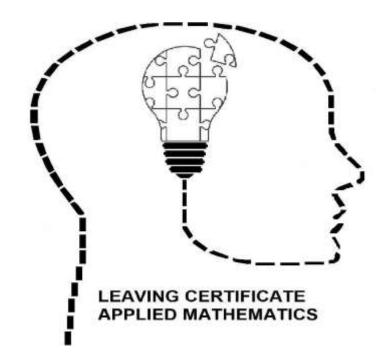


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Supporting the Professional Learning of School Leaders and Teachers



Applied Mathematics Professional Learning Booklet 2023-2024





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Supporting the Professional Learning of School Leaders and Teachers



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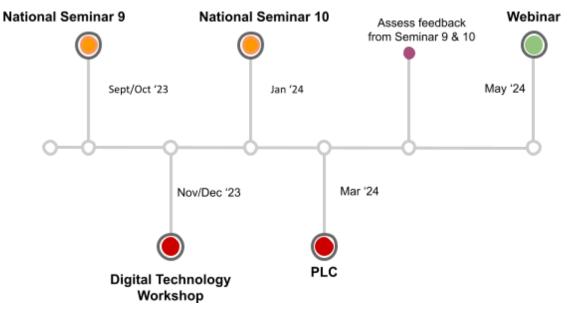


Introduction

Schedule

09:30 - 11:00	Reviewing the journey so far and supporting students with the modelling project
11:00 - 11:15	Tea and Coffee
11:15 - 13:00	Modelling with Multi-Stage Dynamic Programming
13:00 - 14:00	Lunch
14:00 - 15:30	Exploring Difference Equations

Overview Of Professional Development





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Key Messages

1. Core to the specification is a non-linear approach empowered by the use of rich pedagogy which promotes the making of connections between various Applied Mathematics learning outcomes.

2. Strand 1 of the specification is a unifying strand and emphasises the importance of utilising modelling across all learning outcomes.

3. Applied Mathematics is rooted in authentic problems as a context for learning about the application of Mathematics to design solutions for real-world problems and to develop problem solving skills applicable to a variety of disciplines.

Session 1

Discussion - Taking Stock

Now that the first two year cycle of teaching the specification has been completed,

What have your main takeaways been?

What has been your biggest learning as a teacher?







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Preparing For The Modelling Project

Having supported students in completing the first modelling project in 23/24,

What three nuggets of wisdom would you give a teacher who is engaging with it for the first time this year?

Supporting Students With The Project

How best can teachers support students,

before ...

during ...

after ...

the	model	ling	pro	ect?





Formulating Problems

Mathematical Modelling

Computing Solutions

Modelling Problem

Complete a mathematical modelling problem based on the following context:

The 2024 European football Championship takes place at multiple venues across Germany in June/July. A key feature of a team's preparation for this is planning the logistics of travel, accommodation, purchasing and allocating stock for the team and scheduling a team's itinerary.

Select one or more aspects of logistical planning and model the problem(s) you have selected using The Modelling Cycle.



Formulating The Problem

What is your problem statement and what research must you do? What variables (factors) are relevant to the problem? Can you simplify the problem into smaller manageable parts? Consider if there are limitations to your model due to your chosen assumptions? Can you predict what the output of your model will achieve?

What problem statement could students initially choose to investigate?

What research and assumptions would be required for students?





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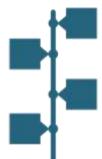
Advice From Other Courseworks



Plan A Suitable Project Timeline

How will you allocate your class time from when the project is released to when it is submitted?

In groups, discuss an appropriate timeline for students' engagement with the project and how teachers will support them during this timeframe.



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Reflection

What were your key takeaways from this session?

How can you implement ideas from this session into your teaching?

What are the next steps for enhancing students' modelling skills in your classroom?



