1958
Integrated Circuits

Learning Outcomes addressed in this section are listed below.

1.2	explain how the power of computing enables different solutions to difficult problems
1.13	identify important computing developments that have taken place in the last 100 years and consider emerging trends that could shape future computing technologies
1.14	explain when and what machine learning and AI algorithms might be used in certain contexts
1.18	recognise the diverse roles and careers that use computing technologies
2.3	implement modular design to develop hardware or software modules that perform a specific function
2.4	illustrate examples of abstract models
2.11	describe the different components within a computer and the function of those components

When other Learning Outcomes are addressed, for instance in classroom activities or through related online resources, the LO is numbered.

The invention of the first programmable, electric computers (Z1, ENIAC and Colossus), it could be argued, was the first time that high level human thought processes were offloaded to machines which could execute these processes both quicker and better. These computing machines provided proof of concept that computers could revolutionise the way humans think about solving problems. For the first time in human history, the question could now be posed – **How do I go about solving a particular problem, knowing I have the additional processing power of a computer at my disposal?**

After World War II, the invention of the solid state transistor almost immediately supplanted the unreliable vacuum tubes used in the first computers. In addition to predictable and reliable behaviour, they opened the floodgates of semiconductor design. No longer would an entire room be required to house all the distinct, discrete components of a computer. Suddenly the possibility of a completely functioning circuit, comprised of many electronic components on a single semiconducting platform, was a real possibility.

Integrated Circuits (IC) were invented in 1958 by electrical engineers Jack Kilby (Texas Instruments) and Robert Noyce (Fairchild Semiconductor). Like many inventions and ideas that have changed our world, their inventions were independently discovered. The drive behind the development of IC was very simple: how can we squeeze more components into a smaller space, at reduced cost and operating at faster speeds? The answer lay in the properties of semi-conducting elements such as Germanium and Silicon. Normally they behave as insulators, in the sense they do not conduct electricity. However using a chemical process known as doping, these substrates can become both conductors and insulators, depending on the conditions applied. There are only two types of doping: n-type doping makes the substrate richer in electrons and p-type doping makes the substrate depleted of electrons. When n-type and p-type are joined together, and a certain voltages applied across the junction where they are joined, the basic ingredients of all micro-electronic semi-conducting devices can be assembled into diodes, transistors, logic gates, memory and microprocessor systems.

Kilby eventually received the Nobel Prize in 2000 for his work, where he acknowledged the now deceased Noyce as his co-inventor. Noyce founded the Intel Corporation with Gordon Moore in 1968. They released the first microchip computer or microprocessor in 1974, paving the way for the first modern Personal Computers.

"Thinking like a computer scientist means more than being able to program a computer. It requires thinking at multiple levels of abstraction." [9]

The above quote is from Jeanette Wing's highly influential paper on Computational Thinking. Using TPSS, discuss the origins of Computational Thinking in the context of the evolution of computers.

LO 1.2

1. A fast-talking technical overview of the development of IC and how Moore's Law might be re-imagined.

2. An animated overview of the limits of IC technology and the potential of Quantum Computing.

In the section on the Turing Machine, the explosion in AI was attributed to Data, Algorithms and Processing Power.

Would you agree with this hypothesis?

LO 1.13

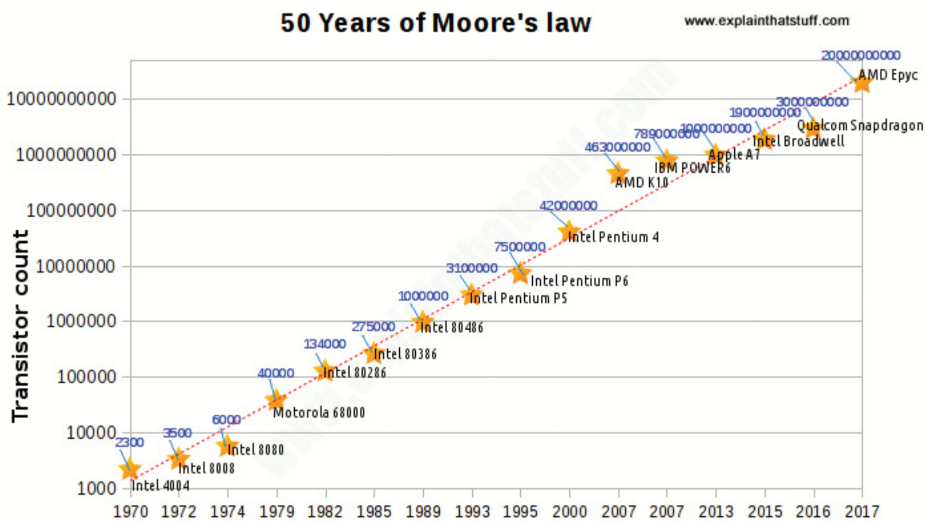
9 Wing (2006) *Computational Thinking* Commun ACM 49 (Carnegie Mellon University) .

