

# Introducing MATLAB into High School Mathematics

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**Abstract:** *MATLAB (Matrix Laboratory) is technical software that is widely used in STEM-related courses and industry. This paper gives an account of how the use of MATLAB was introduced into assessment tasks for high school mathematics students at Ormiston College in Queensland, Australia. In this context, “high school” refers to Years 10 to 12 of secondary school. The tasks were designed in such a way that as well as giving students experience in mathematical modelling and problem solving, they also provided a gentle introduction to the use of MATLAB. This gave these school students valuable experience in working with the software that they are highly likely to use when moving on to tertiary institutions after leaving school. A productive partnership between the school and the manufacturer resulted in a curriculum development project through which a collection of mathematical modelling and problem solving tasks were made publicly available. The way that coding was incorporated into the tasks is demonstrated through examples of students’ responses.*

## 1. Background

Over a period of two years, a series of mathematical modelling and problem solving assessment tasks were set for Year 11 and Year 12 students at Ormiston College in Queensland, Australia. The assessment tasks were relevant to the content of the Queensland Mathematics B and Mathematics C syllabuses and met the requirements of the Queensland Curriculum and Assessment Authority. The school worked in partnership with the manufacturer in creating and implementing the tasks. The manufacturer provided an inexpensive Primary and Secondary School license for the software and customized technical support. Although MATLAB was the software used in the tasks, some free software alternatives, such as Octave or Scilab could have been considered.

The tasks were designed to perform two functions. First, they gave the students the opportunity to use mathematical modelling in real world problem solving. Second, they gave students experience in using technology to enhance their learning. Both of these functions are consistent with priorities in mathematics education across the world. A total of 90 students across five classes completed the tasks. Extracts from the work of four of the students, referred to as Students A, B, C and D are included in this paper. The students were all able mathematics students but had no prior experience in coding.

## 2. Aims

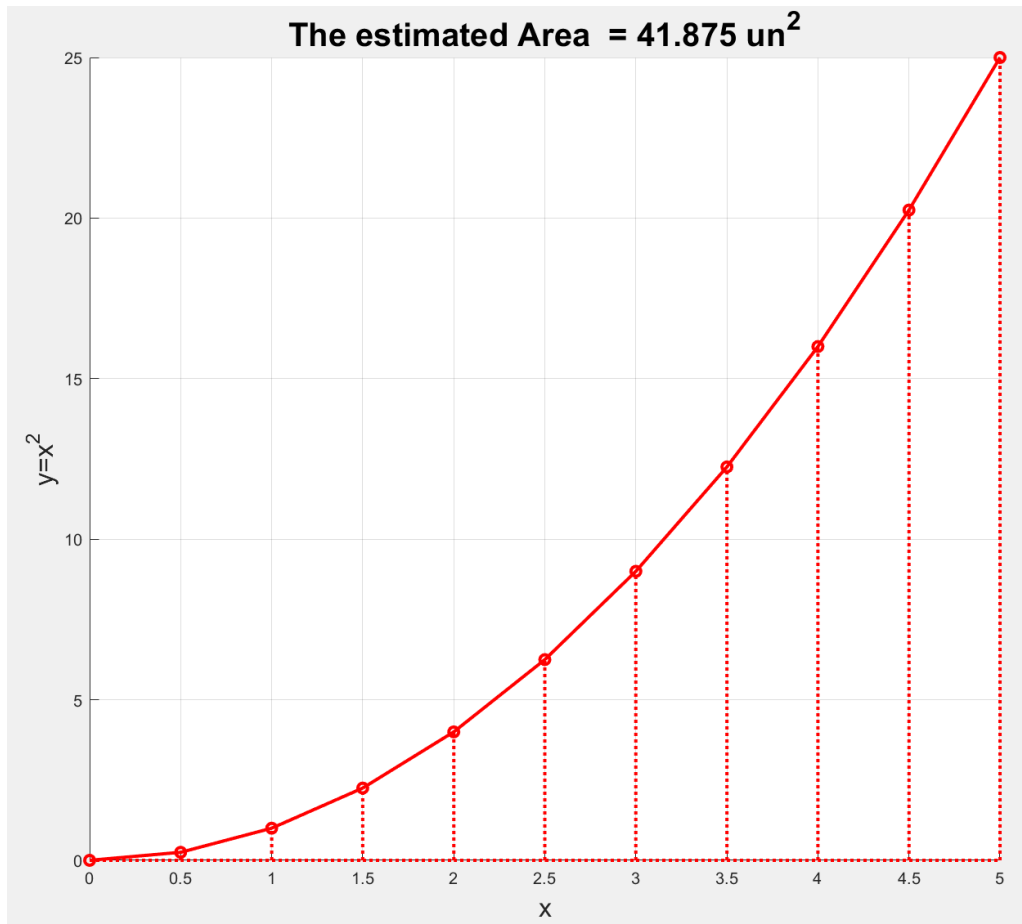
The aim of this paper is to explain how computer coding using MATLAB [7] was incorporated into mathematical modelling and problem solving assessment tasks for Year 11 and Year 12 Mathematics. Using examples of students’ responses, the intention is to show how students can be given tasks that promote mathematical modelling and problem solving, and, at the same time, introduce the use of coding into mathematics.

