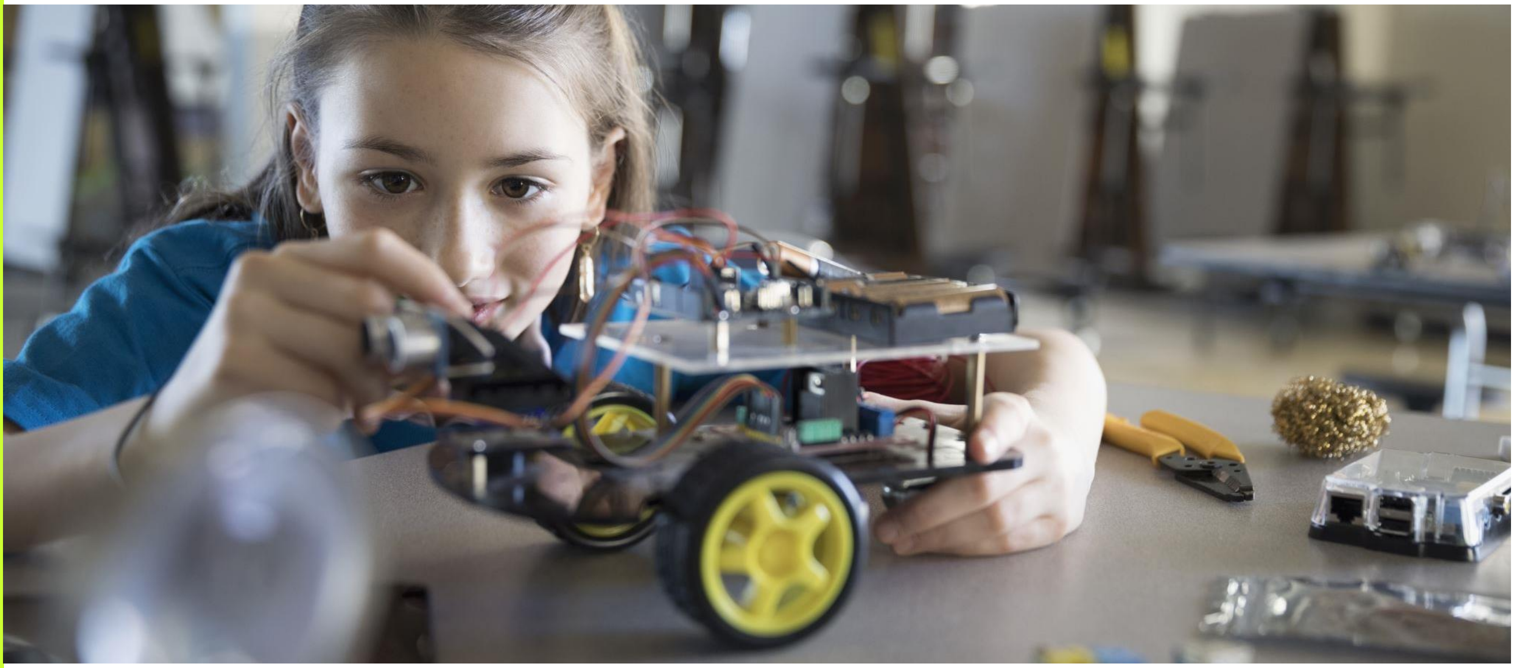
Teacher Continuous Professional Development

Engineering Skills Development



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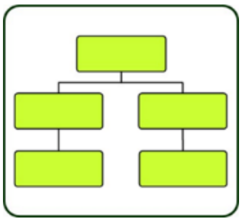
Engineering Skills: Teacher Continuous Professional Development

1. Engineering Skills

Engineering is difficult to define as a subject because it crosses traditional subject barriers to merge science and mathematics with design, art, historical analysis and creativity to solve complex problems. As products have become more complex, engineers have developed new ways to think about how to manage the design and development processes required to create them.