Moore's Law is one of the most famous laws in the world of computer science. The graphic below is from www.explainthatstuff.com. Moore's Law says that the number of transistors on an IC will approximately double every 2 years. Thus the processing power of computers will also double approximately every two years. Moore's Law is more of an observation/prediction than a scientific law. As can be seen by the graphic below, it has been extremely accurate.

Take the Crash Course Video on Integrated Circuits (0.00–9.00) and Moore's Law (9.00–12.30)

From the Crash Course Series on YouTube (Carri Anne Philbin)

LO 2.3, 2.11



But can the size of transistors continue to decrease from microns (a millionth of a metre) into the realm of nanometres (a billionth of a metre)? The state of current IC technology is often called process. In the table below a 4 micron (μm) process refers to the length of the transistor gate.

Remember the width of a human hair is in the range of 80–100 μm.

Processor	Transistor Count	Year	Process	Comparable Objects	Electromagnetic Spectrum
Intel 4004	2300	1971	10 μm	Red Blood Cells	Infra Red
Motorola 68000	68000	1979	4 μm	Most bacteria	Infra Red
Intel 80486	1.18 million	1989	1 μm	E-coli	Visble Light 0.4–0.7 μm
Pentium III	9.5 million	1999	250 nm	Pollen, Viruses	Approaching UV light
Six Core i7/8	2 billion+	2011	32nm	Molecules	UV light
Exynos 8895	20 billion+	2017	10nm	50 atoms of Silicon	Soft X-rays are 1nm

The latest innovations are a 5nm process. This has often been considered the limit for Moore's Law because it is a mere 25 atoms in width and effects such as current leakage and quantum tunnelling have to be overcome. It is not surprising therefore that IC technology as we know it is evolving given that humans are now engineering material at similar widths to a DNA molecule.

The Human Brain Project is attempting to understand what each section of the human brain does and how our brains work.

Watch this 90 seconds video on their webpage showing the multi-scale dimensions of the brain, from centimetres to nanometres.

LO 2.4

Stimulate a Debate on how should we respond as a society to the rapid growth of Artificial Intelligence (AI)

The model for this activity is explained in A Summary of Teaching & Facilitation Methodologies.

1. Watch a Stimulus Video or read a stimulus piece.

In the section on Turing Machines, a short video, on classical versus quantum computers, explored the limits imposed by Moore's law and the possibilities opened up by quantum technology. In addition the rapid growth in AI and machine learning was looked at through the lens of data, algorithms and of particular relevance in this section, processing power. (Why this seemingly sudden explosion?) And what about the ethical implications of the increased automation of human skills and processes? Watch a snippet (10:30–19:49) of a TED talk featuring renowned machine learning expert Jeremy Howard from 2014. The automation of clinical medical analysis, which has already surpassed the best specialists in the world, is advancing rapidly with both positive and negative impacts on society. Make a note of how he defines services and the overlap between services and machines learning to do things under supervision. Why does he think the Machine Learning revolution is different from the Industrial revolution in terms of how it will impact society?

Watch a BBC Click video (7:30 – end) that discusses a range of opinions on how society should change its structures to adjust to the advances of AI. For example, if the diversity of jobs decreases, should we consider universal income for all?

Is this a good time to check the growth of AI? When we call a hotel to make a booking, are we entitled to know if we are speaking to a human or machine?

2. Some prompt questions to provoke class discussion and elicit initial viewpoints.

- The service industry in the developed world accounts for about 80% of employment. From waiters to doctors to accountants, they need to learn how to work with AI in order to thrive. If the services industry does not embrace this technology, will the technology consume the services industry?
- The developing world can save billions in money and in lives by embracing automated services. For example in the area of training doctors or solicitors. Should the training be how to work with and supervise AI as much as learning how to work with patients?
- As the wealth generated by AI increases, and the wealth generated by humans decreases, should we re-structure the relationship between the citizen and the government? For example, should there be a universal income for all citizens? Should health and well-being technology be mandatory for all humans to save on health care and social welfare payments?

3. Divide into research groups to explore the topic from key standpoints.

Themes for different groups:

- The growth of AI and machine learning has an overall positive impact on society and on technology.
- The growth of AI and machine learning has an overall negative impact on society and on technology.
- Societies, both developed and developing societies, must change their structures to accommodate the disruptive effect of AI.
- Societies, both developed and developing societies, must limit the impact of AI to accommodate the needs of their societies.

4. Choose a teaching / facilitation methodology.

Adapt appropriately for your CS classroom.

a. Students first research each topic in research groups of 3.

b. The teacher uses a *Jigsaw Learning Technique* to create groups of 3 comprising one student from 3 different themes. Each person discusses their research within their new group.

c. Reassemble into original groups.

Each group has up to 5 minutes in the *Hot Seat* OR

A *Think-Pair-Share-Snowball (TPSS)* exercise to broaden out the findings and conclusions of each research group.
OR
A *Power of Persuasion* technique is used to group students into their preferred category and try to convince other students over to their viewpoint.

LO 1.12

Students should be able to compare the positive and negative impacts of computing on culture and society

LO 1.18

Students should be able to recognise the diverse roles and careers that use computing technologies