SYSTEMS ENGINEERING

STEAM MECHANICS

LEVEL

Year 11

VCE: Systems Engineering

ACTIVITY DESCRIPTION

Engineers use computers to aid in the creation, modification, analysis and optimisation of a design. Computer Aided Design and Drafting (CADD) programs are interactive graphic programs that automate the methodologies of drafting and design layouts. At Puffing Billy Railway our Engineers use CADD programs for preparation of all steam locomotive and carriage parts. These designs can then be passed to contractors or trades people to create and build.

Students will use Puffing Billy Railway drawings and TinkerCAD software (or preferred program) to create a component of the NA class steam locomotive suspension system. Students will develop skills in drafting designs for parts of a working mechanical system. Students will use 3D printers to produce the component at school. They will analyse and discuss the effectiveness of 3D printing as a manufacturing technique, given students may have to develop alternative design techniques to create this part.

SUBJECT AREA

Systems Engineering Unit 1: Mechanical Systems

Area of Study 1 – Mechanical System Design

MATERIALS REQUIRED

- “NA Class steam locomotive equalising beam” drawing,
- Devices with access to TinkerCad or CADD programs
- Access to 3D printer
- Materials to allow joining of segmented 3D printed components.
- “Steam Mechanics” Worksheet

INSTRUCTIONS

ACTIVITY 1 – COMPUTER AIDED DRAFTING AND DRAWING (CADD)

1. Initially, teachers to ensure students have a required prior knowledge to use TinkerCAD (or an alternative program) to create basic geometry and parts.
2. As a whole class, teacher to show students video of a train suspension system- https://www.youtube.com/watch?v=LuIUX7mJk84
3. Teacher to hand out the “NA Class steam locomotive equalising beam” drawing to each individual student and support students to draft the components in TinkerCAD, or preferred program.
4. Students will present “detailed design” drawings of the drafted component to the teacher for review and feedback, electronically or printed hard copy.

ACTIVITY 2 – 3D PRINTING

1. Teacher to ensure students are familiar with schools' 3D printing setup and constraints (could partner with a tech school if need equipment).
2. Students will use their detailed design drawings from TinkerCAD (or preferred program) created above.
3. Teachers describe to students the process required to complete the segmentation of the parts in their drawings, as students may have to segment or change the design to make it possible to 3D print each part, given that this part is generally larger than most 3D printers, and made of steel.
4. Teacher to allow students time to research designs or techniques to join segmented components.
5. Teacher to assist students with available resources to design segments to allow 3D printing using the equipment available. For example, will the segments be joined together with glue? Screws? Fixtures? Slots? Etc.

REMEMBER: Outline safety expectations and requirements to students using equipment.

6. Students to 3D print segmented components.
7. Students to join components together. The provided drawing is 1 to 1 scale so is generally larger than available 3D printers.
8. Students to use "Steam Mechanics" Worksheet to describe, analyse and discuss the effectiveness of 3D printing as a manufacturing technique, given this part is generally larger than most 3D printers and made of steel. Students also need to describe and discuss the method used to join the various parts.
9. Students to present final component with "Steam Mechanics" Worksheet for final assessment.

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SUGGESTIONS FOR ASSESSMENT

Successful completion of model in TinkerCAD, or preferred program. Successful manufacturing of component via 3D printer and completion of "Steam Mechanics" Worksheet to outline and discuss the method chosen to join the parts.

CURRICULUM LINKS

SYSTEMS ENGINEERING

Unit 1: Mechanical Systems

Area of Study 2

Producing and evaluating mechanical systems

On completion of this unit the student should be able to produce, test, diagnose and evaluate a mechanical system using the systems engineering process.

BACKGROUND INFORMATION

SUSPENSION SYSTEMS

In mechanical systems, suspension is a system of components allowing a machine (normally a vehicle) to move smoothly with reduced shock.