Two methods that have emerged to support the organisation and management of complex products are systems engineering and modular design. Once these concepts have been grasped, they can be widely applied to other structured problem solving tasks such as creating computer document folder structures, organisation charts, project plans and so on.



1.1. Skills Crisis

Rapid changes in technology have created a global skills crisis and there is a pressing need to develop higher order thinking skills such as critical thinking and problem solving. Higher order engineering skills may be developed by promoting the following enquiring habits of mind: 1) creativity, 2) optimism, 3) persistence, 4) systems thinking, 5) collaboration and 6) conscientiousness.

There have been many reports identifying skills challenges. In the 2019 UK “Engineering skills for the future” report by the Royal Academy of Engineering (John Perkins CBE) identified that little progress had been made over the 5 years since a previous report by Perkins in 2013.

1.2. Core Skills

Engineering is a complex field with a bewildering array of disciplines and technologies but there is a general consensus emerging on what might be considered to be the core essential skills. Tables 1 and 2 below, set out 6 lists of core skills proposed by a variety of organisations from the World Economic Forum to the UK’s Royal Academy of Engineering.

1.3. Reflective Task

Take some time to consider the six skills lists provided in Tables 1 and 2 and either individually or with colleagues/students, develop some of your own ideas for five priority skills that you feel should be included. Write your answers in Table 3.

- How does your list compare with the those provided?
- Does your list include new skills not provided in the lists provided?
- Do you feel that your list of five skills provides adequate coverage of this topic?

1.4. Engineering skills lists 1 to 3

#	1 Interesting engineering.com	2 www.link engineering.org	3 www.imeche.org/ www.raeng.org.uk
1	Technical skills	Systems thinking	Visualising
2	Teamwork ability	Persistence	Systems thinking
3	Problem solving	Optimism	Problem-finding
4	Motivation	Creativity	Improving
5	Leadership skills	Conscientiousness	Creative problem-solving
6	Interpersonal skills	Collaboration	Adapting
7	Industry knowledge		
8	Communication		
9	Attention to detail		
10	Analytical mind		

Table 1: Engineering skills list (1)

1.5. Engineering skills lists 4 to 6

#	4 www.thebalance careers.com	5 uk.indeed.com (recruitment site)	6 World Economic Forum (2020)
1	System Design and Analysis	Teamwork	Critical thinking
2	Structural Analysis	Structural analysis	Complex problem solving
3	Statistics	Problem-solving	Creativity
4	Programming Languages	Pressure management	People management
5	Process Management	Leadership	Coordinating with others
6	Nanotechnology	Industry skills	Emotional intelligence
7	Data Modelling	Educational commitment	Judgement/ decision making
8	Computer Science	Data modelling	Service orientation
9	Communication	Creativity	Negotiation
10	Advanced Physics	Computer science	Cognition flexibility
11		Communication	
12		Attention to detail	

Table 2: Engineering skills list (2)

	Your Skills List
1	
2	
3	
4	
5	

Table 3: Skills Response

2. Disruptive Innovation

2.1. Skills and Innovation

The concept of disruptive innovation describes a process where new ideas and technologies are generated that render existing ideas and technologies obsolete. These events often take place in very short timescales however, profound changes can take longer. The sudden changes caused by new inventions are usually associated with a dramatic impact to the way people work and the skills they use. There is inevitability a wider impact on how organisations operate and the markets they trade in.

Disruptive innovations can be so profound that it is important to consider the wider impact, particularly when these issues are complex and difficult to understand. Right now rapid changes in technology and, in particular, information technology is naturally high on the priority list, alongside tackling environmental issues such as pollution, climate change and the impact of the Coronavirus Pandemic.

2.2. Electronic Calculator

The emergence of the electronics age, led in 1961 to the development of the world's first electronic desktop calculator, a product called ANITA (A New Inspiration To Arithmetic/Accounting). ANITA was manufactured by a company called British Bell Punch/Sumlock and weighed 15kg!

