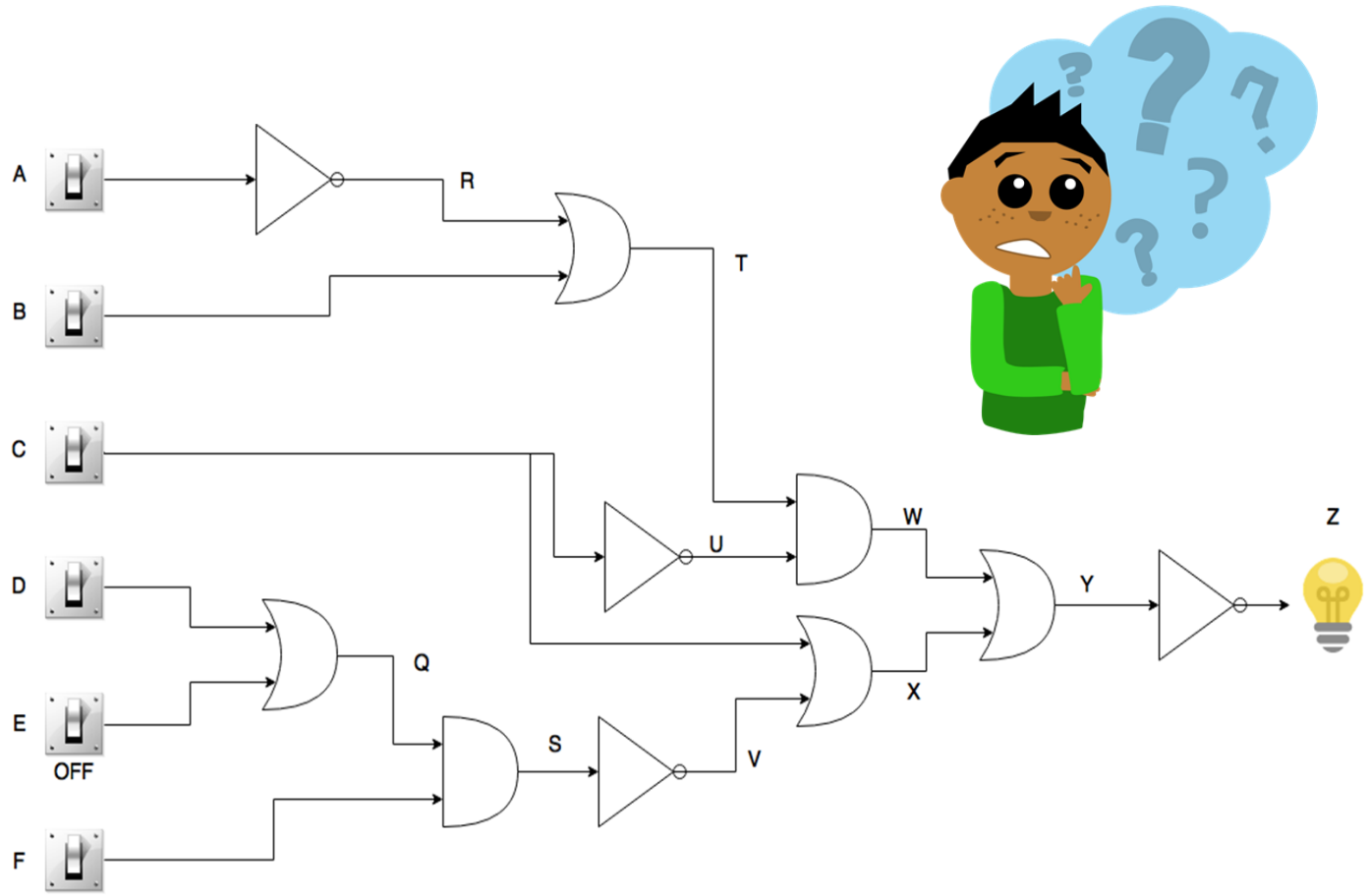
Activity 2.2

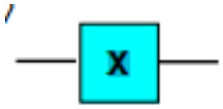
Frank has a problem... Someone has been messing around with all the light switches, and now he can't work out how to switch the light back on! When he asked Claire, the only switch she could remember was that switch E had to be OFF or the system would blow out. Help Frank to work out which light switches he needs to turn on to get the light working again!