Types may include:

- Car suspension, four-wheeled motor vehicle suspension
- Motorcycle suspension, two-wheeled motor vehicle suspension
- Motorcycle fork, a component of motorcycle suspension system
- Bicycle suspension
- Train suspension

Two of the main components of suspension systems in trains are:

- Compensating beams (modern trains have air bags and dampeners)
- Springs

Trains, such as Puffing Billy Railway use leaf springs in their suspension systems. Leaf springs consist of several thin, flat strips of metal stacked on top of each other. The strips bend when weight is applied, providing support and springiness to the system.

Leaf springs are often used in older rail systems or in heavy-duty applications because they can handle higher loads than other types of springs. They also provide more stability during turns, making them ideal for freight trains carrying heavy loads.

To understand the importance and application of suspension systems in trains read more here:

- https://www.europeansprings.com/the-rail-industry-springs-in-trains/
- https://www.tevema.com/performance-contribution-of-springs-in-rail-systems/#:~:text=Leaf%20Springs,-Leaf%20springs%20consist&text=The%20strips%20bend%20when%20weight,than%20other%20types%20of%20springs.

Teachers can show students various suspension systems and how they are applied to different mechanical systems (trains, cars, trucks, etc.). A great example is the F1 car. This is the pinnacle of suspension systems. Teachers can show students the resource below:

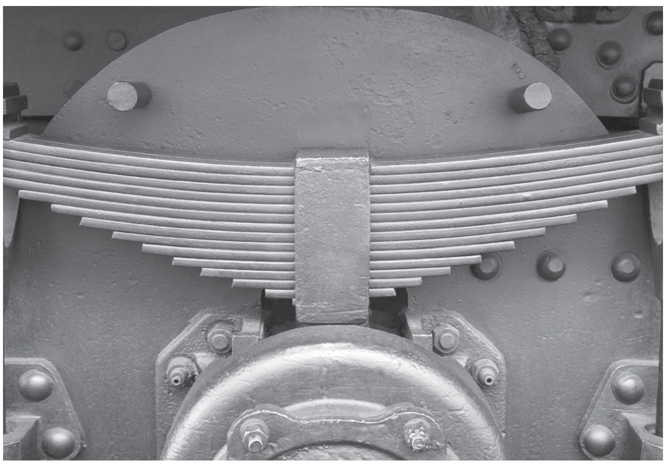
- https://www.mercedesamgf1.com/news/the-suspension-of-a-formula-one-car

Teachers can compare the above F1 Suspension system with that of a train. Details found at the link below:

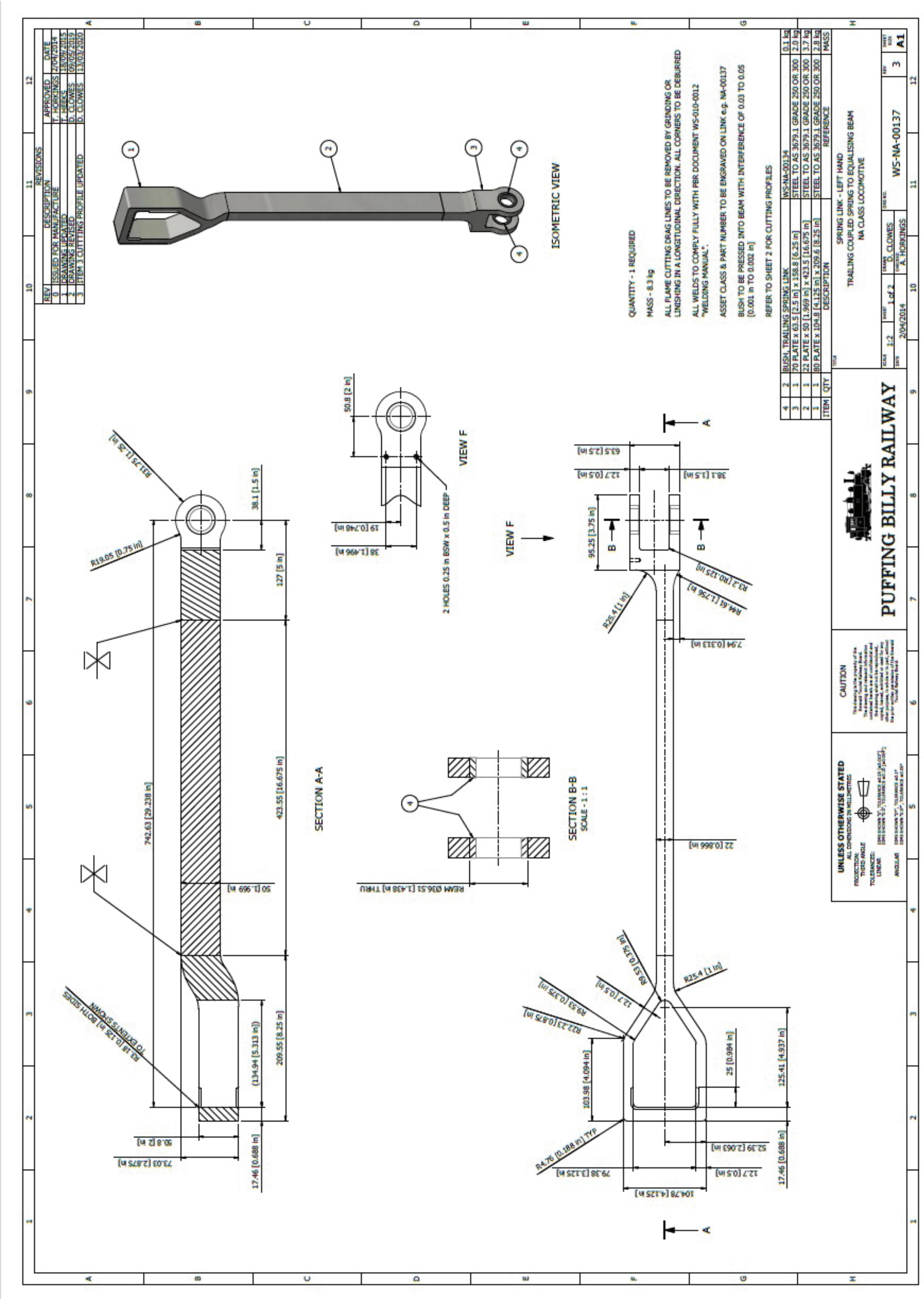
- https://railsystem.net/suspension-systems-for-rolling-stocks/#:~:text=The%20primary%20suspension%20consists%20of,box%20dampers%20in%20each%20bogie.

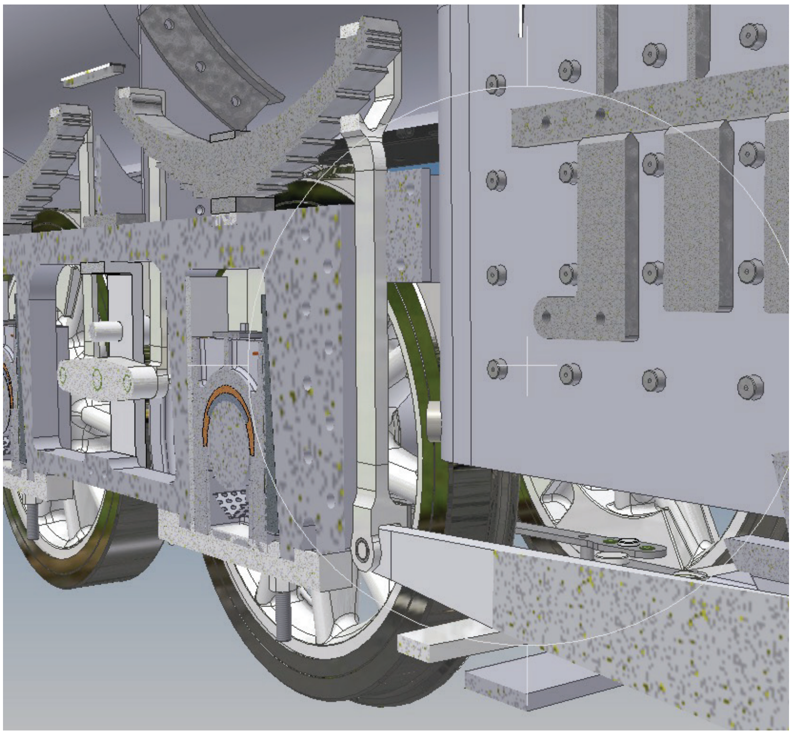
Some examples of suspension system parts and spring systems can be found here:

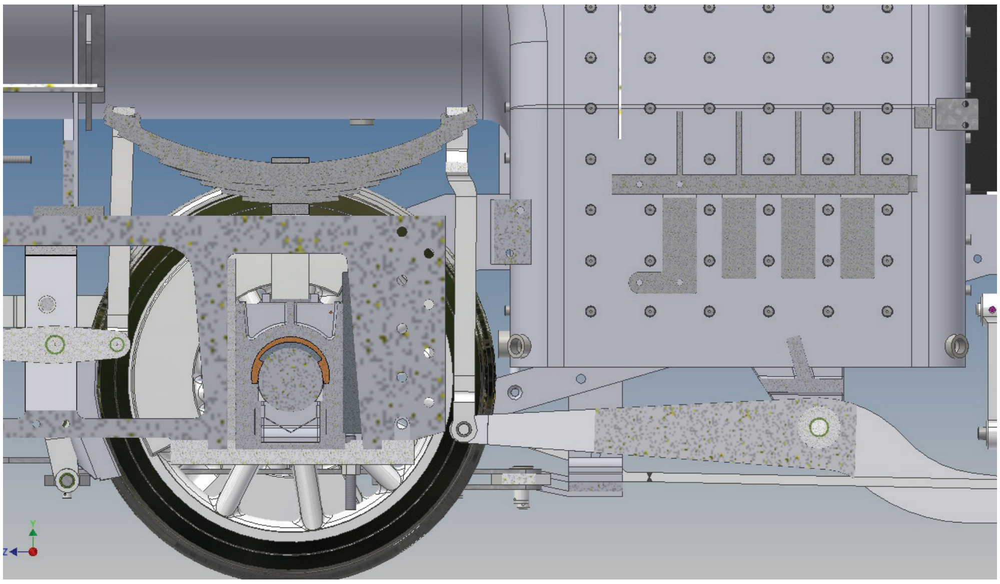
- https://alko.com.au/product/solutions/suspension-systems/



NA STEAM LOCOMOTIVE EQUALISING BEAM DRAWING



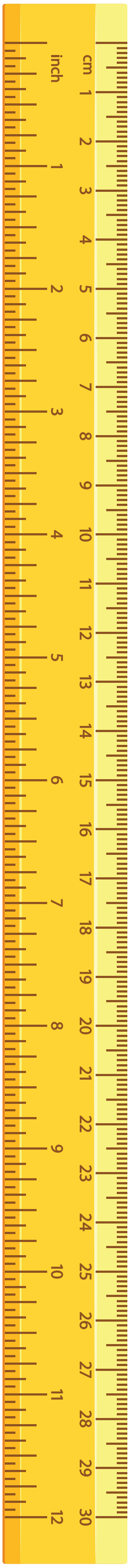




REFERENCE: *Puffing Billy Railway Belgrave Locomotive Workshops*

This component is a part of the NA Class steam train suspension system. This part helps transfer the load from one spring through some pins and bushes and levers to another spring. All the springs on the steam train are mechanically connected, so if one wheel/spring is unloaded, the other springs and wheels take up the load. This makes our little steam trains quick, robust and versatile, which helps them get up the steep and windy hills of puffing billy.