It was not until 1972 that, enabled by semiconductor transistor technology, HP launched the world's first handheld electronic calculator (HP-35) that was able to perform calculations using logarithmic and trigonometric functions.

Prior to this point people used a combination of mental arithmetic and a manual calculating device called a slide rule or slipstick. Slide rules were originally invented in the early 1600s by William Oughtred, a British mathematician. By the time the electronic calculator was created in the 1960s, the slide rule had been in use for around 350 years.

The launch of the electronic calculator was considered disruptive because within the space of a few years the slide rule was effectively rendered obsolete and production of slide rules was brought to an abrupt end. The electronic calculator was faster, easier to use and cheaper. It reduced the time required to conduct calculations and enabled people to spend more time on higher value problem solving activities.

It is perhaps worth reflecting that the slide rule/slipstick was used to design many complex engineering products that are still revered today: Concorde, NASA's Space Shuttle and the Saturn V rockets used by the Apollo missions to put the first man on the moon.

2.3. Reflective Task

Take some time to consider either individually or with colleagues/students, technologies that have been disruptive.

- Thinking about a particular technology or innovation consider what made it disruptive?
- What was the impact of the disruption?

3. Engineering Skills Development

3.1. Industrial Revolution

The Industrial Revolution took place between the mid 1700s and late 1800s and had a massive and transformative impact on society. While today's digital revolution is powered by increasingly miniature transistor technology, the Industrial Revolution was enabled by the ability to manufacture increasingly higher quality iron and steel.

The Industrial Revolution also led to the development of modern engineering skills. As products became more complex, engineers need to develop new processes to create them. Two methods that emerged to enable the organisation and management of complex product design and manufacture were systems engineering and modular design. It's possible to learn more about this period by looking at the ships on display at the UK's National Historic Dockyard in Portsmouth.

3.2. National Historic Dockyard

To understand why systems engineering and modular design are so important we need to take a look at three ships on display at the Historic Dockyard. The ships are: the Mary Rose, HMS Victory and HMS Warrior, please refer to Table 4.

While recognising that HMS Warrior has an iron hull, these ships collectively illustrate that for over 300 years warships retained 3 prominent common design features:

- Sail powered,
- Were of wooden construction
- Were armed with many cannons arranged on a gun deck.

It is also important to note that, even though these ships are taken from vary different periods of time they were consistently operated for many decades.

#	Ship	Years Active	Operating Period	Detail
1	**Mary Rose**	1512 to 1545	33 years	The Mary Rose was Henry VIII's favourite ship
2	**HMS Victory**	1778 to 1830	52 years	HMS Victory is famous in the UK because it fought in a battle in 1805 (Trafalgar) where Britain defeated the French!
3	**HMS Warrior**	1861 to 1883	22 years	HMS Warrior was the first British ship to have a hull made from iron.

Table 4: Ships on Display at the UK's National Historic Dockyard

3.3. Gundeck

Table 5 provides two images of HMS Victory, that present both an internal and external view of the ship with cannons lined-up along the gun deck. The images show the cannons mounted on wooden trolleys with the ropes used to manoeuvre them. This is similar to the fictional pirate ship the Black Pearl that appears in the Pirates of the Caribbean films.

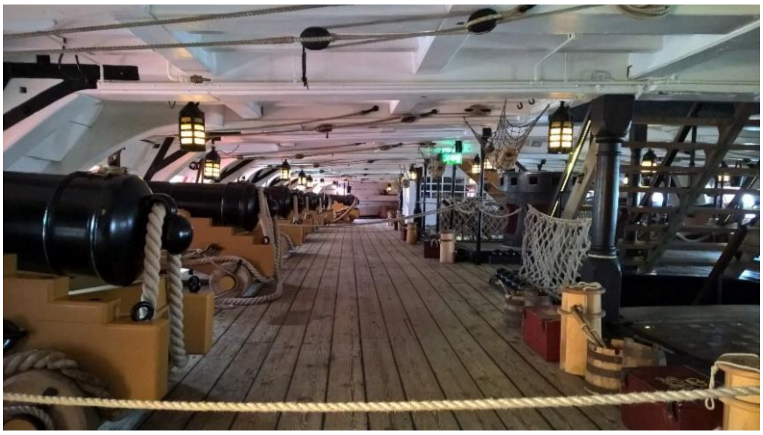
HMS Victory Gundeck	
External view	
Internal View	