## 3. Examples

### The Greek Financial Crisis

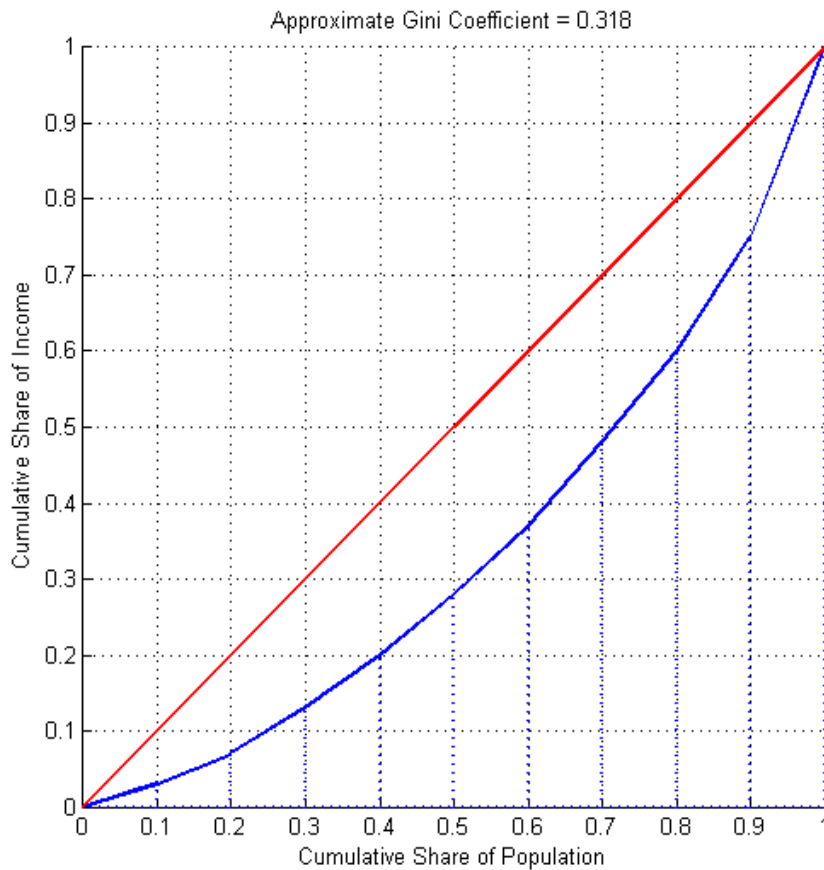
The Greek financial crisis was the main topic of an extended mathematical modelling and problem solving task given to Year 12 students. In the first part of the assignment, the students

were asked to consider the implications of imposing higher taxes and austerity measures on the Greek population. If these measures were to be taken, how could this be done fairly? Should some pay more than others? To investigate this further, the students were asked to calculate the Gini Coefficient for Greece from given data (the Gini Coefficient being a measure of the inequality in the distribution of income in a country which is calculated from the Lorenz Curve). Students were given the MATLAB code for a program which approximates the area under a curve using the trapezoidal method. Figure 1 below shows a screenshot of the graph produced by this MATLAB program.