Interestingly, each axle has a different load. Because the steam train is not symmetrical. Roughly, this works out to, the front axle taking around 9000 kg, the centre axle around 7000kg and the rear axle around 6000kg. If the front axle is unloaded, the centre and rear have the capacity to take more load. As the train travels along the line the loadings change "live" based on the condition of the track.



IMPERIAL TO METRIC SYSTEM

THE METRIC SYSTEM started in France during the 1700's. It's based on the metre (length), gram (weight, or more properly "mass" – *see here for the difference*) and litre (volume). "Metric" comes from the word "metre". There's also a system of prefixes for making things bigger (kilo- , mega- , giga- , tera-) or smaller (milli- , micro- , nano-) in multiples of 1000: think of your milligrams of medicines or your gigabytes of computing power. The metric system is decimal because it is always based on powers of 10.

Metric Measurements:

- 1000 grams in 1 kilogram
- 1000 milligrams in 1 gram
- 1000 milliliters in 1 liter
- 1000 meters in 1 kilometer

THE IMPERIAL SYSTEM is based on the inch / foot / yard / mile (length), the ounce / pound / stone / hundredweight (weight / mass) and the fluid ounce / pint / quart / gallon (volume). The Imperial system is generally not decimal:

For volume measurements, some common imperial conversions are:

- 3 teaspoons in 1 tablespoons
- 16 tablespoons in 1 cup
- 2 cups in 1 pint
- 2 pints in 1 quart
- 4 cups in 1 quart
- 16 cups in 1 gallon

But it's also useful to be able to convert imperial weights to imperial volumes:

- 8 ounces in 1 cup
- 16 ounces in 1 pint
- 32 ounces in 1 quart
- 128 ounces in 1 gallon

LENGTH: There are 12 inches in a foot, 3 feet in a yard, and 1760 yards in a mile

WEIGHT / MASS: There are 16 ounces in a pound, 14 pounds in a stone, and 8 stones in a hundredweight

Most everyday objects we measure are either something you use (a book, a door) or a person (how tall do you think she is?). The inch and foot are just the right size for these measurements! Most of us can imagine someone who's 5 foot 4 quite easily: a foot is, well, about the length of an adult's foot, and the inch is the distance between your thumb and forefinger when you hold them parallel as if to say "about this big". But "one point six three metres" or "163cm" are both harder for us to process – the metre is too large a unit, and the centimetre is too small a unit.

If you're reading this and prefer the Imperial system it may be because it's what you were brought up with so it's what you're used to; but your average Frenchman, or Chinese woman wouldn't understand what a mile, a gallon or a stone means. A huge advantage of the metric system is that it is standardised – it's the same all over the world.

REFERENCE: *https://www.houseofmaths.co.uk/2017/01/which-is-better-metric-or-imperial/*

IMPERIAL TO METRIC SYSTEM

	METRIC	IMPERIAL
Length	millimetre, centimetre, metre, kilometre	inch, foot, yard, mile
Mass	milligram, gram, kilogram	ounce, pound, stone
Capacity	millilitre, centilitre, litre	pint, gallon

Imperial unit	Number of smaller imperial units in it	Metric units (approx)
1 inch	None	2.5cm
1 foot	12 inches	30cm
1 yard	3 feet	91.4cm
1 mile	1760 yards	1.6km
1 ounce	None	28g
1 pound	16 ounces	453g
1 stone	14 pounds	6.4kg
1 pint	None	568ml
1 gallon	8 pints	4.5 litres

REFERENCE: *https://www.theschoolrun.com/what-are-imperial-units*

For other sizes, you can quickly and easily work out the Conversions for yourself, using the following simple formulae;

To convert **Centimetres to Inches**	multiply by; **0.3937**	**mm to Inches**; multiply by; **0.03937**
To convert **Metres to Feet**	multiply by; **3.281**	**Metres to Inches**; multiply by; **39.37**

1 mm / 25.4 (conversion factor) = 0.03937 in

1inch x 25.4 (conversion factor) = 25.4 mm

1 foot = 12 inches

REFERENCE: *https://www.insight-security.com/metric-to-imperial-and-imperial-to-metric-conversion-charts*

TOP DESIGN – SYSTEMS ENGINEERING

Using the skills students have learnt in this program these are the products that students could inspire to create. The link below may give teachers some examples of designs, folios and equipment needed to complete the task.