Table 5: HMS Victory Gundeck – Internal and External views

3.4. The Gun Turret

During the Industrial Revolution and in particular the 1800s, the quality of iron produced increased dramatically. As the power of cannons increased they also became larger and eventually too heavy to manhandle. Ultimately it became necessary to mechanize the process of loading, aiming and firing the guns and the gun turret was invented. The gun turret also offered greater flexibility when aiming and firing.

3.5. Engineering Methods

The adoption of steam engines and gun turrets led to massive changes in the methods engineers used to design ships which in turn led to the development of new skills. Gun turrets were significantly more complex than cannons as they had hundreds if not thousands of components. At this point the concept of "modularisation" evolved to simplify the design process.

The concept of systems engineering also emerged to make life easier. Gun turrets were considered to be the weapon system; the steam engine with drive shafts and propellers became the propulsion system; and the hull was considered as the main element of the structural system.

It's important to stress that the evolution of engineering design methods is a complex topic and the explanation here is a massive simplification of what actually happened. However, the aim of this historical summary is to provide a better understanding of a process that took many years – and continues even now with the rapid changes we are experiencing as part of the digital revolution.

3.6. HMS Devastation

Within 10 years of the launch of HMS Warrior, a new ship was launched called HMS Devastation shown in Figure 1. HMS Devastation had a radical new design and was the first ocean going warship that had no sails or a gun deck. Instead it was fitted with steam engines and gun turrets!

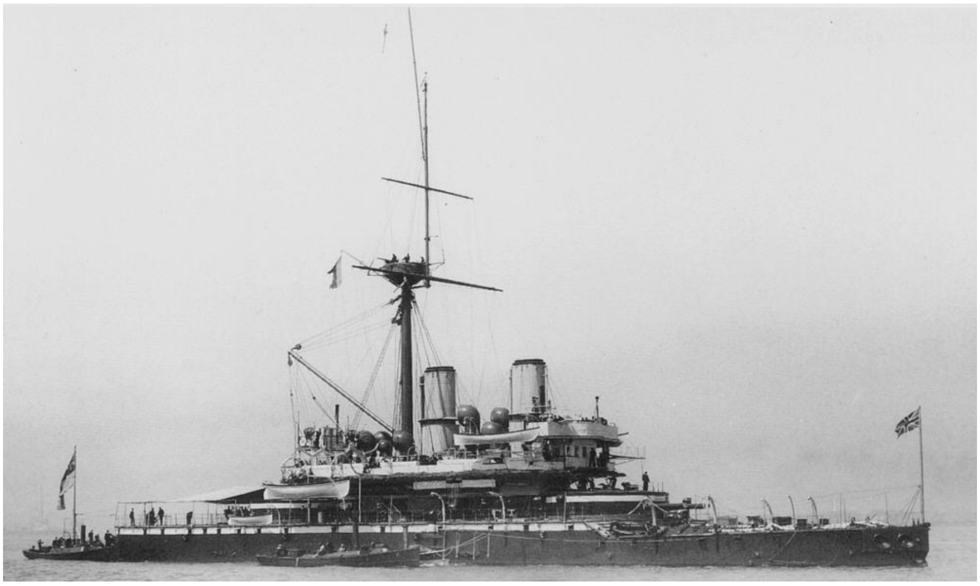


Figure 1: HMS Devastation

3.7. USS Iowa

USS Iowa was probably one of the last operating battleships to be equipped with gun turrets as its main armament and Figure 2 shows the US Navy's USS Iowa in 1984 demonstrating its awesome firepower. The image illustrates the immense pressure waves on the water created by the powerful naval artillery.