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Session 2

Dynamic Programming with Multi-Stage Authentic Problems

Strand 2 Support



Seminar 1:	Introduction to Networks and Graph Theory, Algorithms and
	their applications

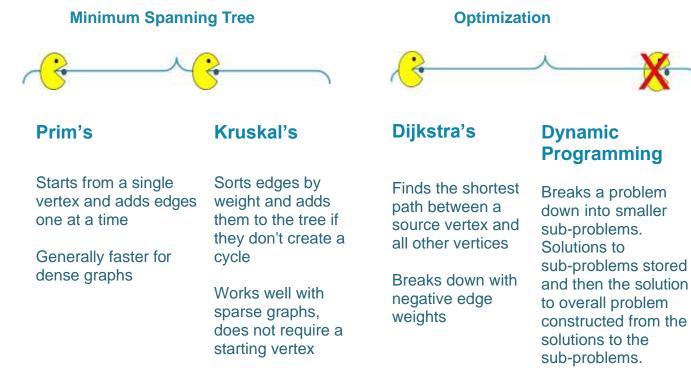
- Seminar 2: Development of Dijkstra's Algorithm through Modelling
- Seminar 4: Project Scheduling
- Seminar 5: Bellman's Principle of Optimality and Dynamic Programming
- Seminar 8: **Exploring Project Scheduling with Project Scheduling** Diagrams

All slides and relevant resources available on:

https://pdst.ie/post-primary/sc/appliedmaths/cpd-resources



Strand 2 Algorithms



Dynamic Programming

- Dynamic Programming is not greedy
- Uses backward recursion, it takes an overall view of a problem.
- Can handle maximum and minimum problems easily and negative edge weights.
- Easily applicable to problems given in the form of a table.

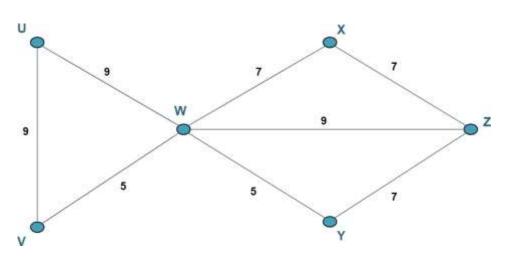
Main disadvantages: requires a staged network and as it stores sub-problems, the time cost and space required to implement are higher.





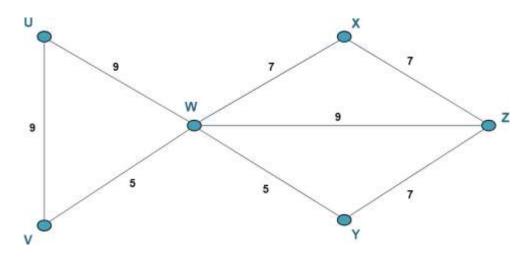
Strand 2 Algorithms Reviewing Prim's and Kruskal's

Find a minimum spanning tree for the below network using Prim's and then Kruskal's Algorithm. There are 4 possible solutions.



Strand 2 Algorithms Reviewing Dijkstra's Algorithm

Apply Dijkstra's algorithm to find the shortest path from U to Z.

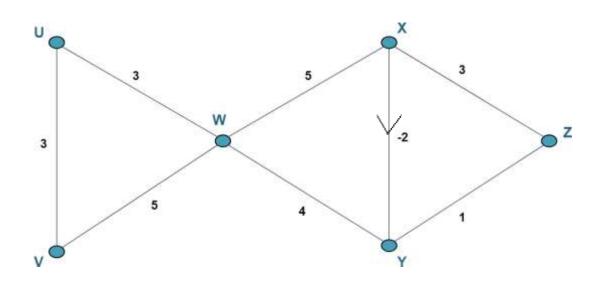




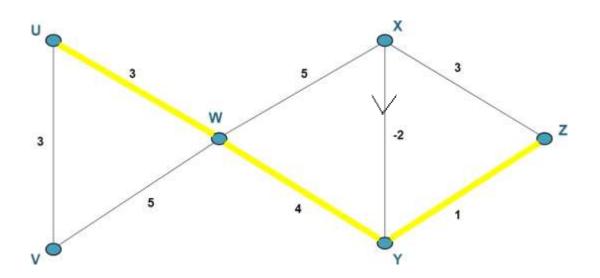
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Strand 2 Algorithms Reviewing Dijkstra's Algorithm

Apply Dijkstra's to find the shortest path from U to Z in this network. Does it yield a correct solution?



Applying Dijkstra's gives a shortest path of UWYZ (shown below) with a total weight of 8. Is this correct, Is there a shorter path?