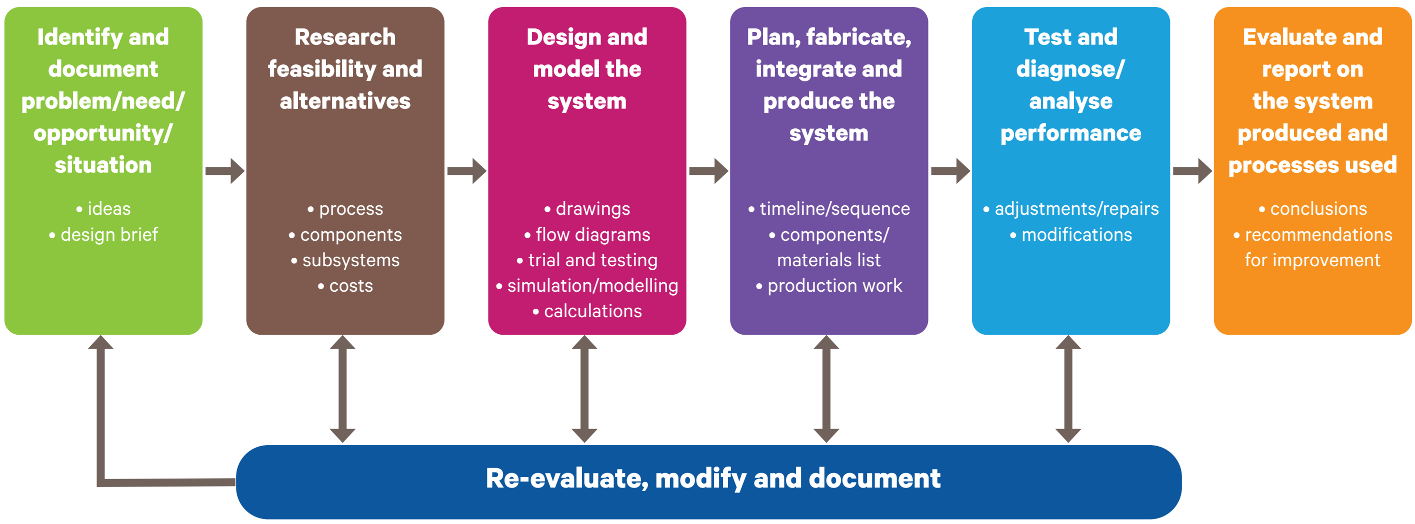
The mechanical and electro technological systems used in our homes and industry have a significant effect on society and the environment. The aim of VCE Systems Engineering is to apply innovative systems thinking and problem-solving skills to understand how technologies can transform people's lives.

In the study, students design, construct and assemble an integrated and controlled aspect of an operational system by using both mechanical and electro technological components. Students design a solution for a system-based problem, need, opportunity or situation by applying technological, mathematical and scientific principles. Production activities are planned and recorded, then testing and evaluation is undertaken. The systems selected for exhibition were completed as School-assessed Tasks, addressing Outcome 1 of Units 3 and 4. Visit the website to see examples of prototypes and folios students have produced:

https://museumsvictoria.com.au/melbournemuseum/learning/top-designs-2022/systems-engineering-folios/

SYSTEMS ENGINEERING PROCESS

The systems engineering process, illustrated below, represents the stages in creating a system. The process is iterative. Students must continuously re-evaluate their progress and make necessary modifications after having revisited an earlier stage or activity. The goal of the application of the systems engineering process is to achieve an efficient, optimised, quality system.