Figure 2: USS Iowa

Design modularisation was an approach that was developed to make the management and organisation of complex designs easier as illustrated in Figure 3.

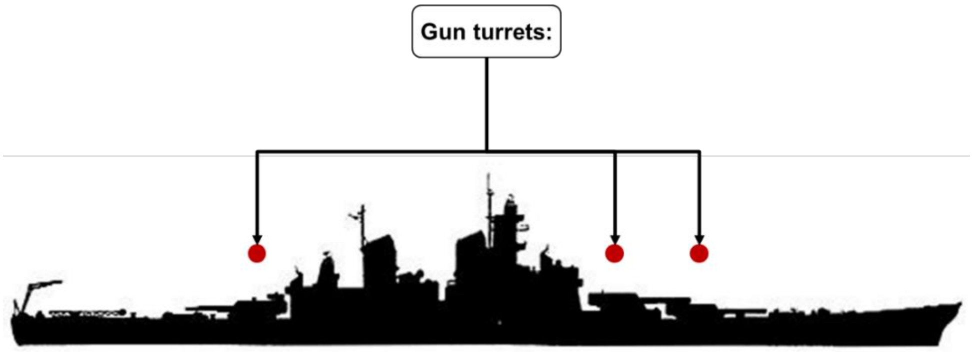


Figure 3: An illustration of the application of modularization

3.8. Design Revolution

This period of rapid technological change had a significant impact on the way engineers thought about the designs of complex products, such as ships, and the design processes they used.

Looking at row #1 (highlighted red) in Table 6, we can say that for hundreds of years ships were equipped with cannons. However, in the late 1800s there was a period of rapid design change when many smaller cannons were suddenly replaced by a few gun turrets.

Gun turrets were significantly more complex than cannons as they had hundreds of components. At this point the concept of "modularisation" evolved to simplify the design process. The concept of systems engineering also emerged to make life easier.

#	Before	After	System
1	Gun decks	Gun turret	Weapon System
2	Sails	Steam engine and propeller	Propulsion System
3	Wooden hull	Steel/iron hull	Structural System

Table 6: Warship Design and Systems Analysis

3.9. Skills Revolution

The impact that rapid technological change had on the way engineers designed products such as ships, also had an impact on skills. Looking at row #1 (highlighted red) in Table 7 illustrates how the trade of armourers that manufactured cannons developed into the trade of weapon system engineer as the processes used to design and manufacture a gun turret became more complex.

Similar changes in trades took place in the area of propulsion where sail and rope makers became propulsion system engineers and so on. It is important to note that this explanation is a significant simplification of a process that took many years and continues today in response the current rapid evolution of digital technology.

	Before		After	
#	Technology	Skill	Technology	Skill
1	Cannons/ Gun Decks	Armourer	Gun Turret	Weapons system engineer
2	Sails	Sail and rope makers	Steam Engine	Propulsion system engineer
3	Wooden hull	Carpenters	Iron/ Steel Hull	Structural Engineer

Table 7: Skills Development

3.10. Diverse Applications of Modular Design

To illustrate the diverse use of the concept of modular design we'll now consider two examples: firstly mobile phones and secondly treatment bags as used by emergency ambulances.

For the first example, we'll consider the modular approach to design used by Fairphone for its Fairphone 2 device. This short YouTube clip (first 2 minutes) provides a valuable introduction: https://youtu.be/wezt4-ut5tI. The modules used to build this phone are listed here:

- Module One: Case
- Module Two: Core module
- Module Three: Screen
- Module Four: Top module (front facing camera and headphone jack)
- Module Five: Bottom module (speaker and micro USB socket)
- Module Six: Main camera
- Module Seven: Battery

For the second example, consider the pictures of UK NHS emergency response vehicles in Table 8 (next page). The images show the treatment bags used to equip ambulances and rapid response vehicles. These have been designed to package equipment in a prioritized manner for specific situations with the objective of providing a standardized and consistent approach. Here are some examples of bags for specific scenarios:

- First response bag: the aim is to ensure every patient has the equipment available for the management of life threatening conditions;
- Resus pouch: additional equipment to support emergency resuscitation;
- Maternity pack: equipment to support child birth;
- Burns kit: contains specialist treatments for burns victims;
- Drugs bags.

3.11. Summary

The Industrial Revolution was a period of significant technological change that caused substantial social upheaval. A key enabler was the dramatic increase in the manufactured quality of iron/steel; this led to rapid changes in technological capabilities and product designs including ships.

As product designs became more complex, the number of components required to manufacture machines also increased - steam engines, trains and so on. As the technical complexity of designs grew, modularisation emerged as a way to simplify the management and organisation of engineering designs. The skills of “systems engineering” and “modular design” gradually emerged in response to the changes in technology. Finally, it's important to remember that skills are constantly adapting – even now - in response to the growth of high tech digital engineering. That means that "systems engineering" and "modular design" are as important as ever.

<table>
<tr><th colspan="2">Example of modular design in the treatment bags used to equip UK NHS emergency ambulances and rapid response vehicles</th></tr>
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Table 8: Use of Modular Design in UK NHS Emergency Response Vehicles

3.12. Reflective Task

The concepts of systems and design modules are commonly used in all walks of life. Take some time to consider either individually or with colleagues/students, examples of systems and or product modularisation. If required draw some inspiration from the following environments: shops, buildings, entertainment, energy supply, transportation, telecommunications and healthcare.

- Write down three systems or product modules;
- Have you found it easy to identify examples?

4. Simple Design Exercise

4.1. Battleship Design

The aim of this exercise is to create a simple design of one of the last operating World War 2 battleships the USS Iowa. Construction of USS Iowa was undertaken in New York Dockyard starting in 1940 and she was launched in 1942. USS Iowa was finally decommissioned from service in 1990and is now a museum ship in the Port of Los Angeles, California.

4.2. www.product-change.com

Using the FREE Product Designer software tool at www.product-change.com create a simple systems diagram of the USS Iowa battleship in line with the details provided in Table 9.

USS Iowa Analysis			
#	Unique Components	Systems	Notes
1	Hull	Structural System	
2	Engine	Propulsion System	
3	Gun Turret	Weapon System	Assume that the three gun turrets are the same – one design can be reused.

Table 9: Input for Battleship Design Exercise

4.3. System Diagram

Follow the instructions provided with the Product Designer software to create a simple systems diagram as follows:

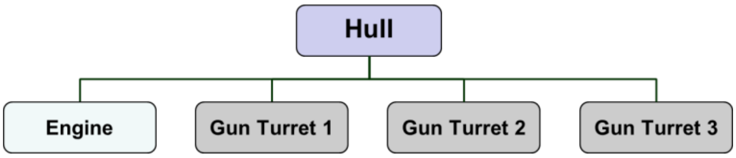

Figure 4: Simple System Diagram – Battleship Design

4.4. Skills Consolidation

To support progress there are a further six case studies that can be modelled at www.product-change.com:

- Lockheed SR-71 Blackbird: the world's fastest jet powered aircraft. The work of this reconnaissance aircraft is now undertaken by satellites and so it is obsolete. Nevertheless the analytical skills developed by reverse engineering a simple systems diagram can be used to create designs of anything from satellites to mobile phones.
- Concorde: the world's first supersonic passenger airliner;
- Mallard: the world's fastest steam locomotive
- Thrust SSC: the world's fastest car – with a supersonic record that has stood for almost 25 years!
- The Rocket: the world's first steam powered passenger locomotive;
- SS Great Britain: the world's first steam powered ship made of iron to cross the Atlantic Ocean.

4.5. Reflective Task

Have these exercises helped you to progress your understanding of the analytical skills required to design and develop world beating products? Take some time to consider either individually or with colleagues/students.

5. Progression

5.1. Complex Products

Complex products such as Concorde, are made using thousands of components and, throughout the design process, engineers need to decide how they will work together and then, how to assemble them. The process of creating and designing such products is complicated and can take many years.

Once a product has been designed and manufactured, they can be operated for many decades. Concorde first started flying with passengers in 1976 and was operated for 27 years until 2003. In 1996 it set the record for the fastest crossing of the Atlantic Ocean by a commercial airliner.

Throughout these long operating lives it is important that designs are managed and maintained in a way that enables products to be operated as intended while also staying safe, economical and environmentally considerate.

5.2. Top Down Design

One of the challenges with managing complex products is that their designs change, not just during initial design and manufacture but also throughout their operating lives too. Software upgrades need to be implemented, old technology upgraded and sometimes components that are not performing as expected must be replaced. These changes are made as engineering modifications.

The process of ensuring designs continue to perform and remain safe requires careful planning and management control – combined with accurate record keeping. The most effective way to manage the overall design of a product is “top down”. The top down approach to design management looks at the overall performance of a product and its key components and systems.

5.3. Product Fleets

The designs of complex products are typically unique. Even within a fleet of new commercial aircraft produced at the same time, on the same production line, the aircraft will show slight design variations in components and or software. The variations might amount to around 5% difference across a fleet of ten aircraft.

These design variations between aircraft that are evident shortly after manufacture, gradually increase due to modifications that are made such as software upgrades. These modifications invariably gradually change the design of the aircraft over time. Furthermore, the modifications cannot be implemented at the same time on all aircraft and as a consequence, the designs of the products in a fleet can be seen to diverge as the fleet ages (Morris).

As a result of this phenomenon, the amount of time engineers spend searching for spares and maintenance information gradually increases. This issue compounds existing information management challenges that are faced when managing fleets of complex products.

5.4. Systemic Properties

A system is considered to exist when a set of related concepts or objects that interact with each other. There are four fundamental characteristics of systems (Checkland):

- The existence of emergent properties;
- Evidence of a hierarchy of subsystems;
- A need for communication and;
- A need for a system of control.

For example an aircraft’s ability to fly can be described as an “emergent property” because it is derived from all subsystems and individual system components operating in an integrated way. No individual component is able to fly on its own.

The design divergence observed in product fleets, is an emergent, systemic property of the fleet. Design divergence cannot be seen when looking at a single product alone. The phenomenon of design divergence illustrates the complex issues that must be considered when looking for ways to improve the management of innovation and engineering design changes for complex products.

5.5. Information Management

Accurate design and maintenance information is required to ensure products are operated in a safe and efficient way. The accuracy of information needs to be sustained even when modifications are implemented and designs change.

There are many product development and support processes needed to create and sustain complex products and these include design, manufacture, test, procurement, finance, sales and maintenance. A huge variety of information systems (software applications) are needed to support these important processes.

To implement modifications to a complex product requires a significant amount of collaboration between the organisations involved. For an aircraft, this could include airlines, an outsourced aircraft maintenance business as well as manufacturers and other suppliers and subcontractors.

The collaboration requires communication of design information both within and between the organisations involved as well as information exchange between information systems.

For information to flow smoothly and efficiently the information systems used by organisations need to be integrated. As organisations continually strive to be more efficient, there is constant pressure to improve information management and communication.

5.6. Reflective Task

In the Higher Education sector a new breed of institutions is emerging that are offering a multidisciplinary approach to problem based learning described by WONKHE.com. Based on this professional development course, please take some time to consider either individually or with colleagues/students:

- How might schools strengthen their ability to promote and encourage engineering?
- How might multidisciplinary/problem based learning be developed in schools?

6. References

6.1. Skills References

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