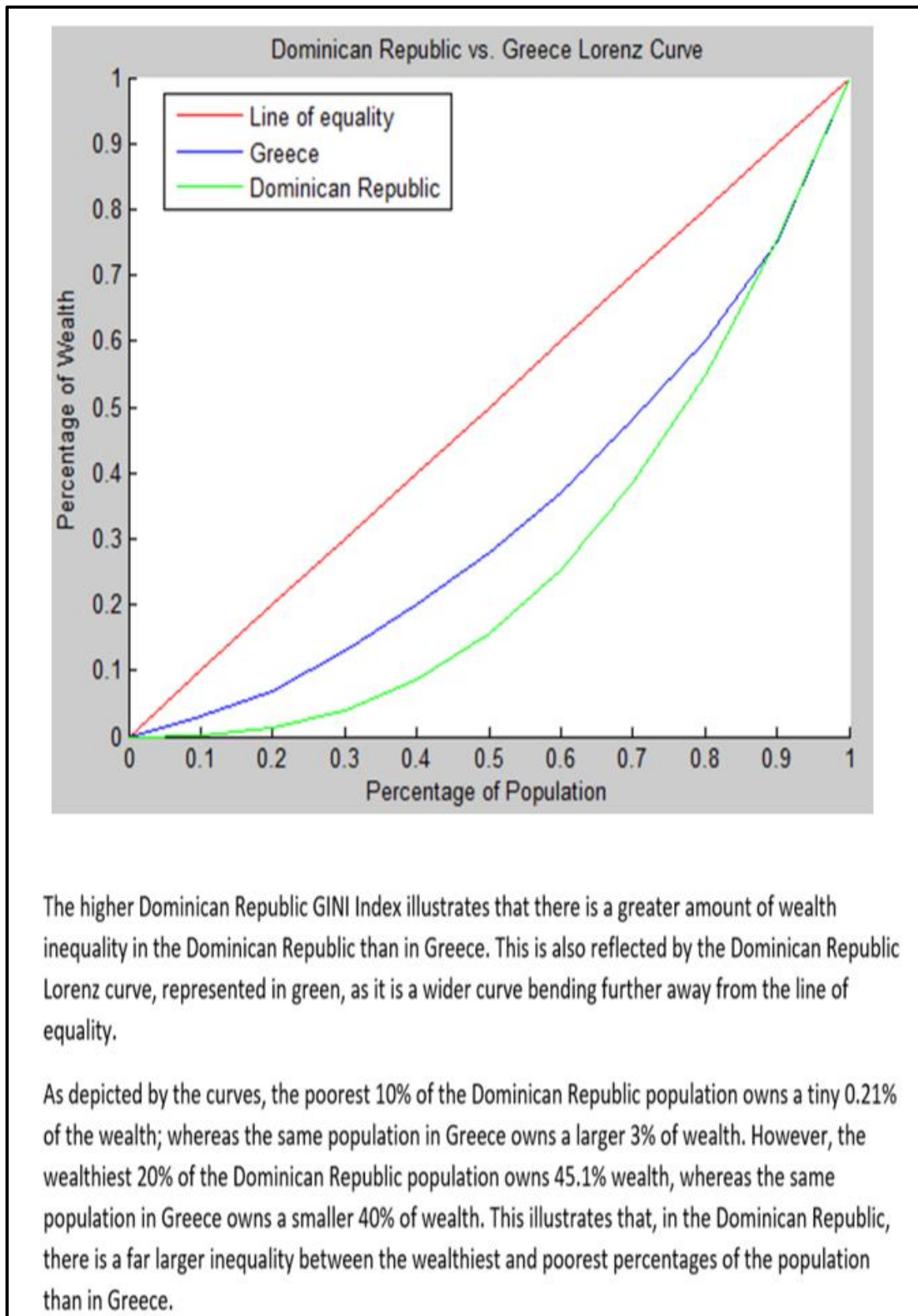
**Figure 1.** Screenshot of the execution of the supplied program

Student A adapted the given code and used it to calculate the Gini coefficient. She then produced a graph displaying the Lorenz curve. The result of this is shown in Figure 2 below.



**Figure 2.** Calculating the Gini coefficient and displaying the Lorenz Curve

In the second part of the assignment, each individual student was given the Gini Coefficient for a different country. In this part, the students had to construct a Lorenz Curve for the country from the Gini Coefficient. They then had to add more code to the MATLAB program so that it would display the Lorenz Curve for Greece along with the Lorenz Curve for the country they were given. Figure 3 below shows how Student B displayed the Lorenz Curves for Greece along with the country they were allocated, and then demonstrated understanding of the context by making interpretive comments on the differences between the curves.