Strand 2 Algorithms Applying **Dynamic Programming**

Dynamic Programming is based on Bellman's Principle of Optimality

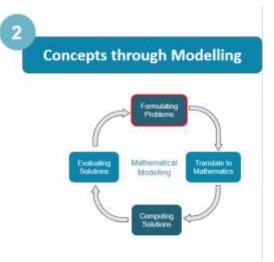
Any part of the shortest/longest path between the source and sink nodes is itself a shortest/longest path

Or: 'any part of the optimal path is itself optimal'

Interpreting a Real-World Problem

In many real-world settings the management of stock is an important consideration.

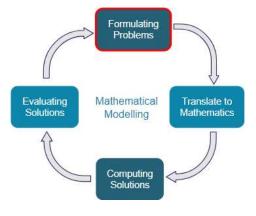
Choose a real-world problem related to the distribution or management of stock and model the problem(s) you have selected using The Modelling Cycle.





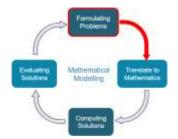
Interpreting a Real-World Problem Formulating Problems

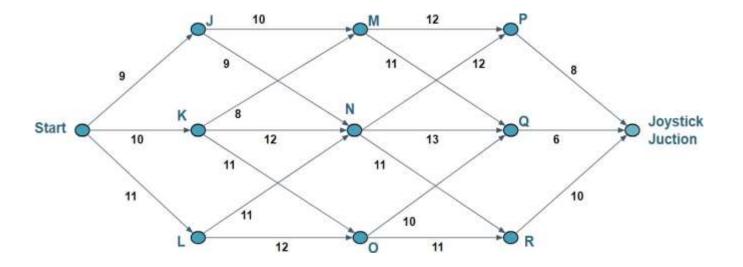
Problem Statement: Joystick Junction has the last remaining stock of a new games console. What is the best route to take to get to Joystick Junction on the other side of the city?



The Modelling Cycle Translating to Mathematics

The city can be represented with a simplified network shown below and Bellman's principle can be applied directly to the network.



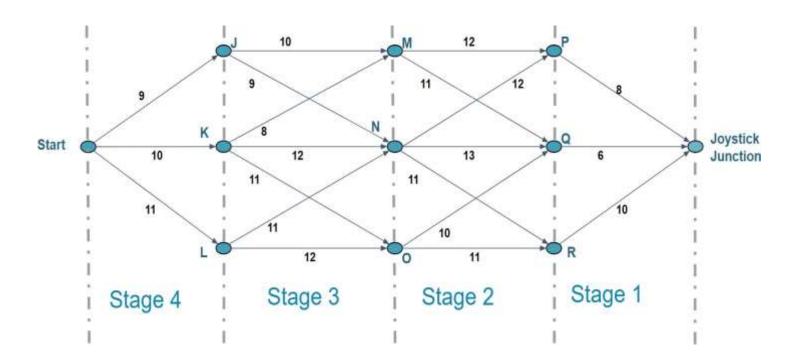




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The Modelling Cycle Computing Solutions

This shortest route problem can also be solved using an analogous table method. The first step is to identify the stages working backwards from the end point as shown below.





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The Modelling Cycle Computing Solutions

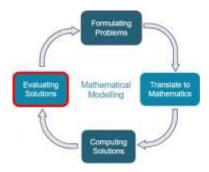
Use a table method to find the shortest route to Joystick Junction

Stage	State	Action	Value
	Р	JJ	0+8 = 8*
1	Q	JJ	0+6 = 6*
	R	JJ	0+10 = 10*
	м	Р	12 + 8 = 20
	IVI	Q	11+6 = 17*
		P	
2	N	Q	
		R	
	0	Q	
	0	R	
	4	M	
	J	N	
		М	ţ
3	ĸ	N	
		0	
	Ĩ.	N	
	L	0	
		J	
4	Start	K	
		L	

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The Modelling Cycle Evaluating Solutions



Interpret your mathematical solution(s) in the context of the problem you are modelling.

How accurate and reliable is your solution based on your earlier assumptions?

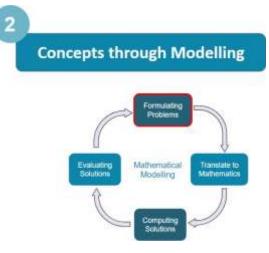
How can you refine your assumptions to improve your solution and how will this change your solution?

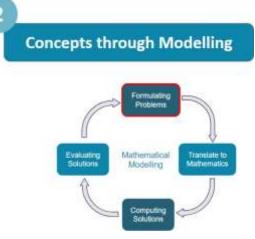


Interpreting a Real-World Problem Formulating Problems

In many real-world settings the management of stock is an important consideration.

Choose a real-world problem related to the distribution or management of stock and model the problem(s) you have selected using *The Modelling Cycle*.









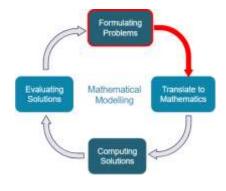
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The Modelling Cycle Formulating Problems

A games manufacturer needs to distribute 500 games consoles every month and can allocate these in multiples of 100 to three different retailers. The distributor fee/profit, in €100s, for the number of units allocated to each retailer is shown in the table.

	Numbe	r of cons	soles allo	cated (x	100)
Retailers	1	2	3	4	5
Joystick Junction	11	25	30	32	33
Button Bashers	15	16	17	18	19
Gamers Grotto	7	14	21	28	35



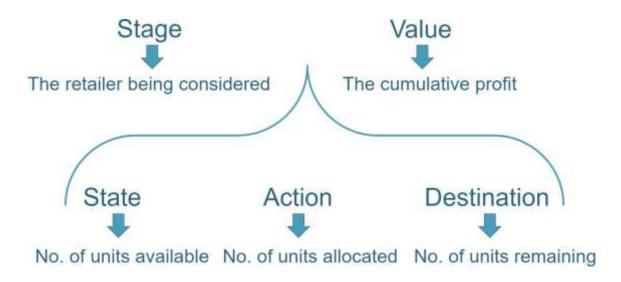
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The manufacturer wants to know how many consoles should be allocated to each retailer to maximise their monthly income.



Use the table to figure out the best way to allocate the 500 consoles in order to maximise the distributor fees/profit.

Stage	State (Units Available)	Action (Units Allocated)	Destination (Units Remaining)	Value (Cumulative Profit)
	0	0	0	0*
	1	1	0	7*
Comment Commente	2	2	0	14*
Gamers Grotto	3	3	0	21*
	4	4	0	28*
	5	5	0	35*
	0	0	0	$0 + 0 = 0^*$
	1	1	0	15 + 0 = 15*
	T	0	1	0 + 7 = 7
		2	0	18 + 0 = 18
	2	1	1	15 + 7 = 22*
		0	2	0 + 14 = 14
		3	0	
	3	2	1	
	5	1	2	
		0	3	
Button Bashers		4	0	
		3	1	
	4	2	2	
		1	3	
		0	4	
		5	0	
		4	1	
	5	3	2	
	5	2	3	
		1	4	
		0	5	
		5	0	
		4	1	
Joystick Junction	5	3	2	
JOYSUCK JUNCHUM	5	2	3	
		1	4	
		0	5	



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The Modelling Cycle **Evaluating Solutions**

Interpret your mathematical solution(s) in the context of the problem you are modelling.

How accurate and reliable is your solution based on your earlier assumptions?

How can you refine your assumptions to improve your solution and how will this change your solution?

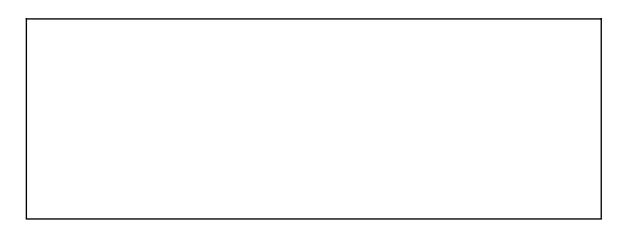
Reflection

What were your key takeaways from this session?

What considerations are needed to take this learning back to your classroom?



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Session 3

Exploring Difference Equations

Prior Knowledge

Difference Equations

A Recurrence relation is an equation that defines a sequence where the next term is a function of the previous term(s).

This mathematical relationship often involves the differences between successive values of a function of a discrete variable - hence the expression Difference equations.

- 4, 7, 12, 19, 28, 39,
- 0, 1, 3, 14, 57, 227, 966,
- 0, 1, 1, 2, 3, 5, 8, 13, 21
- 1, 2, 2, 4, 8, 32, 256,

Prior Knowledge Recall - Word Problem from National Seminar 3

According to legend King Shirham of India wanted to reward his servant for inventing and presenting him with the game of chess. The desire of his servant seemed modest: "Give me a grain of wheat to put on the first square of this chessboard, and two grains to put on the second square, and four grains to put on the third, and eight grains to put on the fourth and so on, doubling for each successive square, give me enough grain to cover all 64 squares."

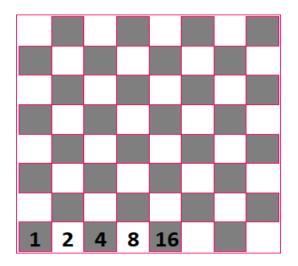
"You don't ask for much. Your wish will certainly be granted" exclaimed the king.

Based on an extract from "One, Two, Three...Infinity", Dover Publications





Prior Knowledge Junior Certificate Mathematics

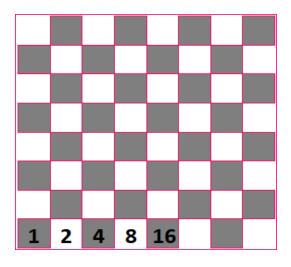


T, = 1	$T_1 = 1 = 2^0$
T ₂ = 2	$T_2 = 2 = 2^1$ $T_3 = 4 = 2^2$
$T_{3} = 4$	$T_3 = 4 = 2^2$
$T_{4} = 8$	$T_4 = 8 = 2^3$
T ₅ = 16	$T_5 = 16 = 2^4$
$S_{64} = 2^0 + 2^1 + 2$	$2^{2} + 2^{3} + 2^{4} + \dots + 2^{63}$

N N N 8

$2 \times S_{64} = 2^{1} + 2^{2} + 2^{3} + 2^{4}$ $- S_{64} = -(2^{0} + 2^{1} + 2^{2} + 2^{3})$	
$= 2^{64} - 2^0 = 2^{64} - 1$	$S_{64} = 2^{64} - 1$

Prior Knowledge Leaving Certificate Mathematics



	T, = 1	$T_{1} = 1 = 2^{\circ}$
	$T_{y} = 2$	$T_2 = 2 = 2^1$
	$T_{3} = 4$	$T_3 = 4 = 2^2$
	T, = 8	$T_4 = 8 = 2^3$
	T. = 16	$T_{s} = 16 = 2^{4}$
Recu	irrence relat	tion $T_n = 2^{n-1}$ neN, n>1
Recu		
Recu	S ₆₄ = 1 + 2 This a geor	tion $T_n = 2^{n+1}$ neN, n>1



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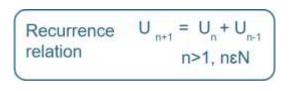
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What Decides the Order of an **Equation**?

Consider the sequence of numbers:



0, 1, 1, 2, 3, 5, 8, 13, 21

Order = difference between the iterates = (n+1)-(n-1) Order = 2=>

This equation is called homogeneous because each term is determined by its previous terms only.

Determine the order of the following

Difference Equation	Order of the Equation	Homogeneous or InHomogeneous
5U _{n+1} +6U _n =0	1	Homogeneous
$3U_{n+2} + U_{n+1} - 2U_n = 0$	2	Homogeneous
$U_{n+2} - 9U_n = 0$	2	Homogeneous
$U_{n+3} - 5U_{n+1} + 6 = 0$	2	InHomogeneous



Characteristic Equation

A Characteristic Equation assists us in determining an expression for any term whether we know its preceding terms or not.

Consider the 2^{nd} order difference equation $U_{n+2} - 5U_{n+1} + 6U_n = 0$ We see the coefficients of each term are $1U_{n+2} - 5U_{n+1} + 6U_n = 0$

Difference Equation	Homogeneous or	Characteristic	Roots of
	InHomogeneous	Equation	Equation
$U_{n+2} - 5U_{n+1} + 6U_n = 0$	Homogeneous	$1X^2 - 5X + 6 = 0$	X=2 , X=3

Group Work

In groups, consider the 2nd Order homogeneous difference equations shown and determine both the characteristic equation and the roots of those equations.

$$5U_{n+2} - 6U_{n} = 0$$
$$3U_{n+2} + U_{n+1} - 2U_{n} = 0$$
$$U_{n+2} - 6U_{n+1} + 9U_{n} = 0$$



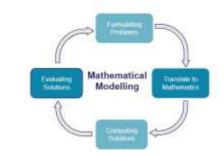


Mathematical Modelling Brief

In many real-world settings the management of stock is an important consideration.

Concepts, then Modelling

Choose a real-world problem related to the distribution or management of stock and model the problem(s) you have selected using The Modelling Cycle.



Mathematical Modelling Problem

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Problem Statement:

Determine the population of trout in the river Slaney over the next few years, following the introduction of a small number of trout to the river prior to their annual breeding season.





Student-Led Enquiry

In groups,

- discuss what background research that students might consider conducting in order to bring clarity to this problem.
- consider any assumptions students may make.



Outcome of Discussion

At the start of 2021 biologists introduced twelve trout to an isolated area of the river just before their annual breeding season.

They found that the population had **doubled** by the start of 2022.

The biologists responsible assumed that the current population of trout may be modelled using a difference equation.





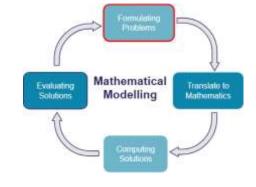
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Formulate the problem - Assumptions

The biologist assumed that the current population of trout may be modelled by the following difference equation:

 $P_n = 2.1 P_{n\text{-}1} \text{ - } 0.9 P_{n\text{-}2}$ where P_n is the current population of trout in the river and $n \epsilon N.$

 $P_0 = 12 \mbox{ in } 2021$, $P_1 {=} 24 \mbox{ in } 2022$



Determine the Population of Trout

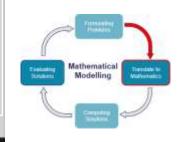
Translate to Mathematics

 $P_n = 2.7P_{n-1} - 1.8P_{n-2}$ where P_n is the current population of trout in the river and $n \in N$.

What type of equation does this represent?

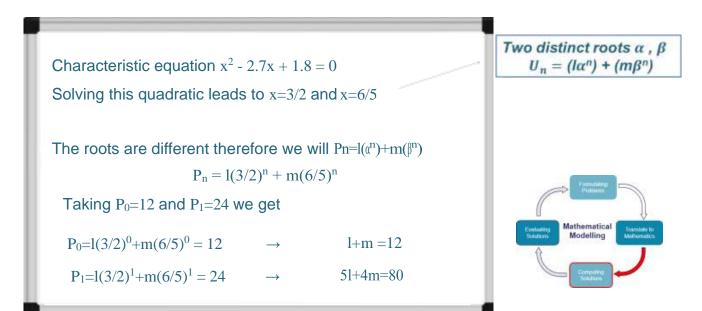
We have to

- (i) Solve this difference equation.
- (ii) Calculate the population of trout for say the following two years

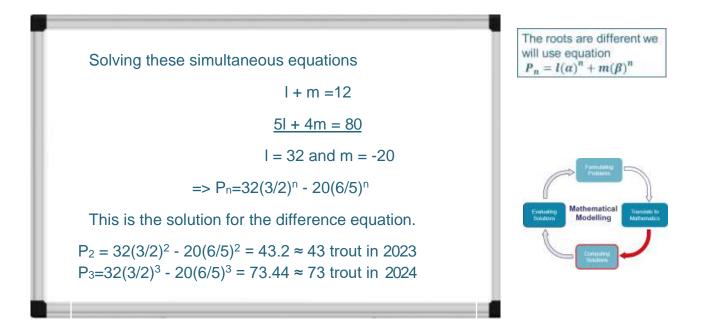




Computing the Solution



Determine the Population of Trout Computing the Solution





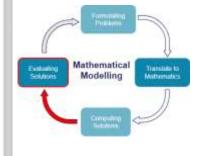
Evaluating the Solution

12 trout in 2021 43 trout in 2023

24 trout in 2022 73 trout in 2024

Does this seem accurate based on earlier assumptions?

What effect would changing your variables/assumptions have on your solution?



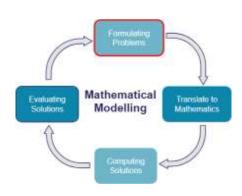
Determine the Population of Trout

Formulate the problem - Assumptions

The biologists, flush with success, adjusted their model to factor in the redistribution of trout to other Irish rivers.

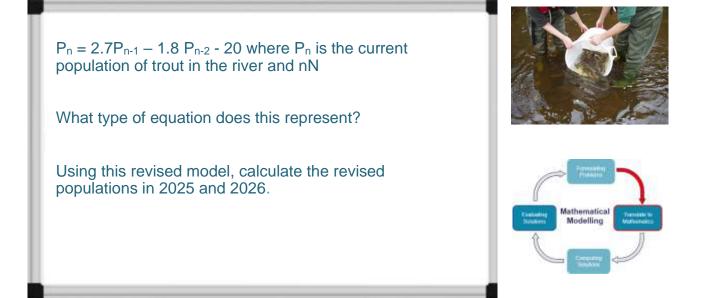
At the start of 2025 Biologists plan to **remove twenty** trout from the Slaney and rehome them in rivers throughout the country.

The biologist revised their model as follows: $P_n = 2.7P_{n-1} - 1.8P_{n-2} - 20$ where P_n is the current population of trout in the river and nEN





Translate to Mathematics



Determine the Population of Trout

Computing the Solution

Taking P_0 =43 and P_1 =73 F(n) Particular solution Population in 2025 $\underline{P}_n = 2.7(73) - 1.8(43) - 20 = 99.7 \approx 99$ trout in 2025 constant constant a an + bPopulation in 2026 Pn = 2.7(99) – 1.8(73) - 20 = 115.9 ≈ 115 trout in 2026 Kn+c an + bKn² $an^2 + bn + c$ Kn² + In + m Revised modelling Equation: $P_n = 2.7P_{n-1} - 1.8P_{n-2} - 20$ an² + bn + c ap" + b kp" $P_n - 2.7P_{n-1} + 1.8P_{n-2} = 20$ Rearranging to find particular solution: - 2.7P_{n-1} + 1.8P_{n-2} = 0n-20 <u>P</u>n -2.7(a(n-1)+b) + 1.8(a(n-2)+b)= 0n-20 (an+b) + 1.8(an-2a+b) = 0n-20 -2.7(an-a+b) an+b Mathematical -2.7an + 2.7a -2.7b + 1.8an -3.6a + 1.8b = 0n-20 an+b Modelling $0.1an = 0n \Rightarrow a = 0$ -0.1b = 20 ⇒ b = -200



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A	Second	order	inhomo	geneous	equation	is of	the	form:	
				-				Contract of the local division of the local	

$$aP_n + bP_{n-1} + cP_{n-2} = F(n)$$

The solution to an inhomogeneous equation has two components

F(n)	Particular solution
constant	constant a
Kn	an + b
Kn+c	an + b
Kn ²	an ² + bn + c
Kn² + In + m	an ² + bn + c
kp#	apn_+ b

 $P_n = [general soln of associated homogeneous difference equation] + [particular soln of full equation]$

So, to solve an **inhomogeneous difference equation** we must first find the general solution to the <u>associated</u> equation (also known as the complimentary equation) and then the particular solution to the inhomogeneous equation.

Determine the Population of Trout

Computing the Solution

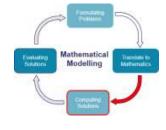
If we use the estimate for 2025 and 2026, we get:

$$P_{n} = I(3/2)^{n} + m(6/5)^{n} - 200$$
Using earlier estimates 2025 P_{0} =99 and 2026 P_{1} =115
$$P_{n} = I(3/2)^{n} + m(6/5)^{n} - 200$$

$$P_{0} = I(3/2)^{0} + m(6/5)^{0} - 200 = 99 \Rightarrow I + m = 299$$

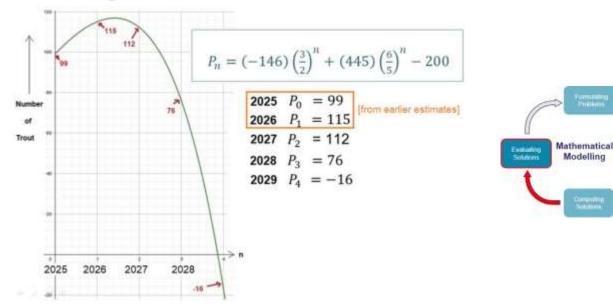
$$P_{1} = I(3/2)^{1} + m(6/5)^{1} - 200 = 115 \Rightarrow 15I + 12m = 3150$$
Solving these simultaneous equations $l = -146$ and $m = 445$

$$P_{n} = (-146) \left(\frac{3}{2}\right)^{n} + (445) \left(\frac{6}{5}\right)^{n} - 200$$



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Evaluating the Solution

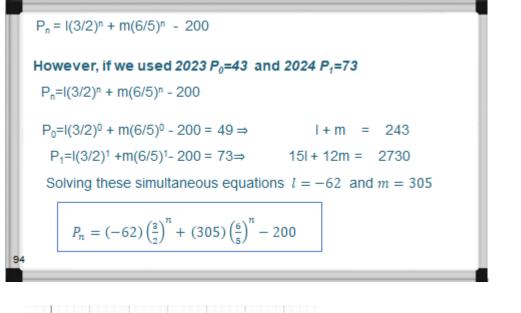


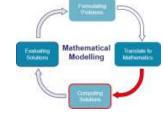
Supporting the Professional Learning of School Leaders and Teachers

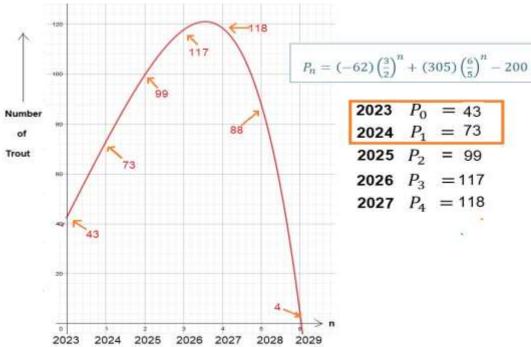
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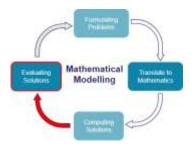
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If we use the $P_0=43$ (2023) and $P_1=73$ (2024), we get:











Extending The Learning



Determine the Population of Trout in river Slaney "...being able to critically evaluate mathematical models is a desirable skill for them to acquire" p.16



Evaluating the Solution:

How accurate and reliable is your solution based on your earlier assumptions? What effect would changing your variables/assumptions have on your solution? How does your solution compare with previous solutions/iterations? Can you refine/alter your assumptions to improve your solution and will this change your solution much?

What might a further iteration look like?

How could the model be refined to improve its accuracy?

Reflection

How well did this session assist you in your understanding of how difference equations can be developed and formalised through authentic modelling problems?



How useful/relevant did you find today's cross-curricular linking to mathematics?





Supporting the Professional Learning of School Leaders and Teachers

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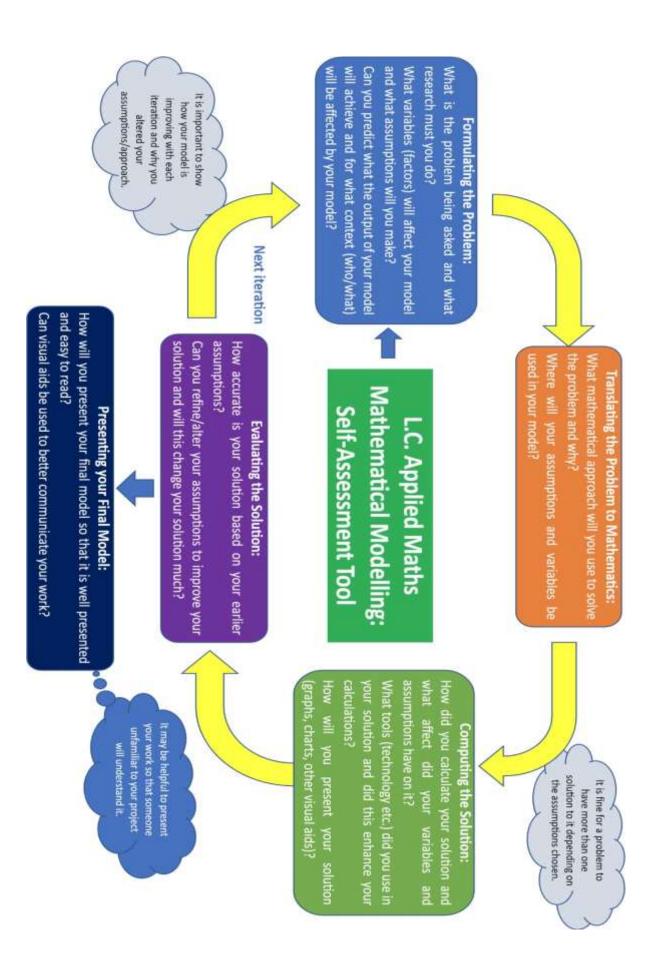
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