**GMAPS**

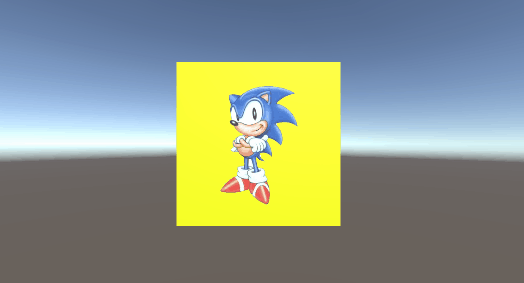
[A picture containing text, table, vector graphics

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**Matrices**

**Worksheet**

**To see the additional comments and resources, make sure you select All Markup in the Review/Tracking pane**



Important note

**PART 1: HMatrix2D**

**Question 1**

Unity has a **Matrix4x4** class, but just like for vectors, we’ll create our own class called (surprise!) **HMatrix2D**.

Download the file **HMatrix2D.txt** from the **Matrices** section on LMS:

Graphical user interface, text, application

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This is a template for the **HMatrix2D** class you will create.

1. Open your **GMAPS\_Oct\_2023\_Worksheets\_STUDENT** Unity project, then add a new script called **HMatrix2D.cs** inside the **Math** folder.

This is a matrix for 2D coordinate space, but because of the h value, we must declare a 3x3 array to store the matrix values.

Do that now:



1. There are THREE constructor functions in the template code.

A screenshot of a computer

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This means we have three ways to initialise a HMatrix2D object when we instantiate one.

Remember that if we multiply a matrix A with the **identity** matrix **In**, then the result of that multiplication is just **A**, i.e. no change.

So, we would like the first constructor to initialise the matrix to the identity matrix.

But we might want to set an HMatrix2D object to identity at any time, e.g. if we have to reset it for some reason. In this case, we should create a function to do this, which we can run any time.

Complete this code:

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Create another C# script called **TestMatrix.cs**.

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Create a **new** **empty game object** in the scene called TestMatrix, add TestMatrix.cs to it, and run the project. You should see this output:

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1. The code in **SetIdentity()** is rather verbose (long-winded).

It can be simplified using what is called the **ternary operator**.

Comment out (don’t delete) the original code, and replace it with the ternary operator version.

Chart

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Text

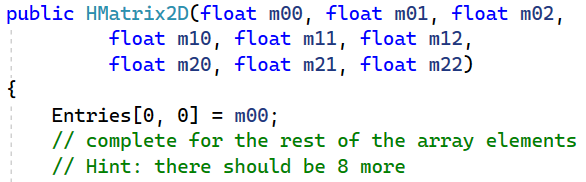
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1. Now you must implement the other two constructors.

Chart, timeline

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and …



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So far, you should understand what the HMatrix2D class is for, and how to create and initialise an HMatrix2D object.

This will be used to perform matrix math, rather than Unity’s built-in Matrix4x4 class.

**Question 2**

The next thing you should do is implement functions for the basic arithmetical operations for HMatrix2D: **add**, **subtract**, and **multiplication** **by a scalar** value.

1. Implement these arithmetical functions now.

Refer to your lecture slides and complete this code:

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If you need a refresher on **operator overloading**, look here.

You also need to check if two HMatrix2D objects are **equal or not**.

1. Now, you must implement checking for equality.

Complete this code:

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Inside the **if statement**, you need to check if any two corresponding elements are *not* equal.

If not equal, then the HMatrix3D objects aren’t equal, so return false.

If after looping across all the elements none of them cause a false return, then return true (the HMatrix2D objects are equal).



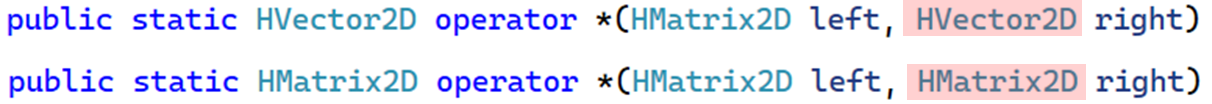
For the **!=** operator, simply reverse where the function returns true and false.

Now you have to think about the more complex multiplication of:

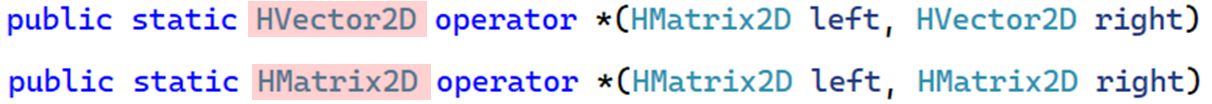
* matrix and vector
* matrix and matrix

In fact, the multiplication of a matrix with a vector is performed the same way as for two matrices, since a vector is really just a matrix.

But because our code defines HMatrix2D to represent a matrix, and HVector2D to represent a vector, we need a separate function for multiplying a matrix and a vector, as shown below:



Also, a matrix-by-matrix multiplication returns another matrix, but a matrix-by-vector multiplication returns a *vector*:



So, we need a \* function with arguments for HMatrix2D and HVector2D objects, and another function with two HMatrix2D arguments.

This is why we must overload the \* operator.

1. Implement the overloaded \* operator function for **HMatrix2D \* HVector2D**.

Chart

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This multiplies left (a HMatrix2D object) and right (a HVector2D object), and returns a new HVector2D object.

Remember that HVector2D has three values: **x**, **y** and **h**.

So why does the function above only calculate the top *two* HVector2D values (for x and y)—what about h?

Looking at the HVector2D constructor, the answer is clear: you’ll see that it takes two arguments, **x** and **y**, and that the third value for **h** is automatically set to 1.

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Remember that HVector2D is a 2D vector, with only x and y values. But it also has an extra h value. The h value is always 1, so we can just set it automatically in the constructor.

1. Implement the overloaded \* operator function for **HMatrix2D \* HMatrix2D**.

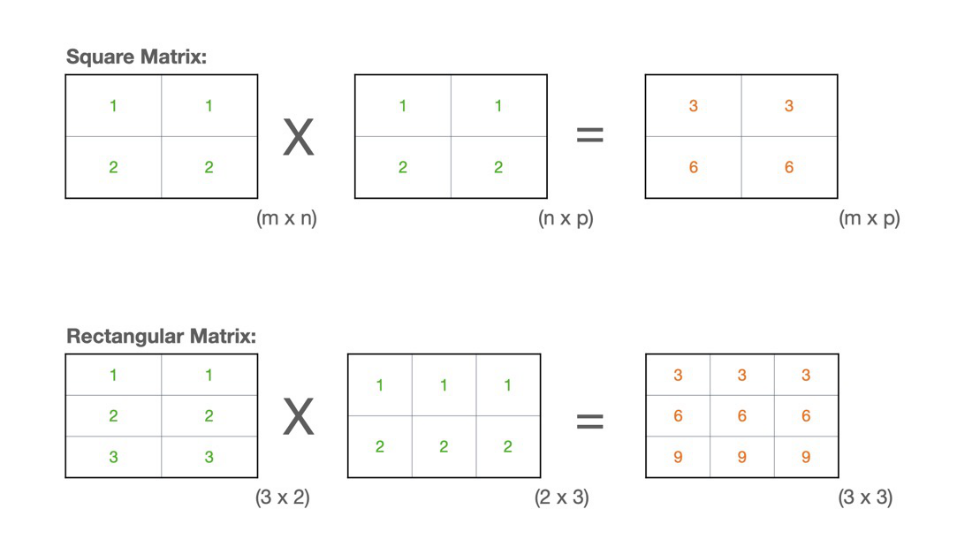
The first two elements in the array in the HMatrix2D template are given. You must complete the rest of the entries.

The code in the template simply hardcodes all the rows and column indexes, and then multiplies these together as shown in your lecture slides.

This is ok for small matrices, but 4x4 matrices and larger would need a more sophisticated approach.

If you search online, you might end up with more complex code that you won’t properly understand, and which isn’t *really* necessary for a small matrix.

*But* you can take a look at this link: <https://www.geeksforgeeks.org/c-program-multiply-two-matrices/>



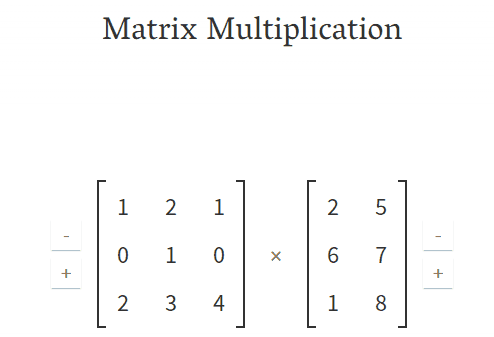
The algorithm can multiply together two square or rectangular matrices of any size.

If you’re able show that you understand the code when you submit your project (properly commenting every line, and with a high-level description of the algorithm in a comment above the function), then you can choose to use this more general approach instead.

1. In **TestMatrix**, add a function called **Question2()**.

Go to this URL:

<http://matrixmultiplication.xyz/>



Try various combinations of 3x3 \* 3x3 and 3x3 \* 3x1 matrices to multiply. You can step through to see the matrix multiplication in action.

Declare three HMatrix2D objects, **mat1**, **mat2**, and **resultMat**. Also declare one HVector2D object, **vec1**.

For each multiplication that you try at the website above, test that the result is the same when you run Question2() in Start().

Check that both overloaded \* operator functions work in your code.

Text

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**PART 2: Application**

**Question 3**

Now you’ll implement **SetRotationMatrix** and **SetTranslationMatrix**.

1. Complete this code (refer to your lecture slides for 2D rotation matrices):

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1. Complete this code (refer to your lecture slides for 2D translation matrices):

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Now you have most of HMatrix2D finished!

Before applying a matrix to transform a game object, we need to access the game object’s *vertices*.

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Look at **MATRICES\_worksheet/Sonic/MeshManager.cs**.

This uses Unity’s **MeshFilter** component to access a game object’s **sharedMesh** vertices and store these in a Vector3 array called **vertices**.

Here’s Unity’s documentation for MeshFilter:

* <https://docs.unity3d.com/Manual/class-MeshFilter.html>

Watch these Unity videos about object meshes:

* <https://www.youtube.com/watch?v=cKJ6dQfgcAU>
* <https://www.youtube.com/watch?v=m3pblzmvFpE> (only need up to 1:30)

Read this Unity forum question:

* <https://forum.unity.com/threads/mesh-vs-shared-mesh-in-procedural-generation.583957/>

**Question 4**

1. Answer the questions below. Make sure you read the code carefully. Expand the answer text box if necessary.
2. Explain *in your own words* what MeshManager’s Awake() function does.

Before the game begins, the script creates a copy of the mesh and overwrites the original mesh as well as storing the vertices and triangle variables. The original mesh still remains stored in memory while we alter the cloned mesh instead.

1. Explain what problem will occur if you don’t use a *cloned* mesh in this code, and how to fix it.

Look here for a hint:

<https://www.kodeco.com/3169311-runtime-mesh-manipulation-with-unity/>

By not using a cloned mesh, we would be directly altering the original mesh and if it is used anywhere else it would not be able to be used. In order to fix this, you would need to end the application and restart it, stopping the runtime.

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1. Create a new script called **TransformMesh.cs** and add it to the Sonic prefab. Then drag an instance of the Sonic prefab to the scene. This should already have a **MeshManager** script attached (if not, add it).

Reset Sonic’s position to the origin.

Add these variables to TransformMesh:

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What each variable represents is discussed below.

|  |  |
| --- | --- |
| vertices | These are the copies of the vertices of the sprite mesh’s vertices which are copied and stored by MeshManager. These are used to transform (translate, rotate and scale) the sprite, otherwise the sprite mesh will have the transformation permanently applied. |
| transformMatrix | This is the matrix object, which is of type HMatrix2D (this is the matrix class you defined earlier in this worksheet). You will use the SetTranslationMatrix and SetRotationMatrix methods of this class to set transformMatrix to translate or rotate the sprite. |
| meshManager | This is an instance of MeshManager, which is used to obtain a copy of the sprite’s vertices. |
| pos | This is the current position of the sprite. When rotating or scaling, the sprite must be translated to the origin, then rotated or scaled, then translated back to its original position. See the diagram below. |

Look at the diagram below. To rotate or scale a game object, we must (a) first move it to the origin, (b) perform the rotate or scale transformation, and then (c) move it back again.

A picture containing shape

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The matrices declared in (b) above represent these different transformation steps.

* **toOriginMatrix**

The translation matrix for translating a vertex position in step (a).

* **toOriginMatrix**

The translation matrix for translating a vertex position in step (c).

* **rotateMatrix**

The rotation matrix for step (b).

* **transformMatrix**

The final transformation matrix, which concatenates all the matrices above (we’ll look at this later), e.g., for rotation, we perform this matrix multiplication:



This lets us perform all the separate steps as a single step! In other words, multiple transformations can be concatenated into a single *composite* transformation. This is why we use *homogeneous* coordinates.

Remember that the matrix multiplication order is right-to-left.

* **pos** is the current position of the game object stored as a HVector2D object.

Text

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**Question 5**

Next, we’ll apply the various transformations to the Sonic sprite mesh.

Complete the steps below. Make sure you read the code carefully.

1. Add the code below to **TransformMesh**:

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**MeshManager** has been added as a component script to the Sonic sprite game object, so we obtain a reference to it, which is stored in **meshManager**.

Then, we store the current position of the Sonic sprite in **pos**.

If we run the scene, nothing happens! This is because we don’t have any methods for transforming the sprite.

We’ll add three methods:

* **Translate**
* **Rotate**
* **Transform**

1. Write the **Translate** method. It will look like this:

A screenshot of a computer code

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You’ll get a compilation error, because you haven’t written the **Transform** function yet.

1. Write the **Transform** method. It will look like this:

A screenshot of a computer program

Description automatically generated

Now you have the Translate function and Transform function.

1. Modify the **Start** method so that the Sonic sprite is moved by (1, 1).

Hint: You need to call the **Translate** method. The sprite might move outside the game window, so view the transformation in the Scene view.

A screenshot of a video game

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You have moved the sprite using a direct matrix multiplication! You didn’t use any built-in Unity API function calls, such as Transform.Translate().

Give yourself a high-five 😊

1. Now try to implement and use the **Rotate** function.

This is more tricky, and you’ll have to refer to the lecture slides.

Remember that we will use these matrices:

* **toOriginMatrix**
* **toOriginMatrix**
* **rotate Matrix**

These are multiplied together *in reverse order*, and stored in **transformMatrix**.

Some clues are given in the code below.

A screenshot of a computer program

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Now you should be able to call the Rotate method to rotate the Sonic sprite mesh:  
  
A cartoon character on a yellow diamond

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Again, you’ve used only direct matrix multiplication, with no Unity API calls. Another high-five! 😊

It’s left as an extra exercise for you to implement scaling.

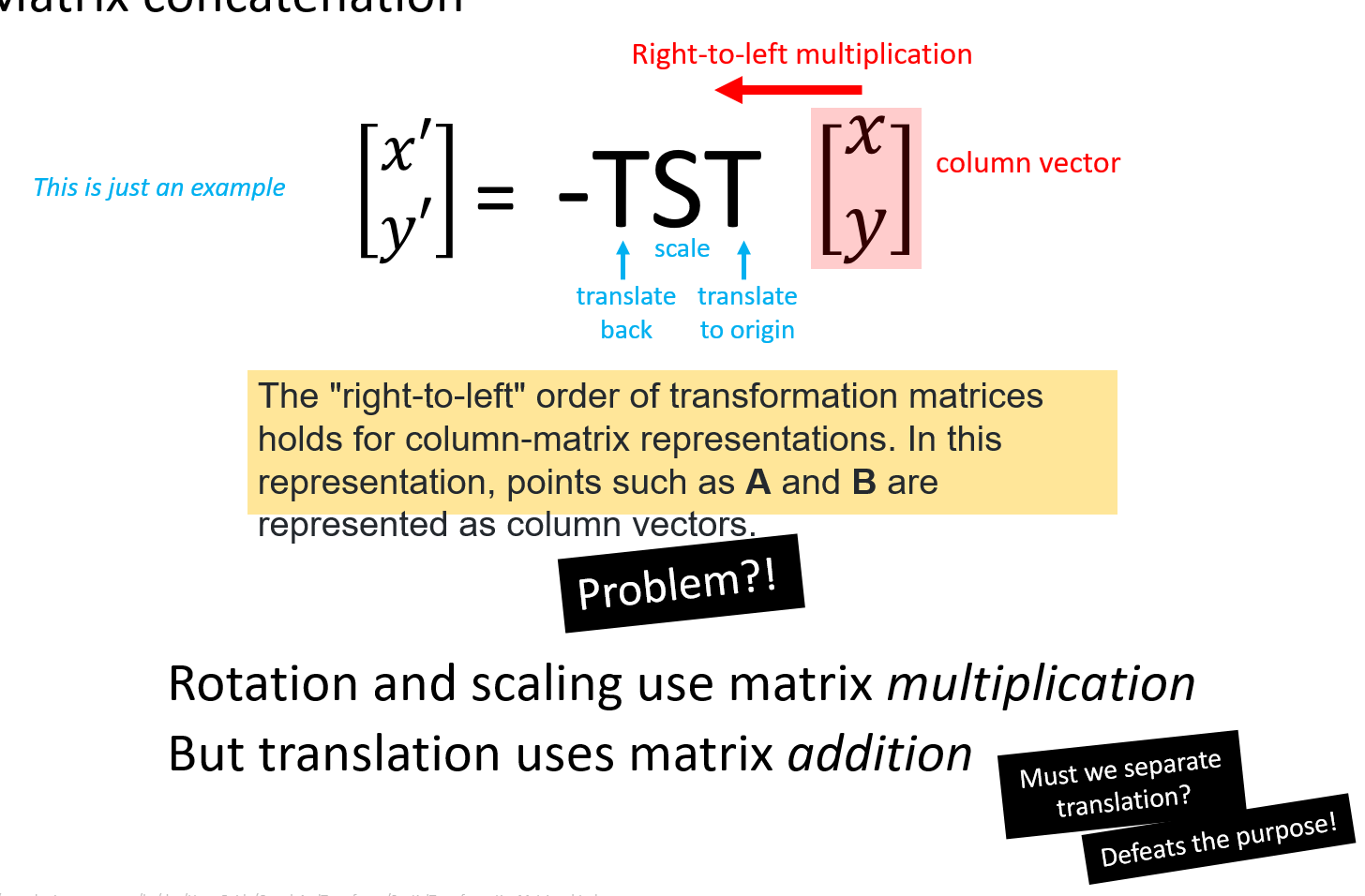
**PART 3: Reflection**

**Question 6**

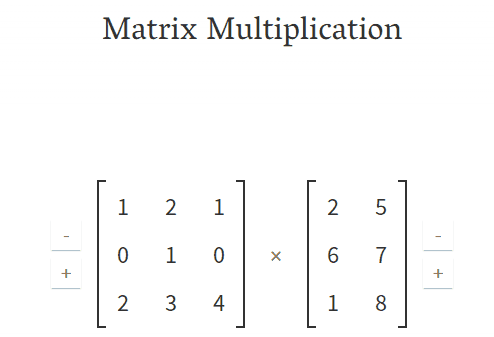
1. What was the most difficult part of this worksheet? Explain why you found it difficult, and how you managed to overcome this (if at all).

Answer) I feel that the most difficult part of this worksheet was doing the HMatrix2D script without a proper understanding of the matrix concepts. I found that when I was attempting to do the HMatrix2D script, not only could I not test the script itself, I had trouble understanding the concepts of matrices, especially matrix multiplication and concatenation

As a result it caused several problems such as with my matrix transformation and concatenation used in the sonic sprite manipulation. I ended up having to ask my lecturer for assistance with the code itself, while also doing a lot of self-learning and research to understand the matrix concept as a whole. For example, I took many hours to break down the matrix concatenation into smaller chunks, by attempting to look at each individual part of the equation in an attempt to understand what it meant.



I also used the method used in this gif to attempt to understand the matrix multiplication as well



Aside from that, I also attempted to do the calculations using a pen and paper myself, this allowed me to get a better understanding of the math as I have never been able to learn math without doing practices to train myself. Using these 3 methods, I was eventually able to fix the problems with my HMatrix2D script, resolve the remaining issues with my SetTranslationMat() and SetRotationMat() scripts for the sonic sprite and finish this worksheet.

1. Choose a matrix topic that you are still unsure about. Explain that topic, and the steps you will take to clarify your doubts. You will be graded on how well you analyse your problem with understanding that topic.

If you are confident about all the topics, select what you consider to be the most difficult topic and explain ONE more advanced concept related to the topic. You will be graded on the complexity of the concept, and how well you explain it.

Answer) I am still unsure about matrix multiplication. Matrix multiplication is used to combine different transformations together into a single matrix. These transformations include translation, rotation, and scaling. This is done by multiplying the individual transformation matrices together before applying the final transformation matrix to the vertices of 3D and 2D models. My biggest problem with understanding matrix multiplication is when I also have to do concatenation. From my understanding, this is when matrices are combined in a certain order, and I could never properly understand what or how the combination should be.

So, some steps that I took to clarify my doubts were things like firstly, identifying which parts I could not understand and finding the corresponding slides in the powerpoint. Next, I would try to ask my lecturer to explain the slides to me properly and 1-to-1. If that didn’t work, I would attempt to research on my own by looking online on Google as well as asking questions on ChatGPT or forums like Mathematics . This is so that I can attempt to understand better and get different opinions and explanations. My hope was that I could either find overlapping explanations to confirm what I was reading was correct, and that multiple answers could fill in any gaps that were missed out.

1. Write a reflection about this worksheet. You may like to include how effective it is to motivate and help you learn, how well it relates to games development, etc.

Answer) Overall, I found this worksheet challenging. My math has never been strong and this worksheet really left me stumped for a while. It was very demotivating at times when I would attempt to debug my program for a question for hours and be unable to solve it, however the reverse was true too. When I managed to solve a question, I would feel a boost of confidence and be motivated to work on the next question.

This worksheet was also very effective because I needed to do a lot of self-learning and research of my own to understand the topics that were covered and needed to be used to write the programs in Unity.

I think that this worksheet does relate well to game development. In most games, having physics is a vital element, however we won’t always be able to use game engines like Unity, Unreal or any other engine that has physics built into it. By doing this worksheet I now have a better sense of how I can add these functionalities into the game or even into the game engine itself without relying on anything else. This will also give me the ability to make my own custom physics in games that could either build on the physics in the game engine or create my own physics entirely. Plus the game engine may not always have the physics that I want, so I can now manipulate the game engine and adjust its physics with my own additional customisation.