REFERENCE: *vcaa.vic.edu.au*

The stages of the systems engineering process for creating a system are:

IDENTIFY AND DOCUMENT PROBLEM/NEED/OPPORTUNITY/SITUATION

- The identification and exploration of a problem, need, opportunity or situation requiring a systems engineering solution. The context, and the constraints and considerations that apply to the problem, need, opportunity or situation, are articulated in a design brief. Criteria are developed to evaluate how well the system satisfies the design brief. Factors are described that influence the creation and use of a system.

RESEARCH FEASIBILITY AND ALTERNATIVES

- Researching the problem, need, opportunity or situation to consider how it can be addressed. This will involve exploring subsystems, components, processes and any associated costs, and generation of various design options with the selection of the most appropriate systems design.

DESIGN AND MODEL THE SYSTEM

- Designing and modelling the potential system, which requires the execution of drawings, flow diagrams, and testing and trialling possibilities using simulation or actual components. Calculations may need to be made to determine functionality and performance. Components and materials that are appropriate for the system or subsystem are selected with reference to technical data and specifications, including online sources.

PLAN, FABRICATE, INTEGRATE AND PRODUCE SYSTEM

- Planning determines how the proposed system will be produced, and involves careful consideration of the sequential steps required to fabricate components that form the system and subsystems. Initially a work plan is developed that includes a sequence and timeline and identifies and sources the required components and materials.
- Once the planning is completed, assembly and fabrication of the system and subsystems is undertaken using a range of production processes, and tools, equipment, components and materials compliant with OH&S requirements.

TEST AND DIAGNOSE/ANALYSE PERFORMANCE

- The system, subsystem or components are then tested and diagnosed throughout production. If necessary, adjustments, modifications or repairs are made to the system to ensure optimal performance.

RE-EVALUATE, MODIFY AND DOCUMENT

- When creating the system, students must continuously refer to the systems engineering process. They may need to trial and test subsystems and components. This may involve commencing the creation of the system, re-evaluating and then returning to planning and initiating a more appropriate selection of components or materials.

EVALUATE AND REPORT ON THE SYSTEM PRODUCED AND PROCESSES USED

- Evaluation of the system occurs after it has been produced. The findings of diagnostic testing are reported and include conclusions about how successfully the system performed in relation to its problem, need, opportunity or situation using the pre-determined evaluation criteria. Recommendations for improvements to the system and processes used are reported in the evaluation.

FACTORS THAT INFLUENCE THE CREATION AND USE OF A SYSTEM

Factors that may influence the creation and use of a system are described in the table below. As part of the systems engineering process, students must consider the factors in the shaded section of the table; the additional factors may be considered if relevant to the system being created.

Factors	Description
Function	Understanding what the system will be used for or what it will need to do.
User needs and requirements	The system will need to be suitable for and appealing to the users/ customers (the market).
Materials and components	Appropriate materials and components must be selected that will meet user requirements and performance expectations.
Environment use	Understanding where the system will be used and the conditions to which it will be subjected.
Safety	Safety must be considered at all stages of creation and use of the system. The risk assessment and management process is used to identify and minimise risk or harm for the maker or user.
Cost	The system should be cost-effective. Users/customers expect both quality and value. The cost of components, housings and ongoing running and maintenance costs must be considered.
Waste and energy	Waste produced during creation and use should be minimised. Energy used in the production of the system and running costs also need to be kept to a minimum.

REFERENCE: *vcaa.vic.edu.au*

3D MODELLING SYSTEMS THAT COULD BE USED:

There are many types of CAD programs. The three below are common ones found in schools but still used by anyone wanting to create 3D modelled designs.

TinkerCAD
This 3D modelling software is among the most simple ones and good for someone who is just getting started with 3D modelling. It is web based.

Sketchup
Sketchup is a fun design program to use to learn 3D modelling. There are free versions, a web based version and a professional version.