**Figure 3.** Displaying two countries' Lorenz Curves

## Rip currents



In this example, the students investigated the effect of rip currents on the safety of swimmers in the sea. Swimming in the sea may seem similar to swimming in a pool, but there are hidden dangers. In particular, rip currents can put the lives of swimmers at risk. What may appear to be a calm inviting area between the breaking waves may in reality be very dangerous. The students were each given data on the performance of a strong swimmer over a five second time period when the swimmer was already in full flow. An example set of data is shown below in Figure 4.

Time (s)	0	0.217	0.45	0.751	0.984	1.201	1.435	1.702	1.952	2.219	2.569	2.686	2.953	3.253	3.437	3.687	3.937	4.204	4.471	4.688	5
Distance (m)	1.19	1.53	1.84	2.26	2.62	2.95	3.27	3.73	4.08	4.43	4.95	5.11	5.47	5.98	6.24	6.58	6.95	7.34	7.68	8.03	8.44

**Figure 4.** Data showing performance of strong swimmer.

The students were also given code (see Figure 5 below) to assist them in producing a smoothed curve illustrating the change in speed of the swimmer. The way that this code worked was explained to the students in a video tutorial. The students then had to perform calculations to determine the variations in the speed of the swimmer over the time period. They were then required to adapt the given code to suit these measurements and add commands so as to produce a fully labelled animated graph showing the changing speed of the swimmer. They were then able to judge how the swimmer would be affected by a powerful rip current. How would this particular swimmer cope if faced by a rip current traveling at 2 m/s?

```
x= [0.217  0.45  0.751  0.984  1.201  1.435  1.702  1.952  2.219
2.569  2.686  2.953  3.253  3.437  3.687  3.937  4.204  4.471  4.688
5];

y = [1.567 1.33 1.395 1.545 1.521 1.368 1.723 1.4 1.311 1.486 1.368 1.348 1.7
1.413 1.36 1.48 1.461 1.273 1.613 1.314];

xx = linspace(0.217,5,1000);
plot(xx,csapi(x,y,xx),'-',x,y,'.','Linewidth', 3)

for i = 1:numel(x)
    hold on;
    plot(x(i),y(i),'r+', 'Linewidth' ,4);
    pause(1)
end
```

**Figure 5.** Code for illustrating changing speed of swimmer.

Figure 6 below contains an explanation by Student C of how she adapted the given code.

For Part b, the provided MATLAB code has been adapted to produce a graph that displays the swimmer's speed against her time over the 5 second period. Figure 1 shows this graph, while Figure 2 displays the code that was altered to plot the data.

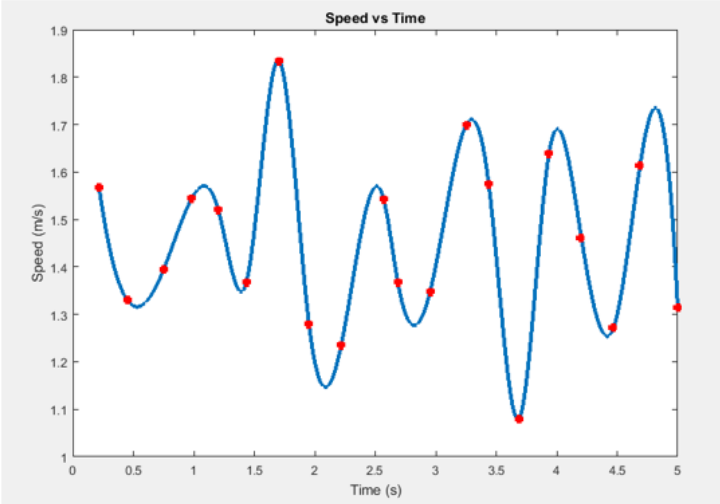


Figure 1: Speed vs Time of Swimmer

```

1  x= [ 0.217  0.45  0.751  0.984  1.201  1.435  1.702  1.952
2  2.219  2.569  2.686  2.953  3.253  3.437  3.687  3.937  4.204
3  4.471  4.688  5 ];
4  y = [ 1.567  1.33  1.395  1.545  1.521  1.368  1.835  1.28
5  1.236  1.543  1.368  1.348  1.7 1.576  1.08  1.64  1.461
6  1.273  1.613  1.314];

7  xx = linspace(0.217,5,1000);
8  plot(xx,csapi(x,y,xx),'-',x,y,'.', 'Linewidth', 3)
9  xlabel('Time (s)')
10 ylabel('Speed (m/s)')
11 title('Speed vs Time')
12 hold on
13 for i = 1:numel(x)
14     hold on;
15     plot(x(i),y(i),'r+', 'Linewidth' ,4);
16     %pause(1)
17 end
    
```

Figure 2: MATLAB coding for graph showing Speed vs Time

In Figure 2, the code was first adapted by inserting the data from Table 1 into the x and y values. Time, as the independent variable, was inserted onto the x axis, while the speed values were entered onto the y axis as the dependent variable. Next, these axes were given appropriate labels and a title was added to the graph, seen in [lines 9, 10](#) and [11](#) of the code (xlabel, ylabel, title). The linspace ([line 7](#) of the code) created to interpolate the data was edited to be between 0.217 and 5.0 seconds, in order for the graphed line to begin from the first recorded speed (1.567s), rather than 0. The pause function ([line 16](#)) was also commented out by using a '%' to speed up the graphing process, as this plots the points on the graph individually every 1 second. This code was then run to create the graph in Figure 1, showing the swimmers speed against their time.

**Figure 6.** Student C explains how she adapted the given code.



Whilst the student did not write the code from scratch, she was able to demonstrate her understanding of it. She inserted data in lines 1-6, added lines 10-12 and adapted line 16. She also made mathematical connections between the output of her code and the real-world context. In Figure 7 below she explains how changes in acceleration are related to the technique of freestyle swimming.

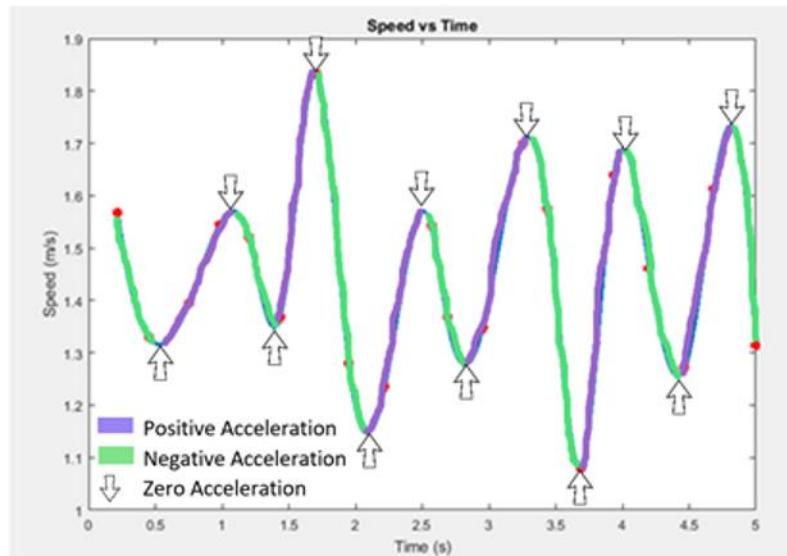
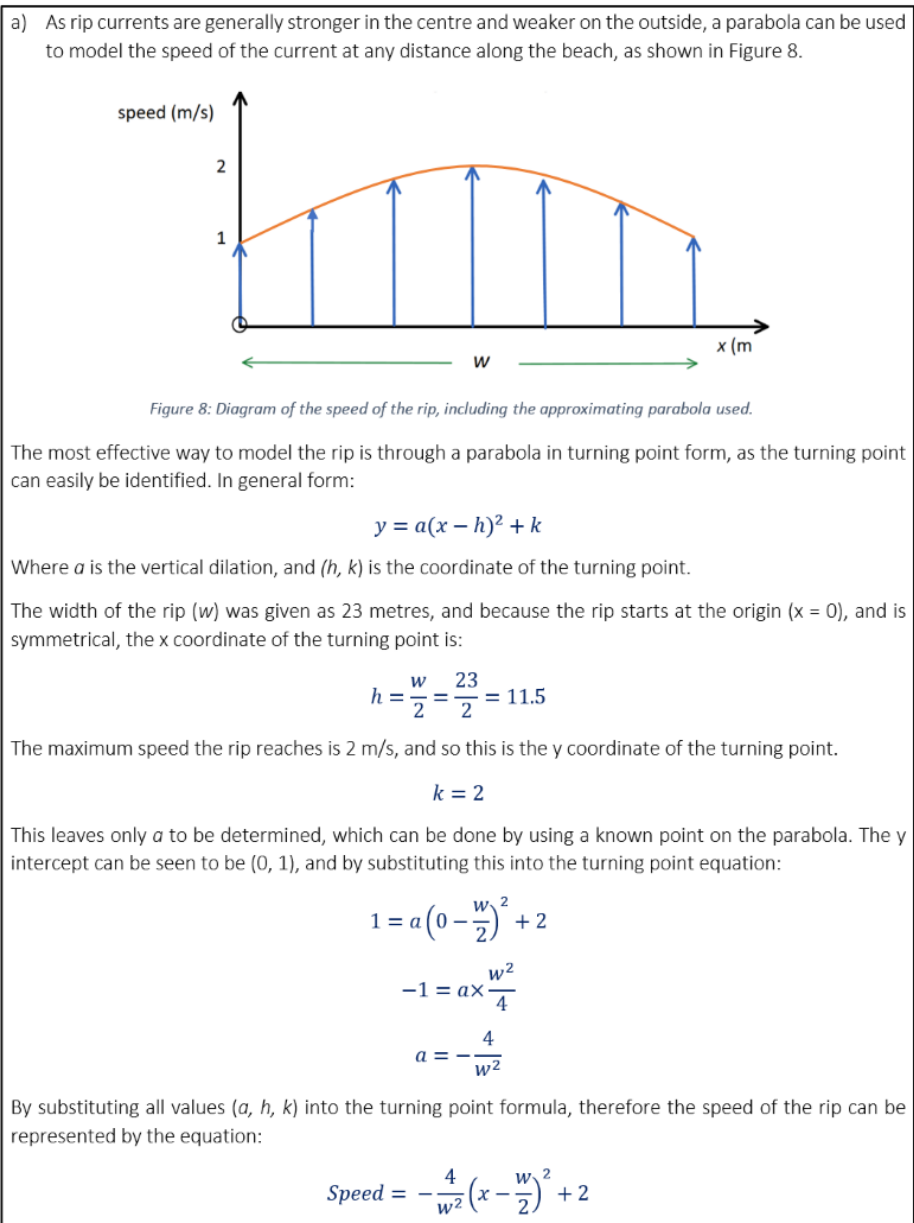


Figure 7: Swimmer's Acceleration

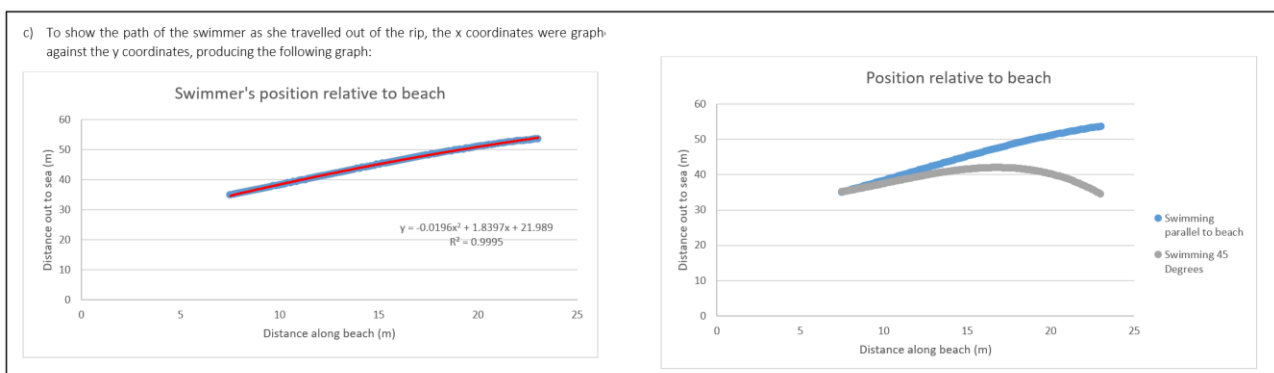
- e) The points of positive, negative and zero acceleration as seen in Figure 7 can be justified according to the swimmer's freestyle technique. When the swimmer drags her hand through the water as part of her stroke, we see the positive acceleration occurring. By dragging her hand quickly under water, she is gaining momentum and travelling forward at a faster speed. Following this, there is a period where she will glide through the water as part of the stroke. This is where the negative acceleration can be seen. The points of zero acceleration would therefore occur between these two motions. This would most likely be when her hand enters the water before completing the stroke, as well as upon its exit after completing a stroke. Because her speed is only recorded over 5 seconds, she would not have needed to take a breath and therefore her positive and negative acceleration is relatively steady.

**Figure 7.** Student C elaborates on the output of the code.

The use of MATLAB related to the first part of the modelling task. In a later part of the task the student justified a mathematical model of the rip current (see Figure 8) and explored scenarios to illustrate how the swimmer could cope when caught in a rip (see Figure 9).



**Figure 8.** Student C justifies a model of the speed of the rip current



**Figure 9.** Student C explores strategies for the swimmer to overcome the rip current.



### Bringing the astronaut home

In another assignment, students were challenged to rescue an astronaut who had become stranded on Mars. In the part that involved the use of MATLAB, the students had to assist the astronaut in making a tricky manoeuvre to reach his rocket. Student D explains his method in Figure 10 below.

Upon making it to the Schiaparelli Crater, Watney is faced with the challenge of getting past a large sand dune (shown in figure 7). The Rover is limited such that it may not tilt at an angle of more than  $40^\circ$ , otherwise it will topple over. Using Matlab, a path is able to be mapped from Watney to the MAV. Figure 8 shows the plotted path that the Rover should take. The dune is too steep for the Rover to go directly through, and therefore the Rover must take a path that is slightly less direct. The points were plotted using Matlab's data-tip tool, and all values were exported to an excel spreadsheet.

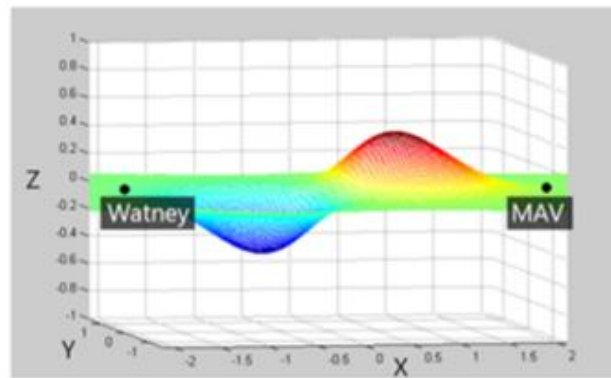


Figure 7: Dune at Schiaparelli Crater

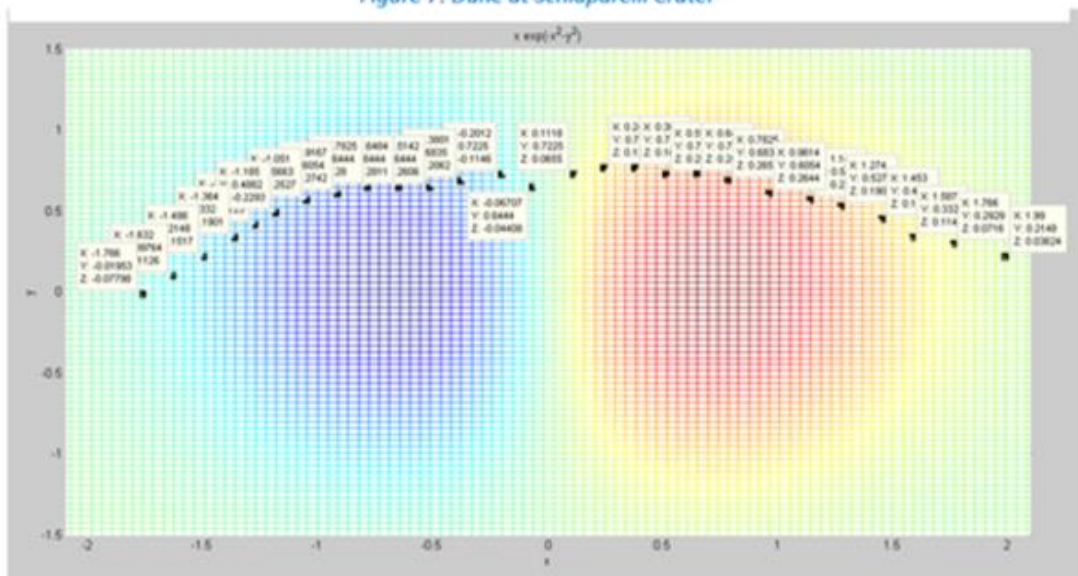


Figure 8: Path taken by Watney over the Dune

Figure 10. Finding a safe path for the astronaut.

## 4. Discussion

The examples above provide excerpts from the students' responses to the assessment tasks. These excerpts relate to the parts of the tasks where coding with MATLAB was involved. They give some insight into the nature of the tasks. The tasks referred to in this paper were selected from a set of ten tasks which are summarized below:

### Task 1: Striving for Accuracy

This task involves an analysis of the shooting technique of a famous basketballer. Students use mathematical modelling to compare trajectories and generate an animation of the flight of the ball.

### Task 2: Measuring Inequality

This task involves comparing distributions of wealth from different countries. Students adapt code for calculating numerical integrals and apply this to the financial context.

### Task 3: Cracking the Code

This task explores a variety of techniques that have been used throughout history to create secret codes. Students use commands and scripts to decipher coded messages.

### Task 4: Uncle Albert's Legacy – A Tale of Growth and Diversity

This task involves the use of linear programming to find optimal investment strategies. Students use commands and scripts to perform the simplex method.

### Task 5: Bring Him Home

This task involves rescuing an astronaut who has been stranded on Mars. Students use three-dimensional plotting to find a safe path for the astronaut.

### Task 6: Caught in a Rip

This task involves investigating the effects of rip currents. Students adapt code to generate a model of the progress of a freestyle swimmer and consider the implications of being faced with a rip current.

### Task 7: Flying High

This task involves an investigation into airfoils. Students learn about Bezier Curves and adapt code to generate airfoil shapes.

### Task 8: Foolin' Around with Fibonacci

This task involves an exploration of patterns in the Fibonacci sequence. Students use programming commands to investigate numeric patterns and visualizations associated with the Fibonacci sequence.

### Task 9: Toyin' Around with Triangles

This task involves an investigation into Pascal's triangle. Students use programming functions to explore patterns in the triangle and generate Sierpinski's gasket.

### Task 10: Function Families

This task involves an investigation into the effects of changing the parameters of a quadratic function. Students use a programming function to help them visualize the changes.

The tasks may be viewed in full from the academia section of the MathWorks website [5]. Full details of all the tasks are available via the hyperlink in reference [5] along with the associated MATLAB scripts, helpful video tutorials, and indicative responses. A description of the journey taken by Ormiston College in introducing MATLAB into mathematics assessment is also available from the company section of the MathWorks website [6] and can be accessed from the hyperlink given in reference [6].

Providing students with tasks that require the use of mathematical modelling for real world problem solving is consistent with the aims of curricula across the world. The OECD mathematics framework [8], for example, states that

“...an individual’s capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments, and to use and engage with mathematics in ways that meet the needs of that individual’s life as a constructive, concerned and reflective citizen.” (p.14)

In the United States, the Common Core State Standards Initiative – USA: [2] states that

“Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace.” (p.1)

In Australia, the Australian Curriculum Assessment and Reporting Authority [1], make the assertion that

“mathematics aims to ensure that students are confident, creative users and communicators of mathematics, able to investigate, represent and interpret situations in their personal and work lives and as active citizens.” (p.1)

The tasks not only connect with priorities associated with mathematical modelling and problem solving, they also relate to the meaningful use of technology in mathematics education. Moreover, the combination of mathematical modelling and technology brings opportunities to integrate with other disciplines. Of great significance in this regard is that mathematical modelling aided by the use of technology can be viewed as a bridge to STEM education [4].

Finally, the interaction between real world problem solving and the use of technology brings together generic skills that are beneficial for students of the 21<sup>st</sup> century. In the 21<sup>st</sup> Century Learning Design framework [3], teachers are encouraged to set extended tasks that promote Real World Problem Solving and Innovation. A student-centered use of technology is also encouraged in this framework whereby the students are actively engaged in the use of technology rather than being passive recipients. The excerpts from the students’ responses illustrate the students’ engagement with the problem solving and their active use of technology.

## 5. Summary

This paper has described how the use of MATLAB was introduced into high school mathematics assessment tasks. A collection of assessment tasks was produced as a result of a productive partnership between Ormiston College in Queensland, Australia, and the manufacturers of MATLAB. The tasks were designed to develop students’ skills in mathematical modelling for real world problem solving, and, at the same time, give them experience in using technology that they are likely to use in STEM-related courses after school. Actual excerpts from students’ responses were

reproduced which illustrated how the students dealt with incorporating the use of this technology into the mathematical modelling and problem solving tasks. Giving students experience with both mathematical modelling for real world problem solving, and the use of technology was shown to be consistent with current international perspectives in education.

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