Modern computers are built from networks of logic gates • Quantum computing uses logic gates in a similar way: networks of them are constructed to perform certain operations. There are many more possible quantum gates (infinitely many) and they must all be reversible.

Examples of Quantum Gates

One-Input gate: NOT

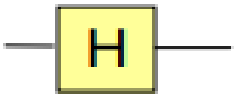


Inputs (which are states |0 > and |1 >) are mapped thus:

0 → 1

1 → 0

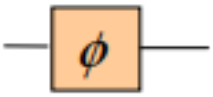
Hadamard Gate :



Takes classical states 0 and 1 halfway between 0 and 1

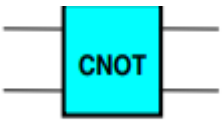
> Maps $|0\rangle \rightarrow 1/\sqrt{2}\,|0\rangle + 1/\sqrt{2}\,|1\rangle$ and $|1\rangle \rightarrow 1/\sqrt{2}\,|0\rangle - 1/\sqrt{2}\,|1\rangle$ so it "randomizes" the basic states

Phase-Shift Gate



Maps $|0\rangle \rightarrow |0\rangle$ and $|1\rangle \rightarrow e^{i\phi}|1\rangle$ so it "twists" the 1 state by an angle ϕ

Two-input gate: Controlled Not—CNOT



Three basic quantum gates used in quantum computation

- The NOT gate
- The Controlled Not (CNOT)
- The TOFFOLLI gate .

The CNOT gate is a two-qubit gate, where the value of the first qubit (called control) determines what happens to the second qubit called (target). So if the first qubit is 1, we apply the NOT gate to the second gate or otherwise nothing happens to it.

The TOFFOLI gate can also be seen as the Controlled NOT .

This is a three qubit gate, where by the target qubit undergoes the NOT operation only when the two controls are in state 1

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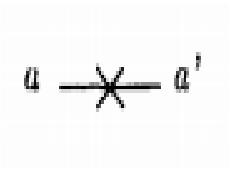
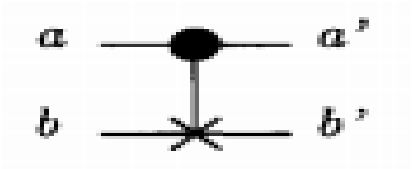
Homework

Complete the truth table below. Use the NOT gate for (i), the CNOT gate for (ii) and the TOFFOLI gate for (iii).

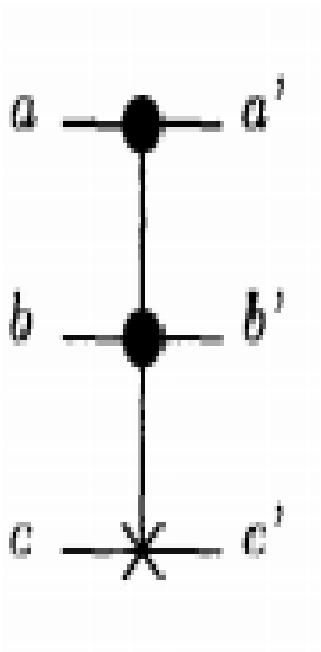
Note: the control qubit is represented by 'dot' and the target qubit by 'cross'



a	a'
0	
1	

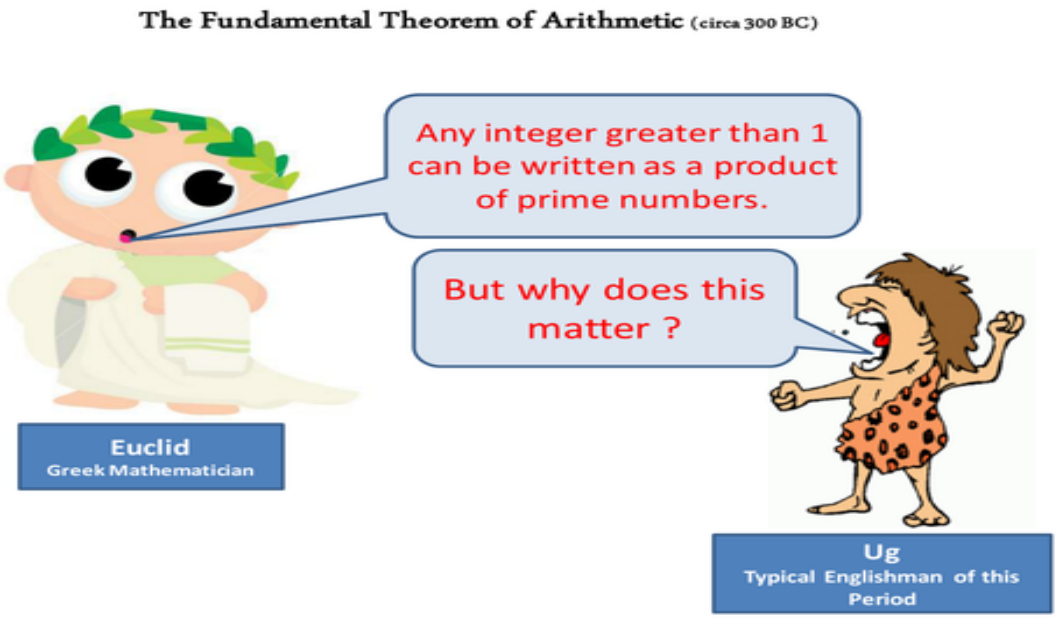


a b	a ' b'
0 0	
0 1	
1 0	
1 1	



a	b	c	a'	b'	c'
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

Tutorial 3 – Quantum Arithmetic



What is the Purpose of Tutorial 3?

- To explain why prime numbers are important
- How to calculate a number in modular arithmetic
- Use the idea of prime numbers in key exchange/cryptography

Prime numbers are the building blocks of numbers. Every number can be factored into its primes

$$N = p_1 \times p_2$$

It is this process that is used every single time you use your credit card online, all banking and internet security is reliant on using prime numbers.

Note that factoring a number is relatively hard compared to multiplying the factors together to generate the number.

The prime factorisation of a number n is when its written as a product of primes

E.g. 91 is 7x13 ;

3600 is $2^4 \times 3^2 \times 5^2$

Activity 3

Your task is to decipher the message, using your knowledge of prime factorization .
The prime factors relate to letters that jumbled to make a very bad maths joke!

Each letter of the code is represented by a prime number as shown below.

The code is:

a = 17	h = 23	s = 43
b = 11	i = 31	t = 5
c = 13	l = 29	w = 2
d = 3	n = 41	y = 37
e = 7	o = 19	

The message reads:

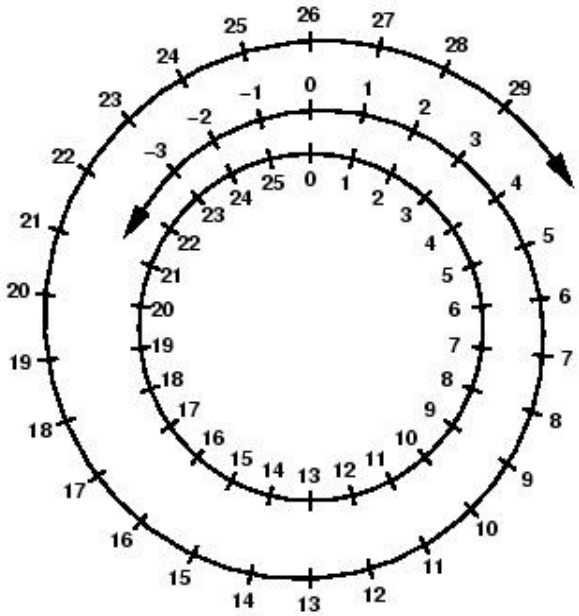
3910 17157 805 **0** 27047 95 805 **8**?

115661 11165

The bold numbers are left as numbers in the final message

Modular Arithmetic

This is basically doing addition (and other operations) not on a line, as you usually do, but on a circle; the values wrap around, always staying less than a fixed number call the modulus



0 mod 7=0

1 mod 7=1

2 mod 7=2

3 mod 7=3

4 mod 7=4

5 mod 7=5

6 mod 7=6

7 mod 7=0

8 mod 7=1

9 mod 7=2

10 mod 7=3

Modular Exponentiation

Suppose we are asked to compute $3^8 \bmod 7$

It will be a lot of work to naively perform seven multiplications and one huge modular reduction. Instead we can perform three smaller multiplications and three smaller reductions.

$((3^2 \bmod 7)^2 \bmod 7)^2 \bmod 7$ will be $(2^2 \bmod 7)^2 \bmod 7$

This reduces to 16 mod 7 which is 2..

This kind of arithmetic is ideal for computers as it restricts the range of all intermediate results

Activity

Please reduce the numbers in modular arithmetic

1. $18 \equiv \quad \pmod{12}$
2. $37 \equiv \quad \pmod{12}$
3. $40 \equiv \quad \pmod{5}$
4. $189 \equiv \quad \pmod{17}$
5. $352 \equiv \quad \pmod{3}$

Reduce the following in modular 12 arithmetic (Note all answers must be between 0 and 11)

1. $-2 \equiv \quad \pmod{12}$
2. $-19 \equiv \quad \pmod{12}$
3. $-5 \equiv \quad \pmod{12}$
4. $-11 \equiv \quad \pmod{12}$
5. $-8 \equiv \quad \pmod{12}$

Compute the following

1. $3^6 \bmod 9$
2. $5^4 \bmod 7$
3. $7^8 \bmod 3$

HOME WORK

1. Work out what the following numbers are congruent to when working in modulo 5.

16	21	18	441	444	325	651	235	901	999

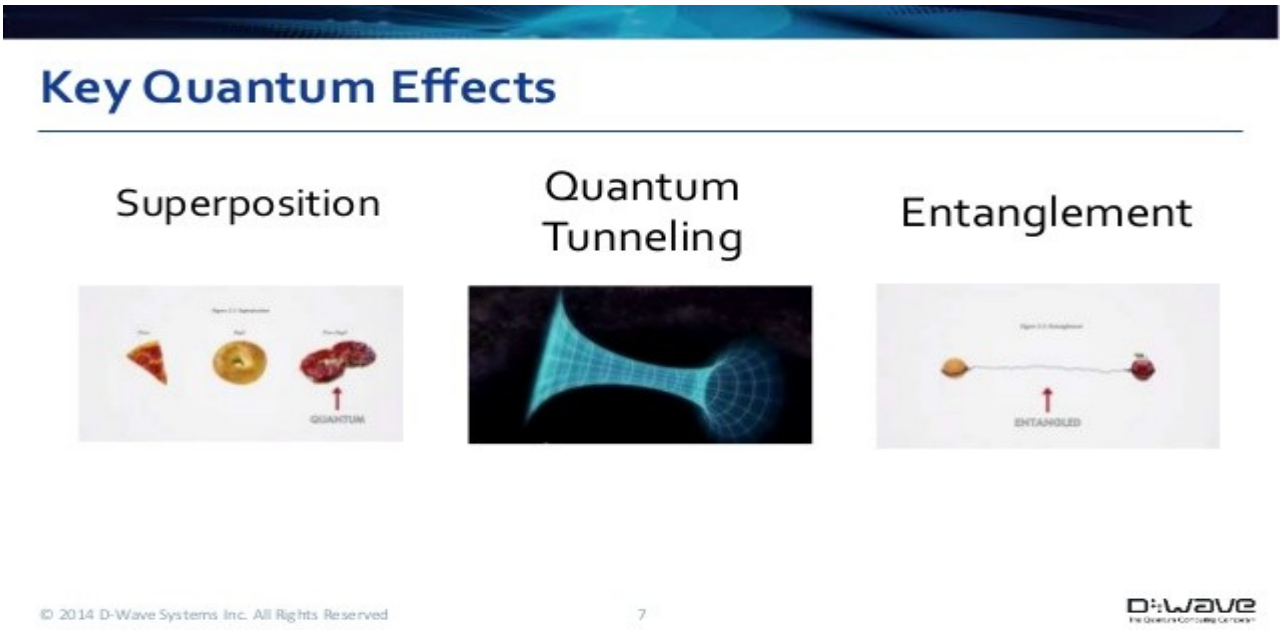
2. Work out what the following numbers are congruent to when working in modulo 7.

15	65	81	73	14	21	34	30	19	88

3. Calculate 9^{13} mod 11 by first evaluating:

$9^1 \bmod 11$	$9^2 \bmod 11$	$9^4 \bmod 11$	$9^8 \bmod 11$

Tutorial 4 – Quantum rules



What is the Purpose of Tutorial 4?

To understand the following key concepts;

Superposition, Entanglement, No cloning and observational dependency.

Activity

Using the link http://qcraft.org/about/

Watch the qcraft game tutorial and write down and explain the quantum rules for the game.

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Homework 4

Reflect on how the key concepts of quantum computing will inform the motivation for research in quantum computing discussed in tutorial one.

Research other examples or use an example used in today's tutorial.

Tutorial 5 – Applications of quantum computing

Labeling images

Extracting meaning from news stories

Detecting and tracking objects in images

Finding correlations in bioinformatic data

Improving natural language in machines

Creating and testing scientific hypotheses

Key questions

What is Grover's algorithm and Shor's algorithm?

What are the consequences of these two algorithms?

What is the Purpose of Tutorial 5?

Recap the importance of quantum computing research

Introduce the Grover's algorithm and Shor's algorithm

Areas that may be revolutionized by quantum computing

How to design an effective poster presentation

Homework 5

Create a draft of your poster on the question 'will quantum computers change everything?'

Final Assignment

The final assignment will be composed of two parts; an essay and a poster presentation . You should communicate your ideas clearly . Please check the marking scheme for more details on how you will be evaluated.

Part one

Write an essay on the question 'Will quantum computers change everything?'

The essay must show your knowledge on the following;

- Ongoing research in quantum computing
- The major concepts/rules behind quantum computing
- How the rules will influence modern day computing
- An area/technology that may be influenced by quantum computing

Part two

Prepare a poster presentation on the above topic.

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

My target for future work is…

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?

What did you find challenging about the programme?	How did you overcome these challenges?

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment:** After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].

2. **Bibliography:** This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

Websites – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

Books – Author, date published, title of book (in italics), pages where the information came from.

E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

Articles – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2 – Using the VLE

VLE username	
VLE password	

Please remember the following key details:

You are able log into the VLE either through the link on our website (www.thebrilliantclub.org) or going directly to the VLE site at (https://portal.thebrilliantclub.org/sign-in).

- Please update your profile with your full name and email address- this will allow you to retrieve forgotten passwords or usernames

If you forget your log-in details you can request them to be emailed to you by clicking the link on the VLE home page. (If you are still having problems you can email: schools@thebrilliantclub.org)

What is the VLE?

The VLE is a virtual learning environment for all pupils on Uni Pathways it is used for:

messaging your tutor

submitting homework

submitting your final assignment

accessing resources for your tutorials

finding out more information about university and careers

How should I use the VLE?

The VLE is a professional academic environment in which pupils are able to message their PhD Tutor. Here are a few things to consider:

Ensure you keep a professional tone in the messages you send to your tutors.

Ensure you always reply to your tutors in a timely manner.

Thank your tutor for the effort they are putting in to give you your feedback etc.

Submit all homework to your tutor on time.

IMPORTANT: Final assignment

- When you submit your final assignment, please remember that you need to do so through the 'My Activities' tab and not as an attachment to a message.

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