Autodesk Fusion 360
A cloud-based 3D CAD/CAM tool for product development. It is free for teachers and students. Design files are saved on the cloud but it can be used off-line

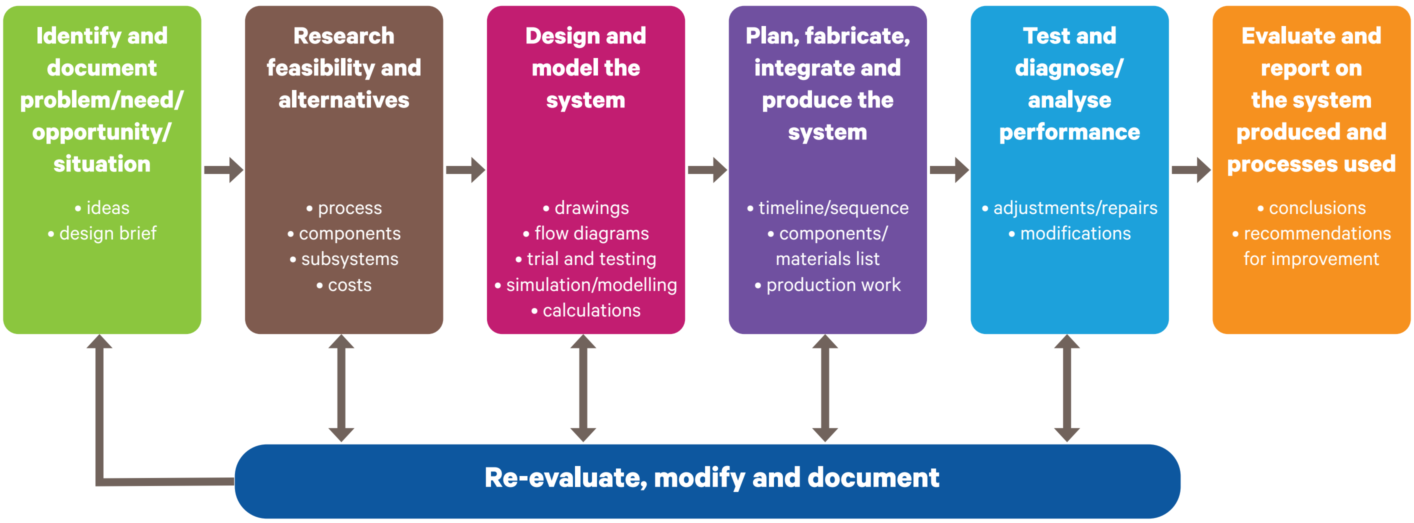
STEAM MECHANICS WORKSHEET

Using your detailed drawing from TinkerCAD (or preferred program) of an NA Class steam locomotive equaliser beam you will create a 3D printed Puffing Billy Railway steam train component.

The equaliser beam designed will be too large for most 3D printers and is made of steel. Therefore, you will need to change the design into segments to print it. You will have time to research designs and techniques to join the segmented components.

Using Systems Engineering Processes, fill in the table below throughout the design process and on completion of your 3D printed component.

SYSTEMS ENGINEERING PROCESS



REFERENCE: *vcaa.vic.edu.au*

IDENTIFY AND DOCUMENT PROBLEM/NEED/ OPPORTUNITY/SITUATION	RESEARCH FEASIBILITY AND ALTERNATIVES
What is the problem?	What processes could you use to join the segments together?

DESIGN AND MODEL THE SYSTEM	PLAN, FABRICATE, INTEGRATE AND PRODUCE THE SYSTEM
How will the segments be joined together? Why did you choose this design?	What materials do you need? What safety measures do you need to consider? Show the steps taken to join the various parts of your steam train component:

TEST, DIAGNOSE, ANALYSE PERFORMANCE	EVALUATE AND REPORT ON THE SYSTEM PRODUCED AND PROCESSES USED
What worked well?	What would you do differently next time?
What didn't work?	Analyse and discuss the effectiveness of 3D printing as a manufacturing technique:

CONCLUSION: