An AI-literate mathematics education: Possibilities and Realities

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National Institute of Education, NTU | June 5, 2026

[Google A.I. System Wins Gold In International Math Olympiad](#)
The New York Times (2025)

By way of background


The New York Times
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Google A.I. System Wins Gold Medal in International Math Olympiad

OpenAI said it, too, had built a system that achieved similar results.

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In 2025, Google's Gemini Deep Think and a new experimental OpenAI model both solved **5 out of 6 IMO problems**. Unlike previous math AI models that relied on formal or symbolic techniques, these systems tackled problems using **natural-language reasoning** — mirroring how humans think and communicate.

Brown University professor and former IMO gold medalist Junehyuk Jung: AI can now solve "**hard reasoning** problems in natural language," paving the way for future **collaboration with mathematicians** (Reuters, 2025)…

… Optimism that such AI reasoning systems could soon tackle **unsolved problems in mathematics, physics**, and other scientific domains .

AI in mathematics education: The Hong Kong context

"**Empower** students for tomorrow: Cultivating a future-ready generation for the age of AI" (Hong Kong Jockey Club Charities Trust, 2026).

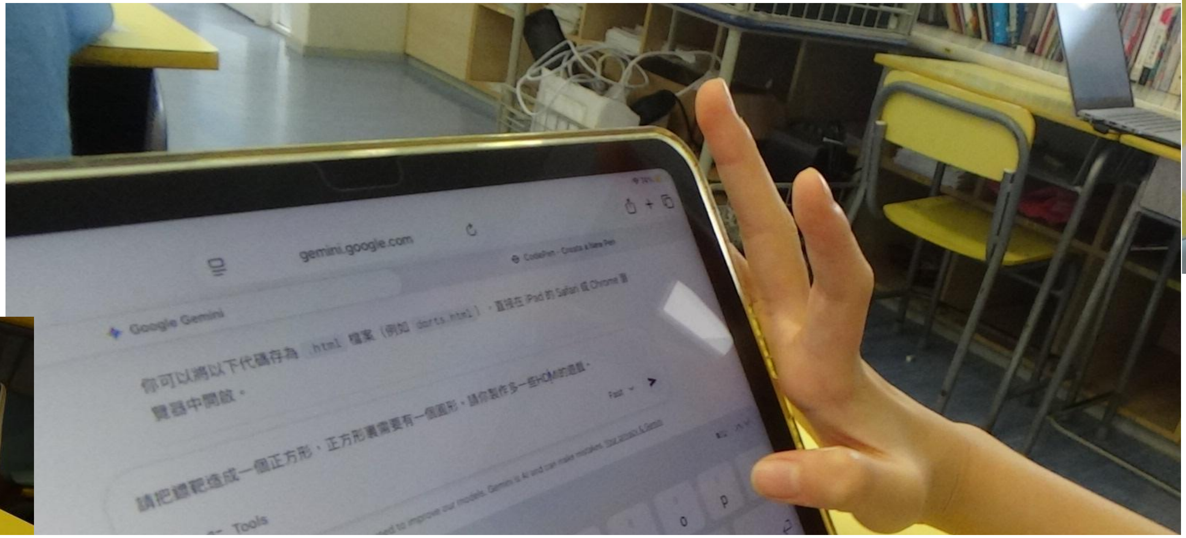
Generative AI tools and pedagogies are integrated in subject (e.g., mathematics) teaching and learning

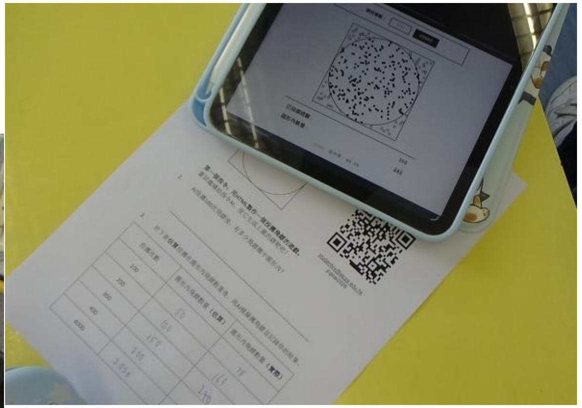
https://www.jcgoai.hk/en

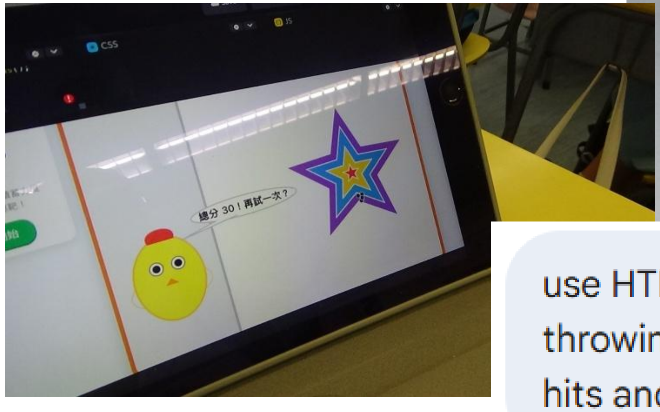
If machines can compute, conjecture, and even "explain," what, then, should school mathematics education **aim to cultivate**? What should be **valued in mathematics learning** and **problem solving** in the AI era?

Creativity and construction (Papert, 1980)

Mathematical creativity: the human capacity to design, interpret, and remake mathematical worlds.



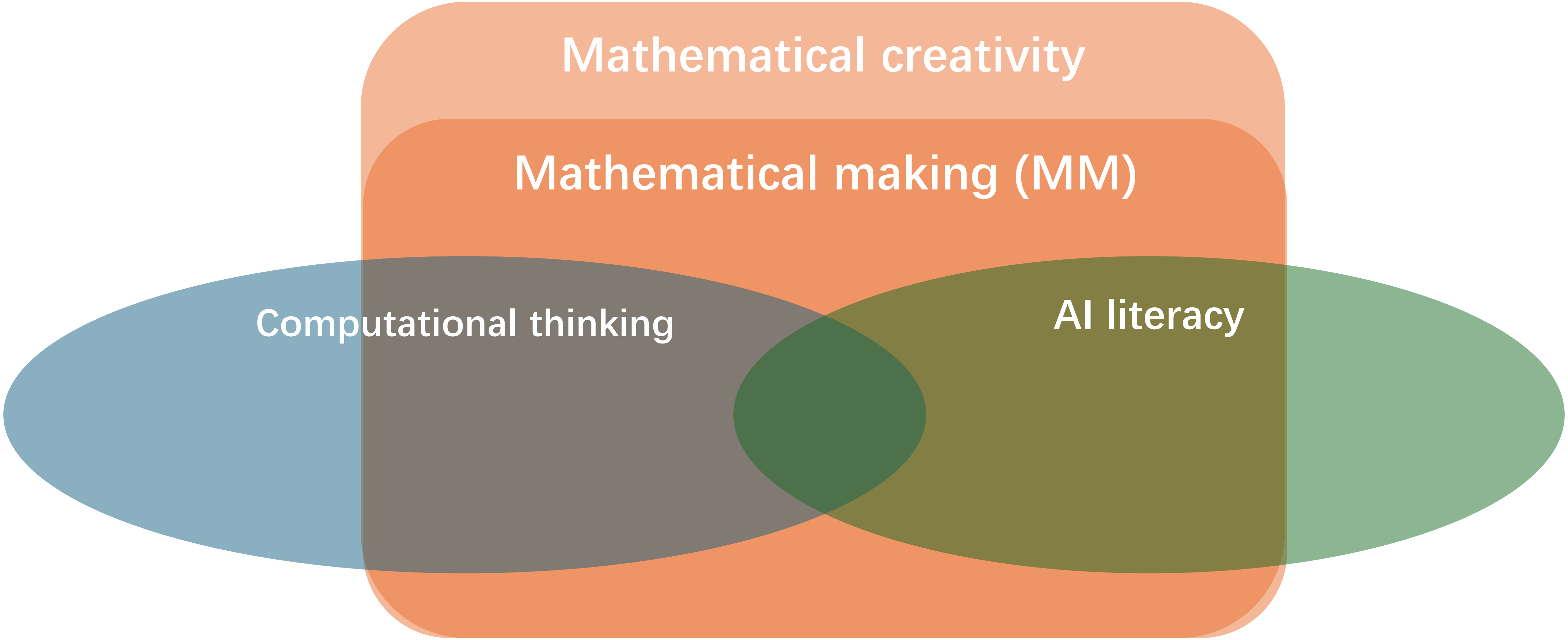




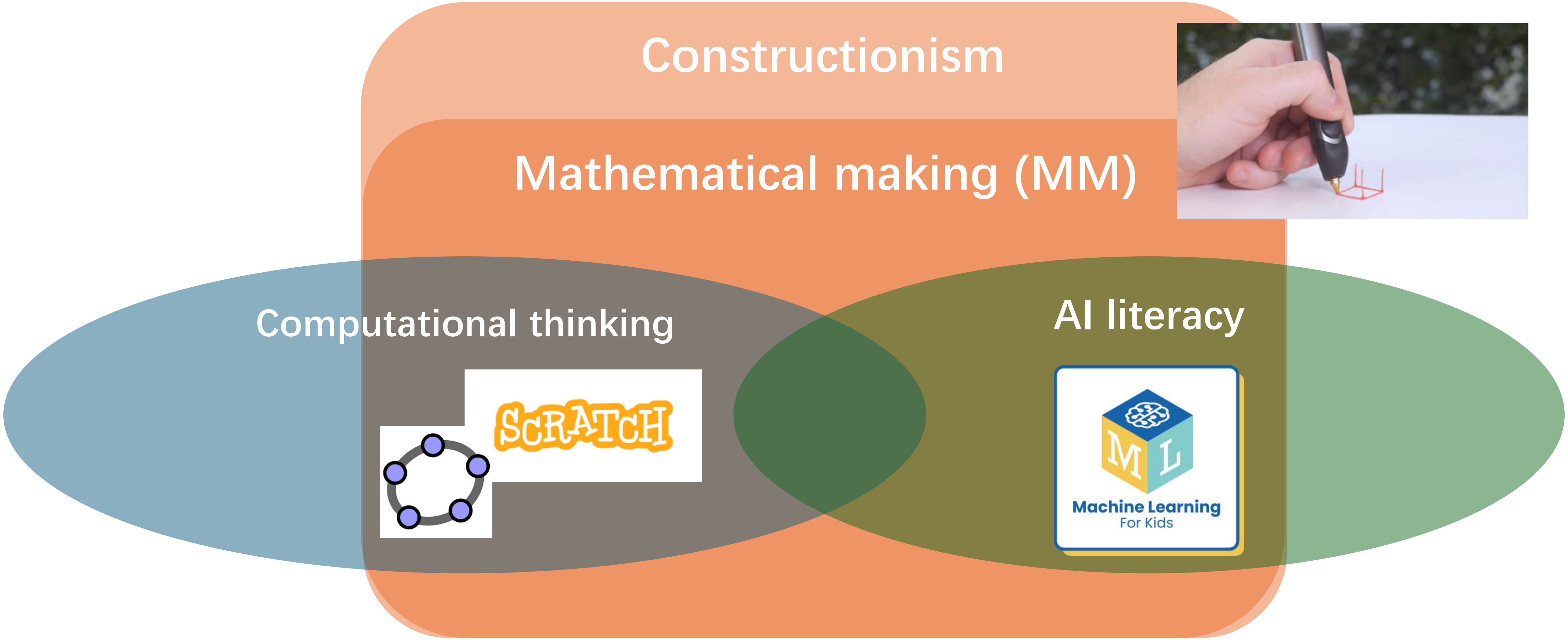
use HTML codes only to create a dart throwing simulation, throwing darts randomly and recording the number of times it hits and misses the dart board

Learning-by-making: constructing models, representations, and refining them rather than applying established procedures.

Overview of presentation

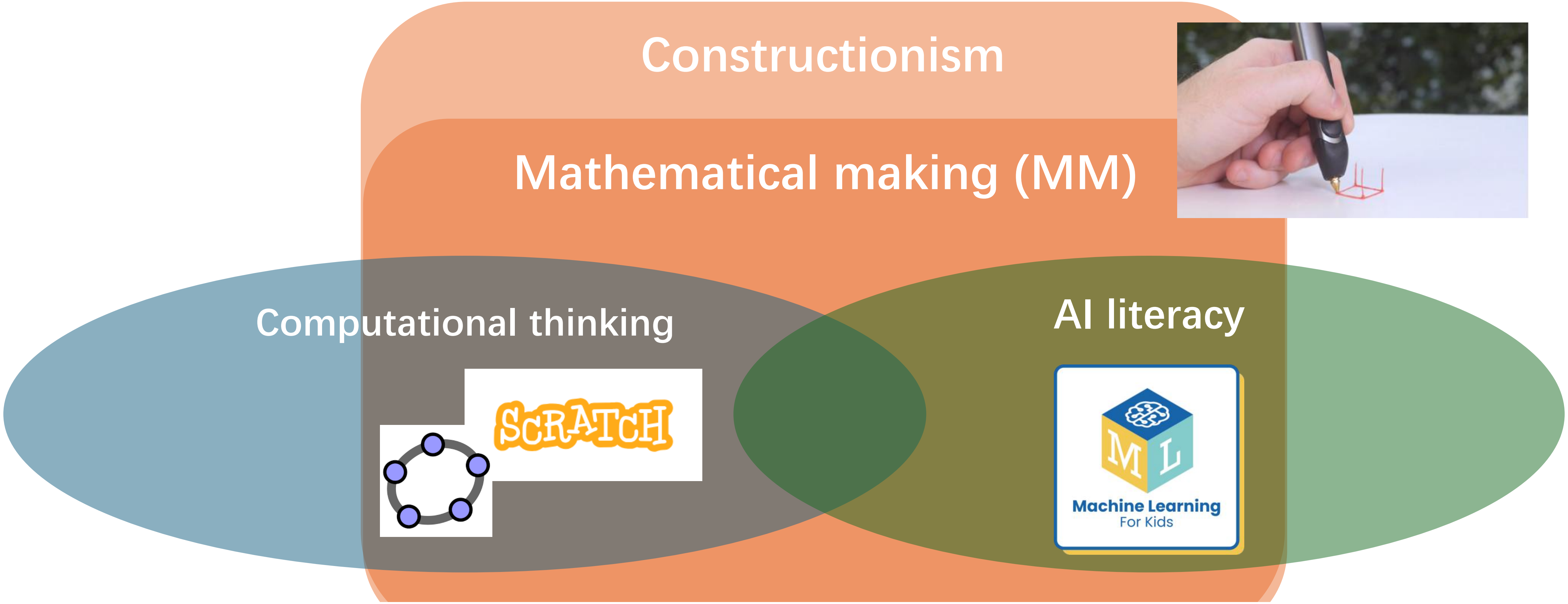


Overview of presentation



Overview

Expanding forms of **mathematical world-building**, where learners construct artefacts, generate data, and critically evaluate models.



Mathematical creativity becomes visible; digital and AI literacy emerge within practices of mathematical making.

A word of thanks

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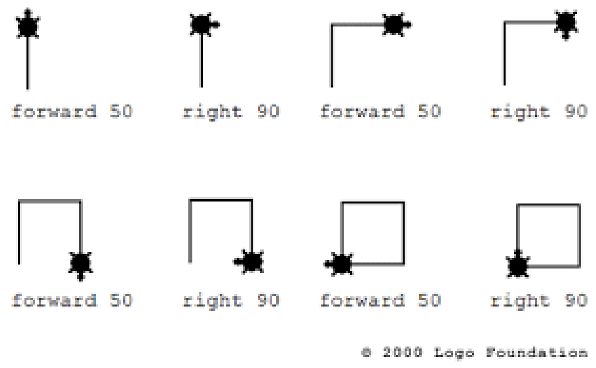
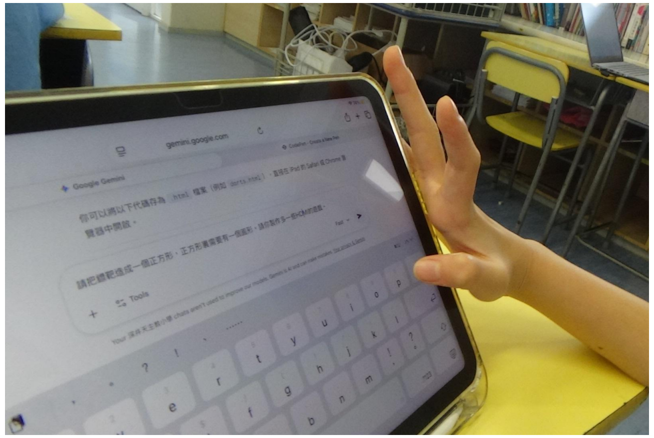
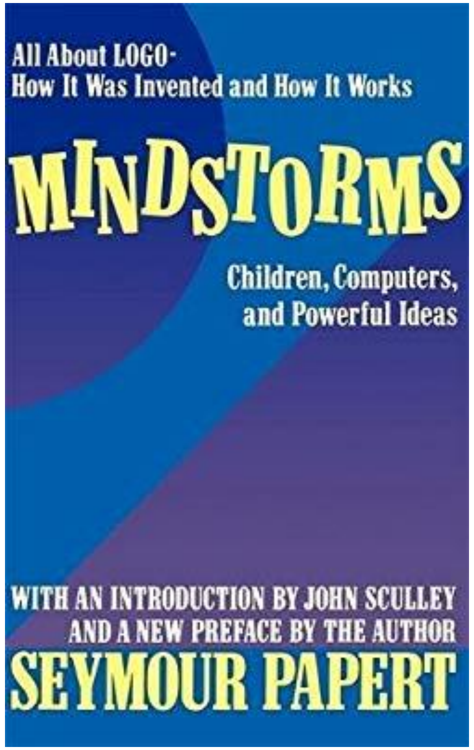
1. Mathematical Creativity in the AI Age

Papert's (1980) **constructionism** shares the constructivist view of learning as "building knowledge structures", but also underpins the context whereby the learner is consciously constructing a public entity—a form of "learning-by-Making"







In constructionist learning, the process of building – whether programming a turtle in Logo to draw shapes or designing a project – requires **planning, execution, and reflection**.

This mirrors the skills needed for interaction with **GenAI**, where learners must monitor and adapt their cognitive strategies: **plan prompts, execute them, and reflect** on the outcome. (Levin et al., 2025)

1.1 Mathematical making with 3D pens

Extend 2D construction to the 3D environment (Ng, 2017)

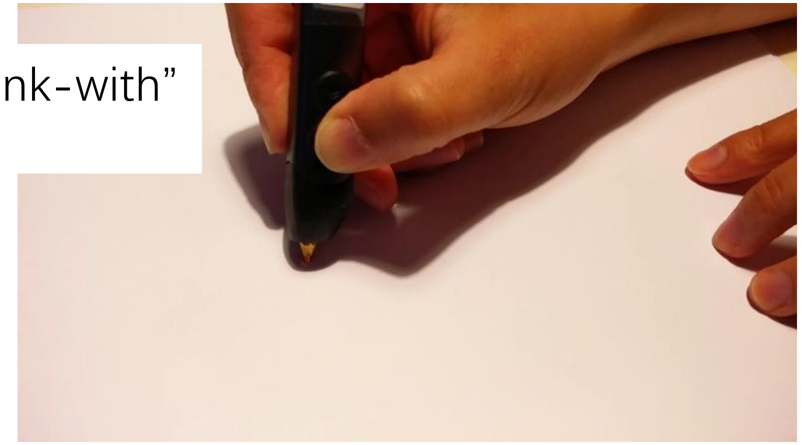
Gestural forms of thinking
(Ng & Sinclair, 2018)

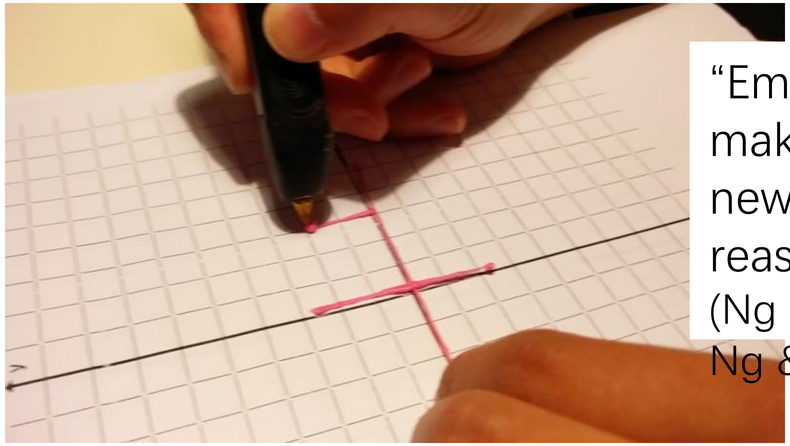
Promote longer learning retention (Ng et al., 2020)

Redistribute learning across the material activity
(de Freitas & Sinclair, 2014)

Learning is moving in new ways
(Abrahamson & Sánchez-García, 2016)

"Object-to-think-with"
(Papert, 1980)



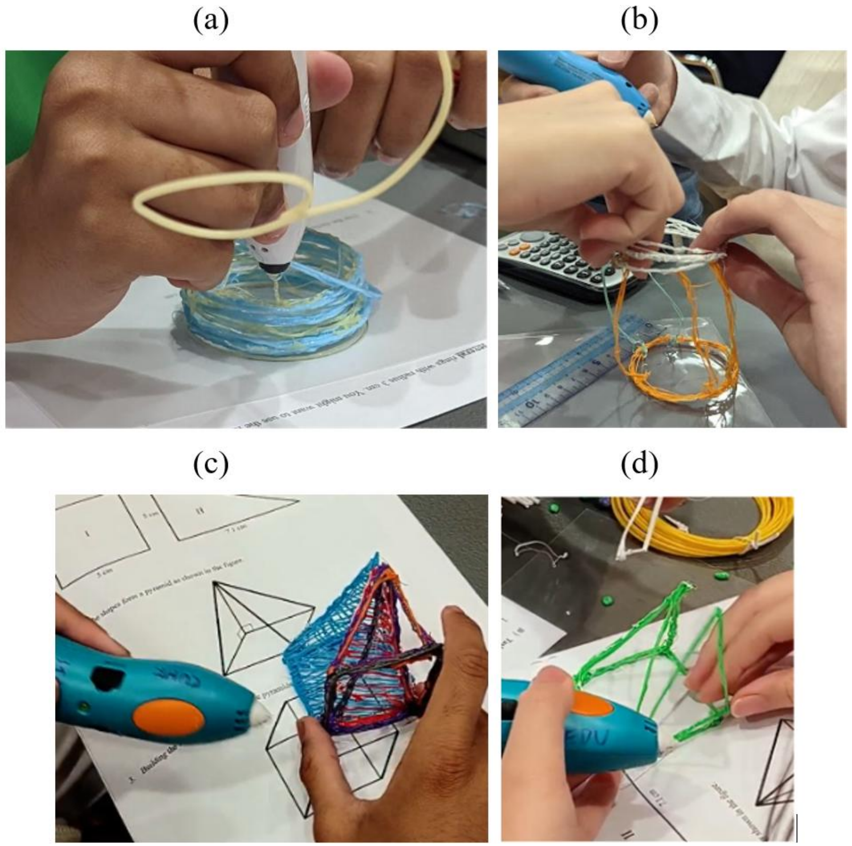


"Embodied making"; offering new modes of reasoning
(Ng & Ye, 2022;
Ng & Ferrara, 2020)

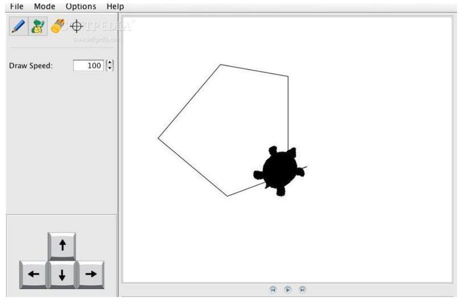
Ng, O., & Ye, H. (2023). Doing mathematics with 3D pens: Five years of research on 3D printing integration in mathematics classrooms. In F. Dilling, F. Pielsticker, & I. Witzke (Eds.), *International Symposium on 3D Printing in Mathematics Education*. Springer

1.2 Mathematical making with 3D pens

From cognitively knowing to shaping mathematical worlds



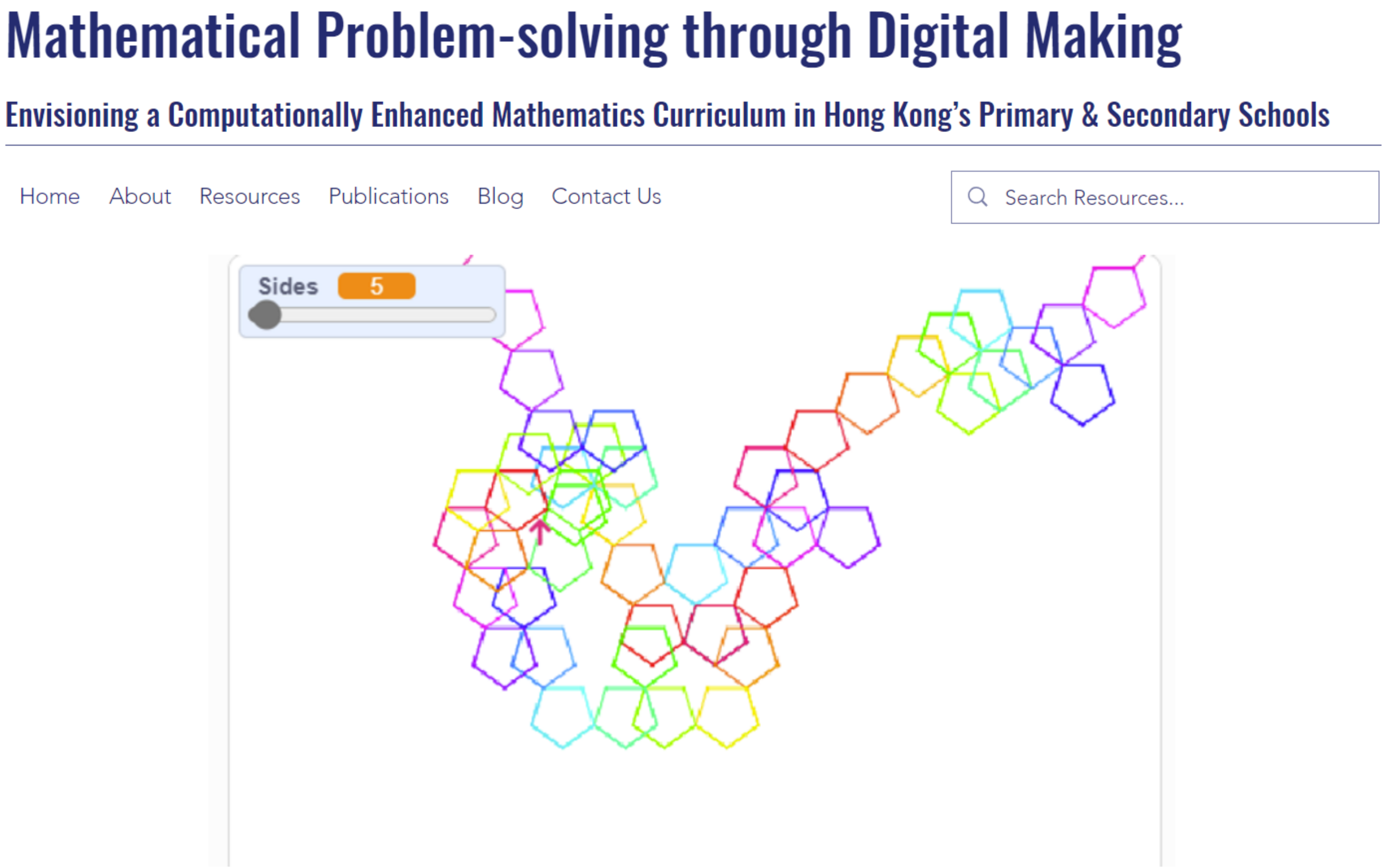
Mathematical making, is situated, adaptive, and aesthetic decision-making as learners negotiate the affordances and constraints of materials and tools. It unfolds as an iterative process of refinement and adjustment, deeply responsive to material feedback (Papert, 1980).



Each action generates new conditions for thinking, prompting further sensing, responding, and re-making. Mathematics is not imposed from outside the activity but emerges through cycles of embodied construction.

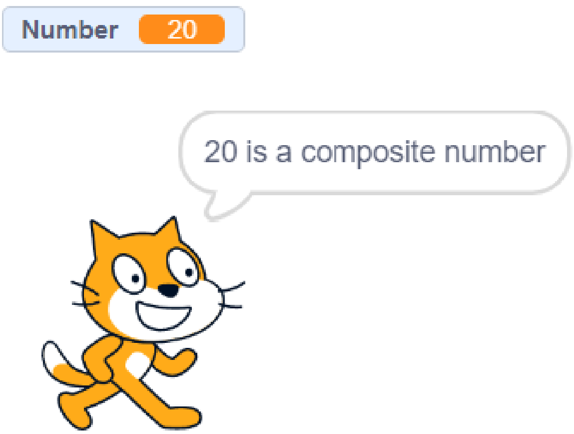
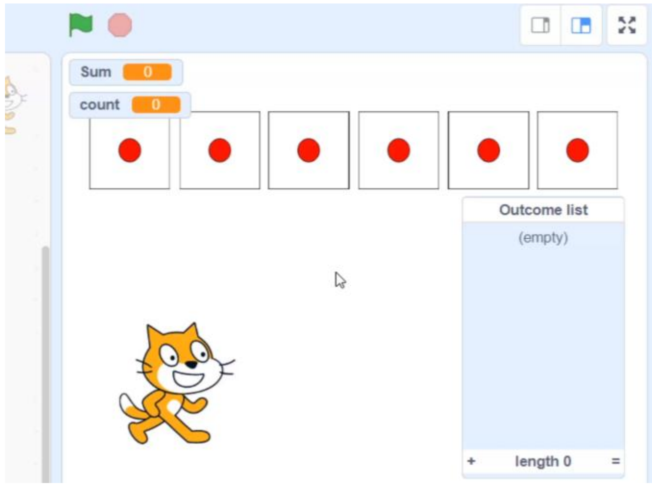
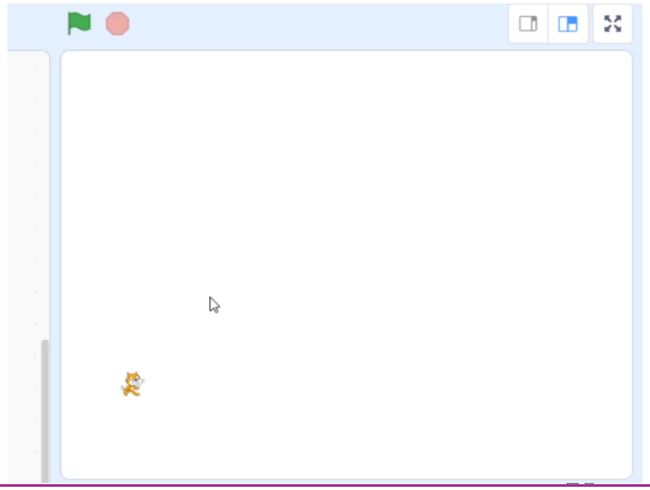
Yeung, W., Ye, H., & Ng, O. (forthcoming). Crafting Mathematics: Embodied Creative Actions and Craftsman Creativity in Making-Based Geometry Learning. In T. T. Lam, & P. Taylor (Eds), *Mathematical Creativity, Challenges and Competition*. Springer

2. Mathematical making and CT



2.1 Empirical research on digital making

This design-based study builds on the PI's previously developed conception of "learning as Making" to envision a computationally enhanced mathematics education (2021-2024).

	Number and Algebra	Counting and Probability	Geometry
Math	Prime and composite number	Counting and list; Experimental & theoretical probability	Fractal geometry
CT	Variables, iteration, Boolean logic	Nested loops	Recursion
			

2.1 Methodology

Design-based research (DBR):

- Design experiments featuring teacher-researcher collaboration (**6 schools, 25 lessons planned, 160+ contact hours, 250+ students**) in a diverse range of contexts:
    - Online; face-to-face lessons; regular class time; extra-curricular hours
- 4 iterative cycles of implementations in primary and secondary schools in Hong Kong.
- Task design: https://ngoilam.hk.wixsite.com/digitalmaking
- Data collection: classroom videos, screen-recording, classroom artefacts, post-lesson interviews

2.2 Digital making as CT-math integration

Decomposition	Breaking down a complex problem or into smaller, more manageable parts.
Algorithm	Developing a step-by-step solution to the problem or the rules to follow to solve the problem.
Abstraction	Focusing on important information only, ignoring irrelevant details.
Pattern Recognition	Looking for similarities among and within problems.

(Angeli & Giannakos, 2020; Cansu & Cansu, 2019; Shute et al. ,2017)

CT is **a medium for human and machine collaboration** through formulating and decomposing problem, system thinking, modelling, and communicating solution understandable by both.

(Aho, 2012; Waterman et al., 2020; Wing, 2006)

Why bring **CT** to the mathematics classroom?

- CT as a "boundary process" in STEM communities (Ng et al., 2023)
- Reciprocal relationship—using one to enrich learning of other (Weintrop et al., 2014; Ye et al., 2023)

2.3 Insights from the literature

CT Concepts	CT Concepts as Defined in Reviewed Literature	CT Concepts as Applied in CT-Based Mathematical Context
Variable	An entity that can store, retrieve, and update values[1]	A numerical (e.g., number of times to carry out a specific mathematical procedure)[1], algebraic (e.g., result of operating with two or more variables)[1, 2, 3], or geometric (e.g., movement of a point having a variable location on a circle)[4] representation of an entity whose values can be stored, retrieved and operated on
Conditionals	Instructions that either perform an action or not, according to a given condition[5]	A set of decisions, actions, statements executed based on numerical (e.g., when a number equals a certain value)[1], algebraic (e.g., when a parametric equation determines the amount of rotation of the wheels)[4] or geometric properties (e.g., when a draggable point determines how much a given shape is scaled by)[4]
Loops	The control structure that makes it possible to repeat one or more sequences multiple times[5]	Repeatedly carry out a mathematical procedure, e.g., a numerical calculation[1], or geometric construction[4, 6, 7].
Sequences	The sequence or structure of instructions that should be followed to complete a goal[5]; or a series of individual steps or instructions to be executed by the computer[1]	A sequence of steps set up according to mathematical rules or logic to perform a particular instruction for solving a mathematical task, e.g., to program a sequence of codes for testing prime number and then illuminating the LED lights accordingly[1]; to move the robot based on a target geometric pattern[6,8]
Event (handling)	Handle one thing that causes another to happen[1,9]; and Instructions that make it possible to interact with objects in the programming environment[5]	When an instruction that can be converted into mathematical information is executed, another instruction related to it with numerical (e.g., as pressing a button the variable "day" increases by 1, and another variable "the balance" will increase by 222)[1] is executed.
Subroutines	A procedure that can be called within another procedure[4]	A set of instructions designed to perform a specific mathematical procedure or task (e.g., geometric construction)[4]; that can be used repeatedly within a program
Operators	Provide support for mathematical, logical, and string expressions[1,9]	The of use of symbols or functions to denote or perform a mathematical (e.g., >, <, mod, ceiling, floor) or logical operation (e.g., AND, OR)[1]

Note: [1] Ng & Cui (2021); [2] Dickes et al. (2020); [3] Kaufmann & Stenseth (2021); [4] Sinclair & Patterson (2018); [5] Rodríguez-Martínez et al. (2020); [6] Jurado et al. (2020); [7] Miller (2019); [8] Muñoz et al., 2020); [9] Brennan & Resnick (2012)

Ye, H., Liang, B., Ng, OL. *et al.* Integration of computational thinking in K-12 mathematics education: a systematic review on CT-based mathematics instruction and student learning. *IJ STEM Ed* **10**, 3 (2023).

2.4 Digital making and *data practices*

Variable

An entity that can "store, retrieve, and update values" (Ng & Cui, 2021, p. 6)

- A numerical, algebraic, or geometric representation of an entity whose values can be stored, retrieved and operated on.

  (Ng & Cui, 2021; Dickes et al., 2020; Kaufmann & Stenseth, 2021; Sinclair & Patterson, 2018)

Iteration

The outcome of each iteration as the starting point of the next iteration (Dickes et al., 2020).

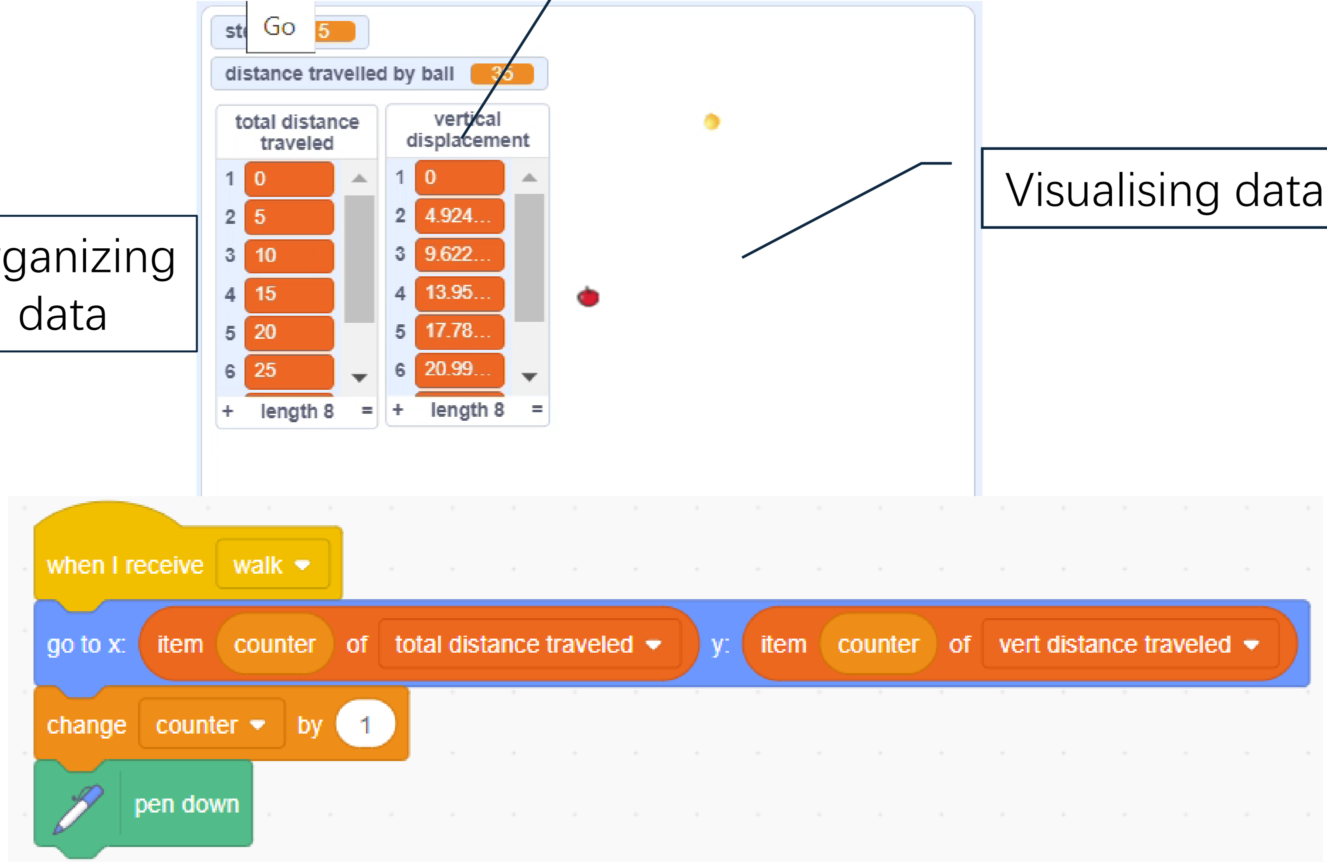
- Replacing the current value by X more than itself regardless of what it is (Ng et al., 2023b)

2.4 Digital making and *data practices*

Organizing data

Creating data

Visualising data

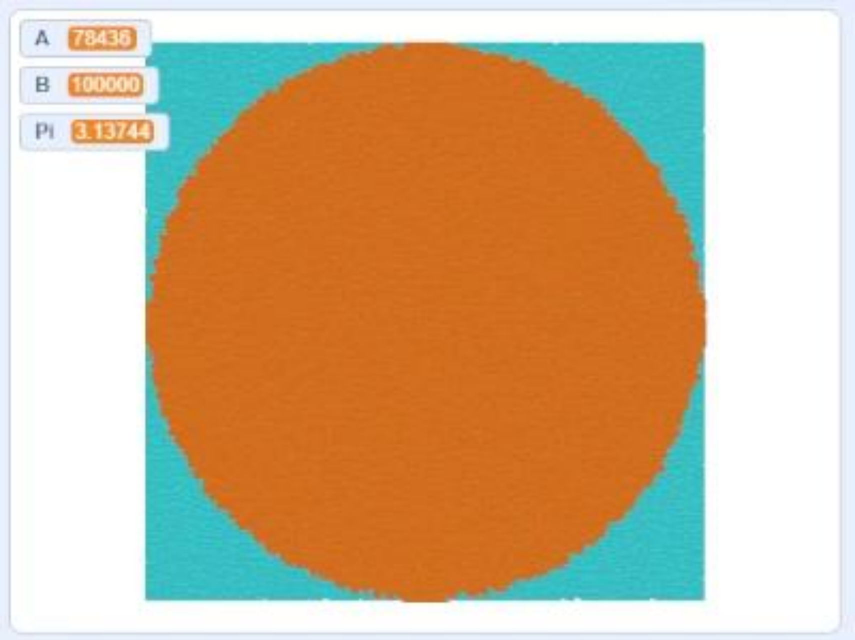


2.5 Digital making and *simulation*

Loop

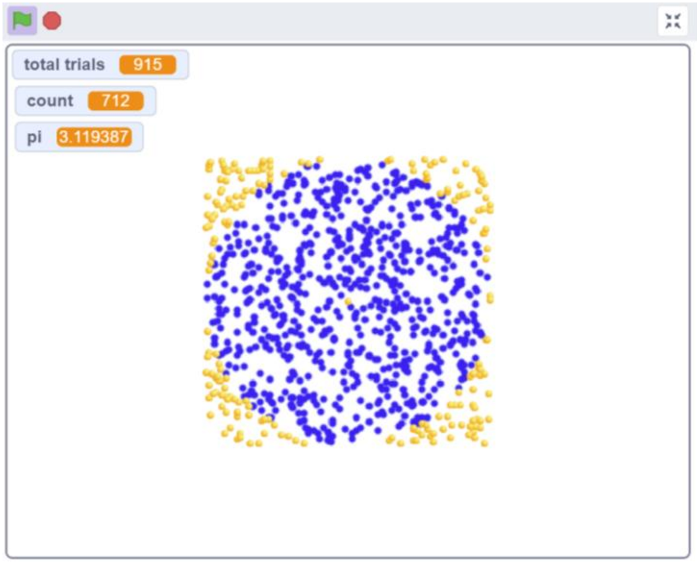
“The control structure that makes it possible to repeat one or more sequences multiple times” (Rodríguez-Martínez et al., 2020, p. 319)

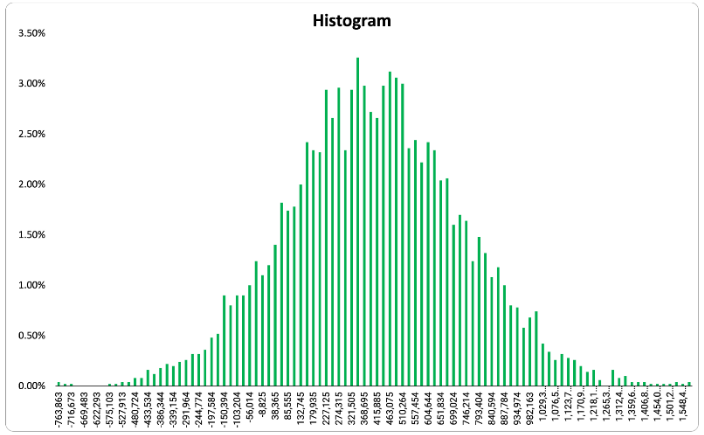
- Repeatedly carry out a **mathematical procedure**, e.g., **a numerical calculation** (Cui & Ng, 2021), or **geometric construction** (Dickes et al., 2020; Jurado et al., 2020; Miller, 2019; Sinclair & Patterson, 2018; Weng et al., 2022).



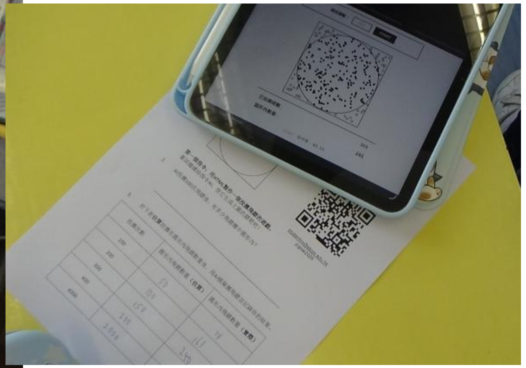
2.5 Digital making and *simulation*

- Stochastic process: performing simulations using random variables, to approximate pi.
- Monte Carlo experiment: taking up repeated random sampling to obtain numerical results.
- The underlying concept is to use randomness to solve problems that might be deterministic in principle.
- The stochastic process acted as bridge between experimental probability (i.e. counting the number of desired outcomes in a random event) to theoretical probability (i.e. approximating the value of pi).
- Such simulations are widely used in the scientific fields from economics to physical sciences, including areas in AI and machine learning.





2.5 Digital making and *simulation:*
Dart-board making with AI

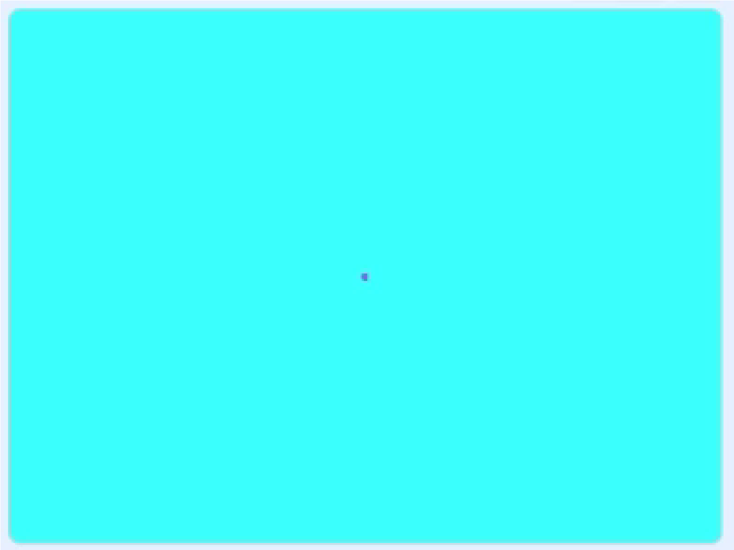


use HTML codes only to create a dart throwing simulation, throwing darts randomly and recording the number of times it hits and misses the dart board

"make a dart-board in the shape of a square; there needs to be a circle inside the square"

"a square with a circle inside that touches the sides"

2.6 Digital making and *tinkering*



Conditionals

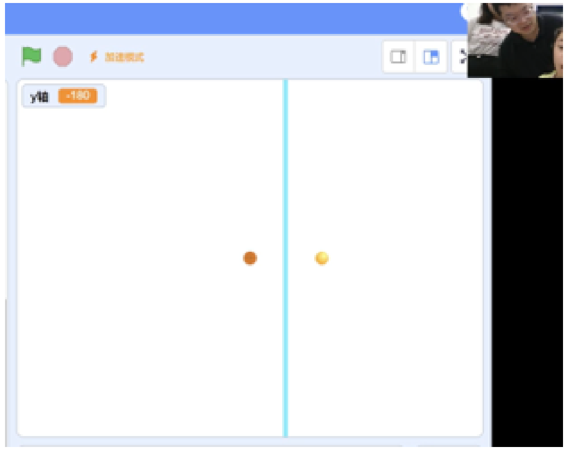
Instructions that either perform an action or not, according to a given condition (Rodríguez-Martínez et al., 2020, p. 319)

A set of decisions, actions, statements executed based on numerical, algebraic or geometric properties.

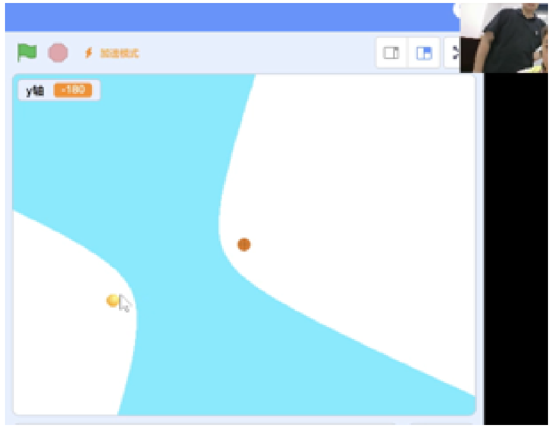
- Numerical: when a number equals a certain value (Ng & Cui, 2021);
- Algebraic: when a parametric equation determines the amount of rotation of the wheels (Sinclair & Patterson, 2018);
- Geometric: when a draggable point determines how much a given shape is scaled by (Sinclair & Patterson, 2018)

2.6 Digital making and *tinkering*

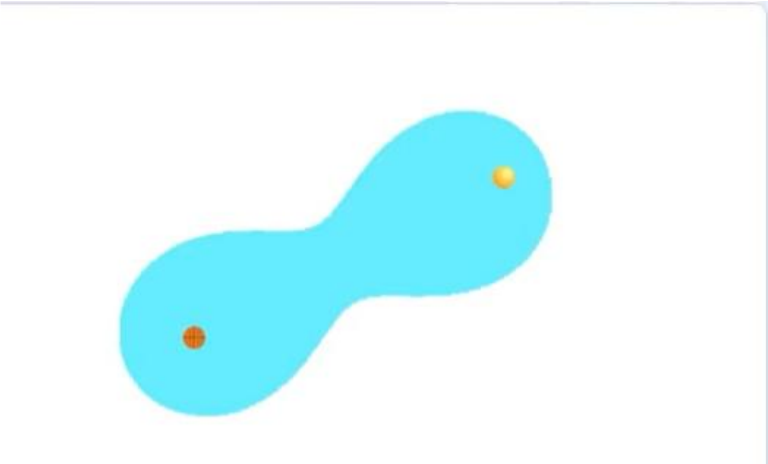
- “What other conditions would you like to try?”
- “What other relationships between the measurements can you think of?”



Condition by equating the distances, |PA|=|PB|



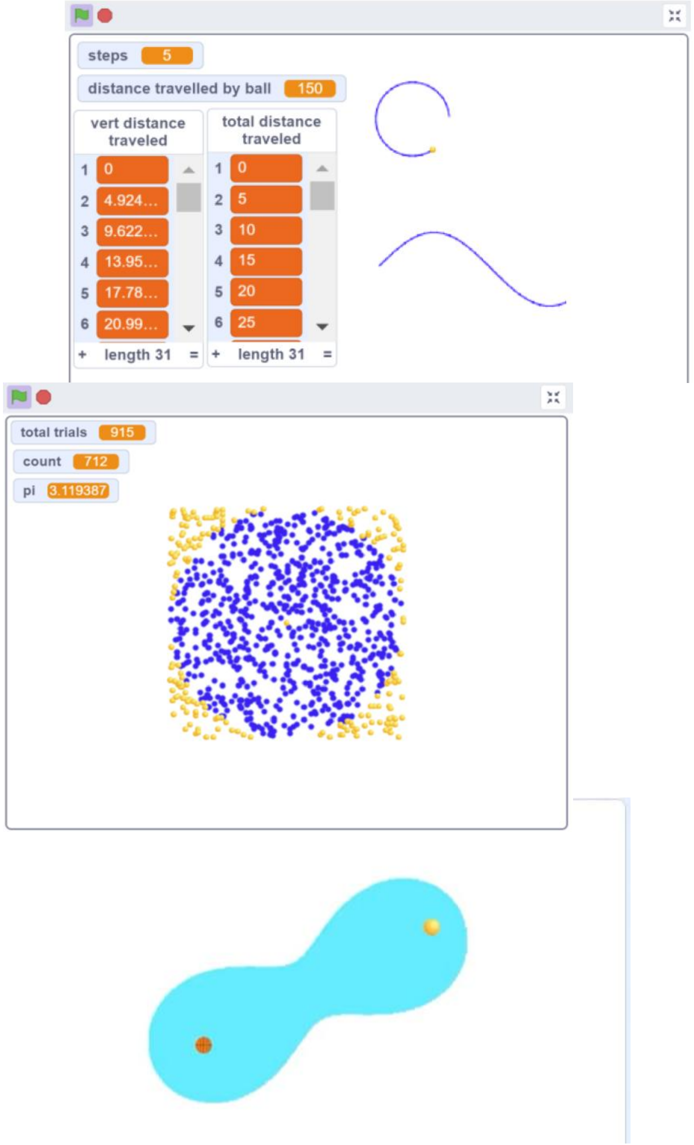
Condition by operating on the distances, |PA| - |PB|



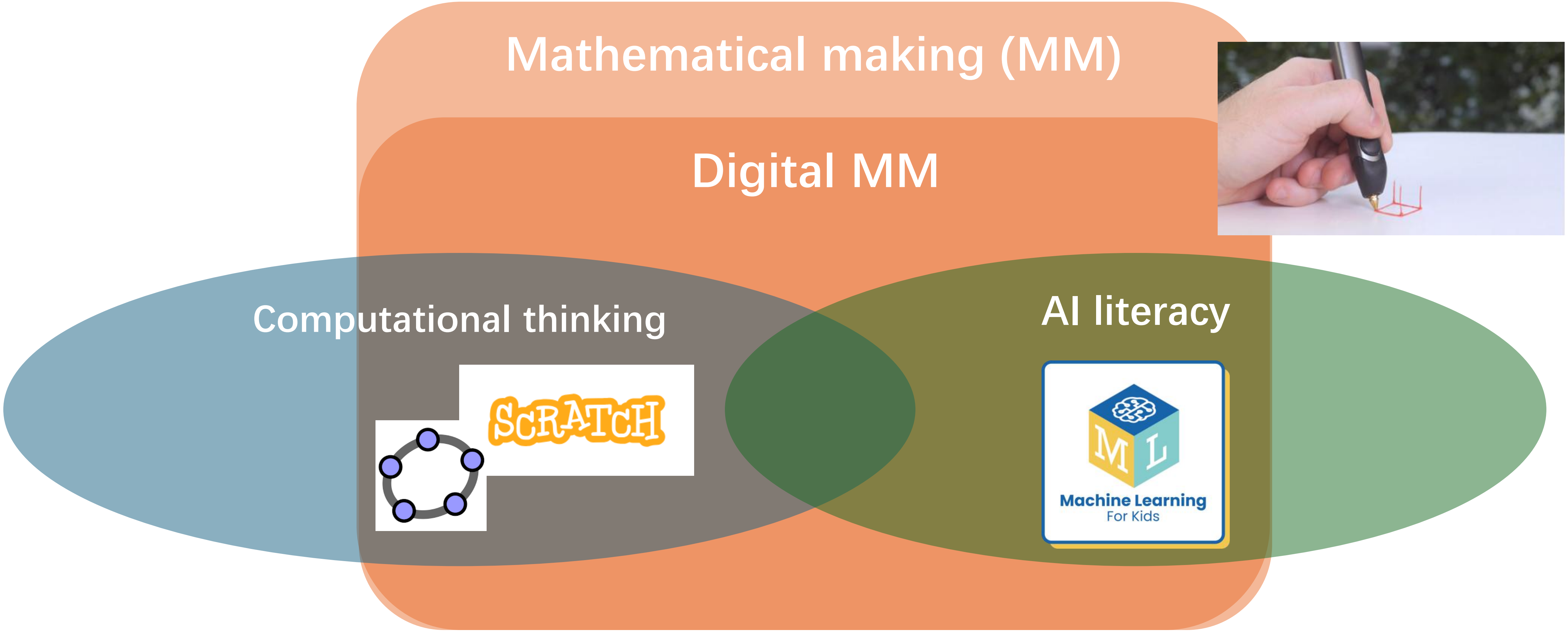
Condition by operating on the distances, |PA|*|PB|

2.7 Summary thus far

- Mathematical making:
  - Personally creative act; not reproducing some things/concepts that are pre-existing
  - Afford non-prescribed mathematics learning/making in unstructured ways and with little prior knowledge necessary
  - Tool-mediated; artefacts as “object-to-think-with”
- Digital making with Scratch:
  - Offer new modes of mathematical reasoning: **data practices, simulations, tinkering** which are not emphasized/addressed in the current curricula
  - Task design can contribute to generating new mathematical knowledge alongside CT development

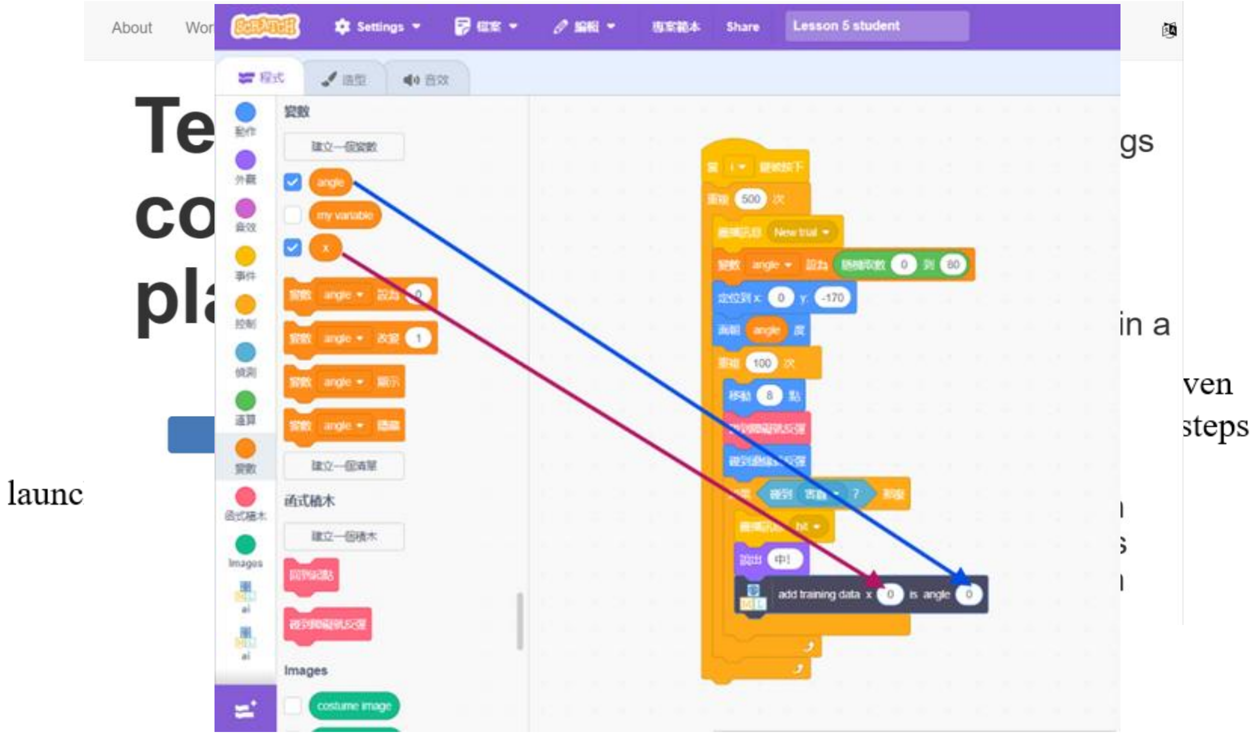


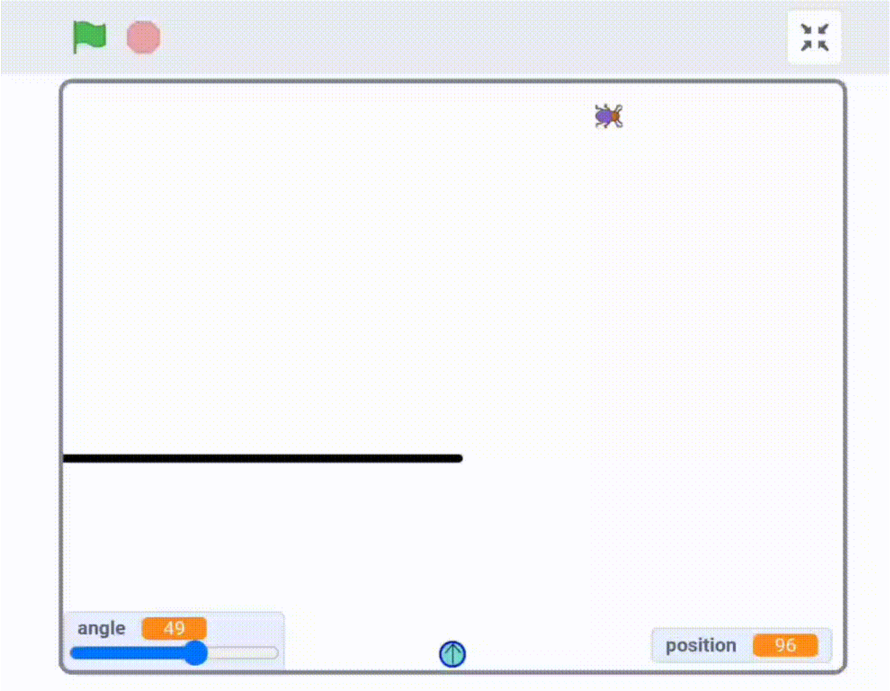
Recap


Mathematical making (MM)
Digital MM
Computational thinking
AI literacy
SCRATCH
Machine Learning
For Kids

3. Mathematical making and AI literacy

Problem: An insect enters the room randomly. Program the cleaning robot to bounce off walls and obstacles to successfully catch the insect.

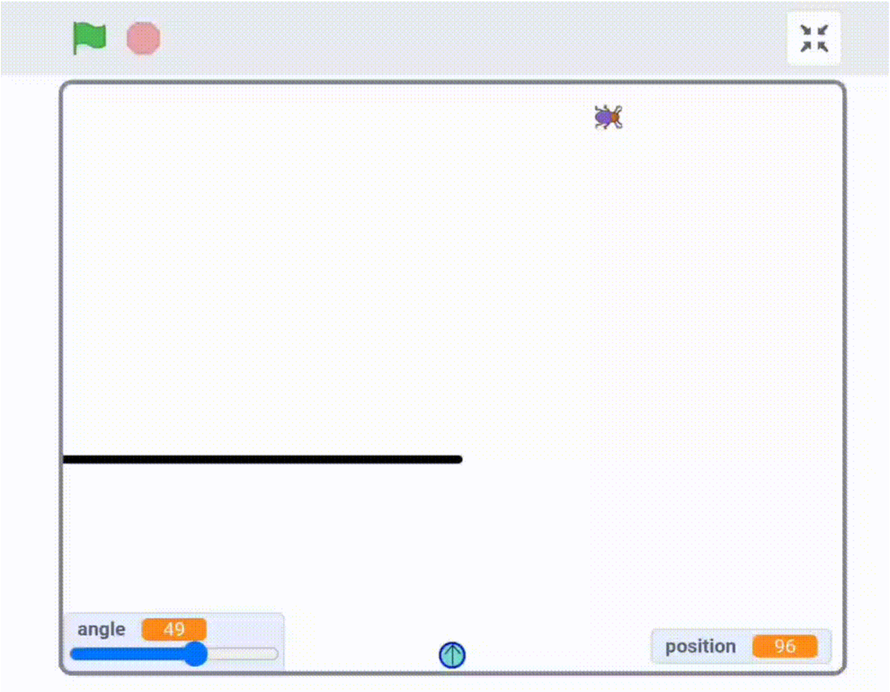




Ng et al. (2026). Design principles for curricular and instructional innovations toward supporting a computationally enhanced, AI-literate mathematics education. *ZDM-Mathematics Education.*

3.1 (Task 1) Problem-solving with Scratch

Each time we press the 'a' key on the keyboard, the robot will return to its starting position. Try using the blocks below to create the effect in the video, where the robot is launched, attempting to hit a rubbish, stopping after reaching 800 steps.



https://scratch.mit.edu/projects/1227874663

3.2 (Task 2) Problem-solving with AI

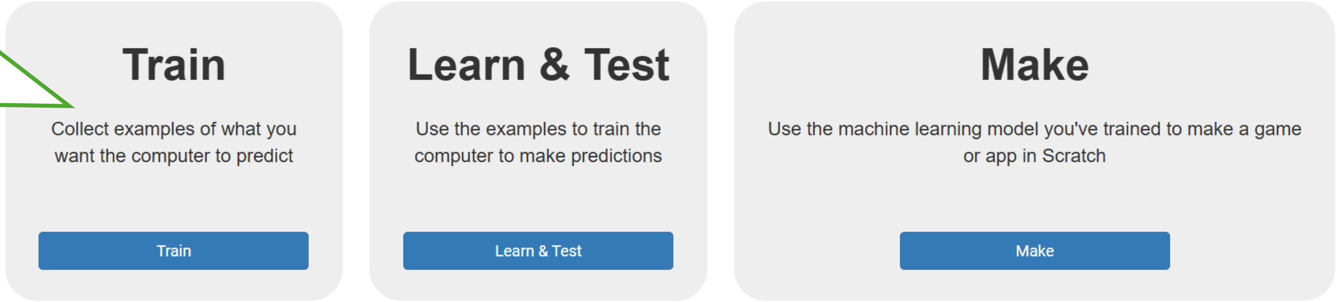
It's difficult for the robot to hit the target <u>randomly.</u>
To improve the hit rate, we can use AI to help us.

Task 2a: Train an AI model (https://machinelearningforkids.co.uk/)

- Supervised learning (a ML paradigm): Train a model by mapping function from input to output

Think: What kinds of data do we need to train the model?

(input: *x*-coordinate, output: angle)



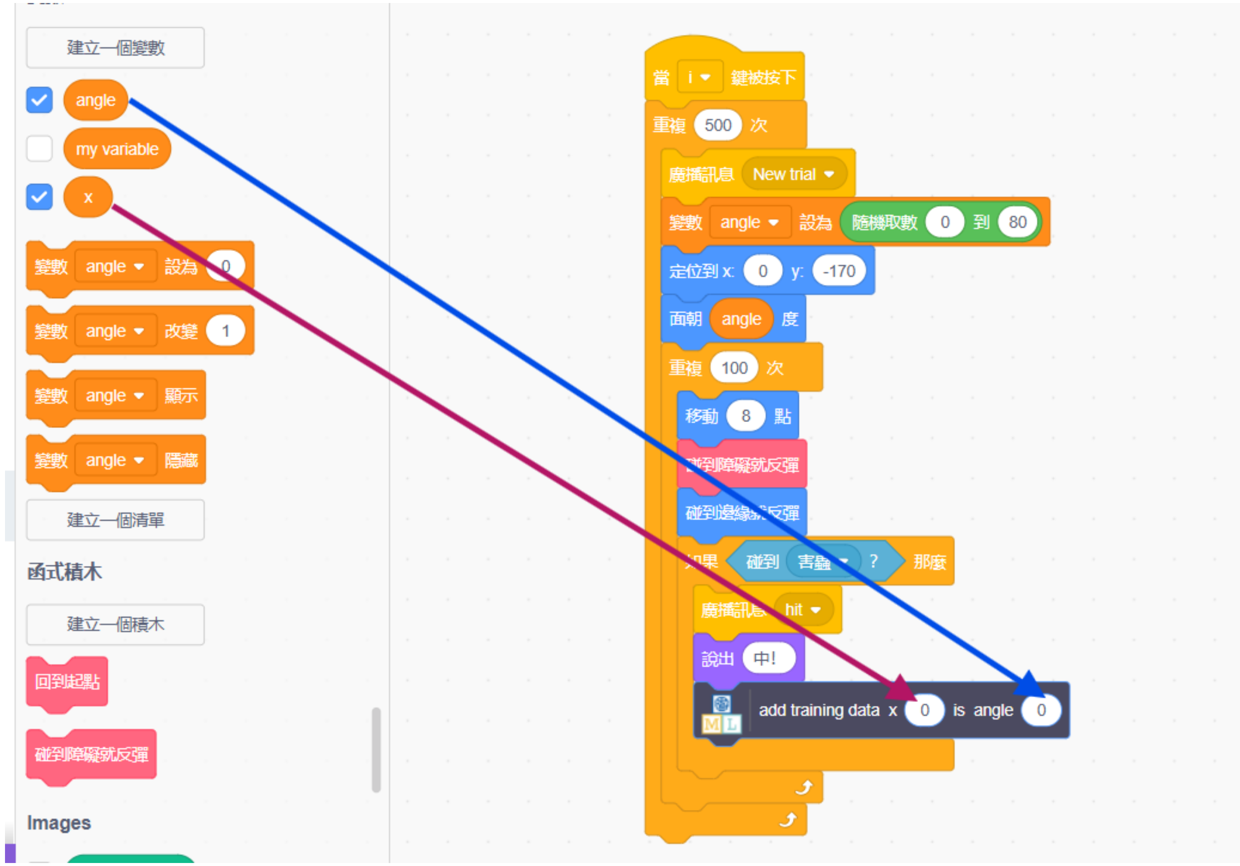
Task 2b: Examine your AI model (how accurate is it?)

3.2 (Task 2) Problem-solving with AI

Task 2a: Train an AI model (https://machinelearningforkids.co.uk/)

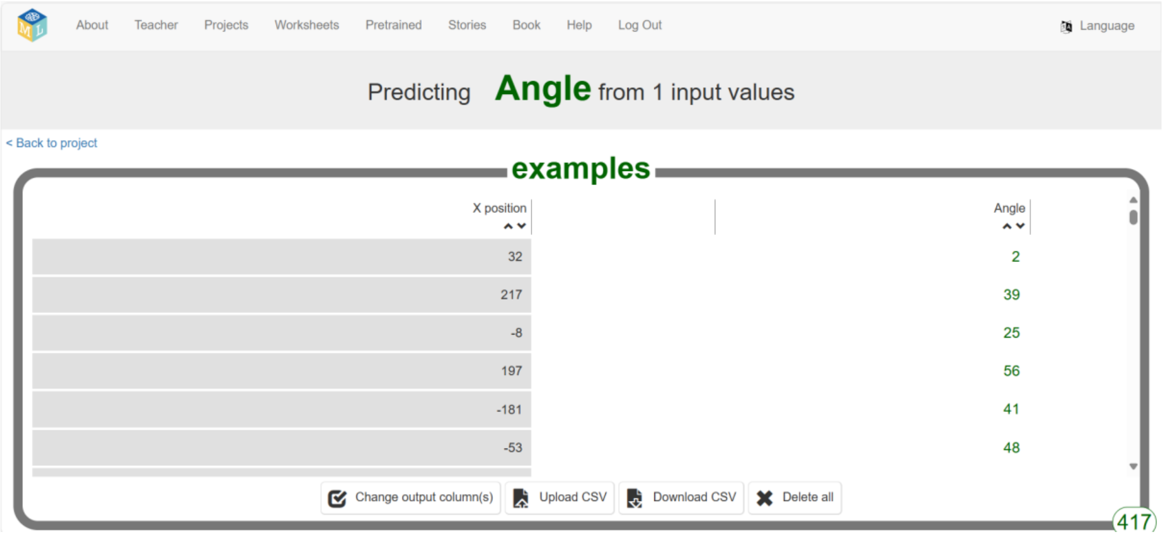
Task 2b: Examine your AI model

- Check the accuracy of the model's prediction of the launching angle.

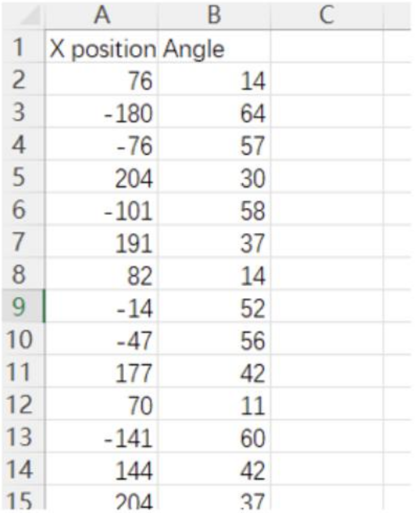


3.3 (Task 3) Reflection on AI model

- Creating and interpreting the scatter plot and line of best fit
- How does AI predict angles?
- Let's understand the AI model from the perspective of regression fitting

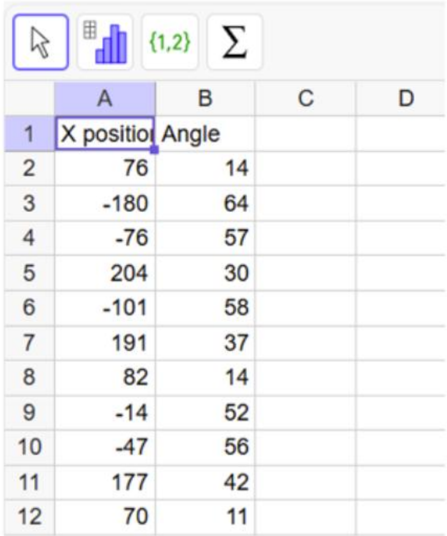


X position	Angle
32	2
217	39
-8	25
197	56
-181	41
-53	48



	A	B	C
1	X position	Angle	
2	76	14	
3	-180	64	
4	-76	57	
5	204	30	
6	-101	58	
7	191	37	
8	82	14	
9	-14	52	
10	-47	56	
11	177	42	
12	70	11	
13	-141	60	
14	144	42	
15	204	37	

Excel



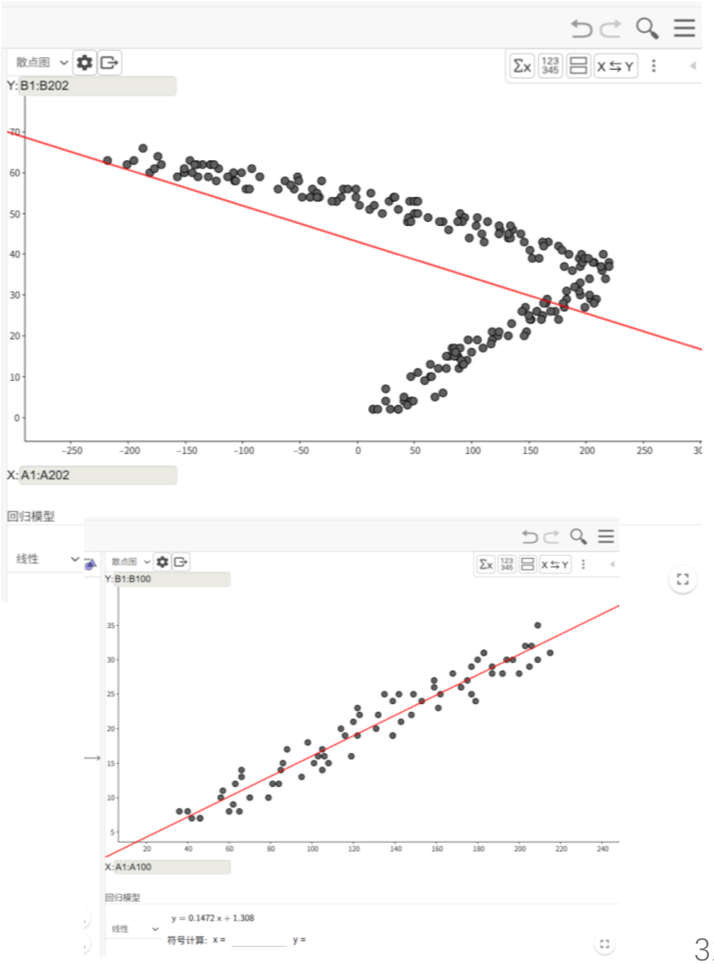
	A	B	C	D
1	X positio	Angle		
2	76	14		
3	-180	64		
4	-76	57		
5	204	30		
6	-101	58		
7	191	37		
8	82	14		
9	-14	52		
10	-47	56		
11	177	42		
12	70	11		

GGB

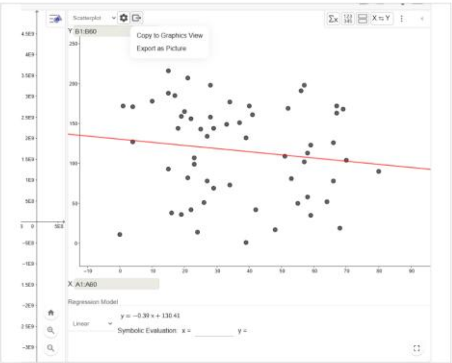
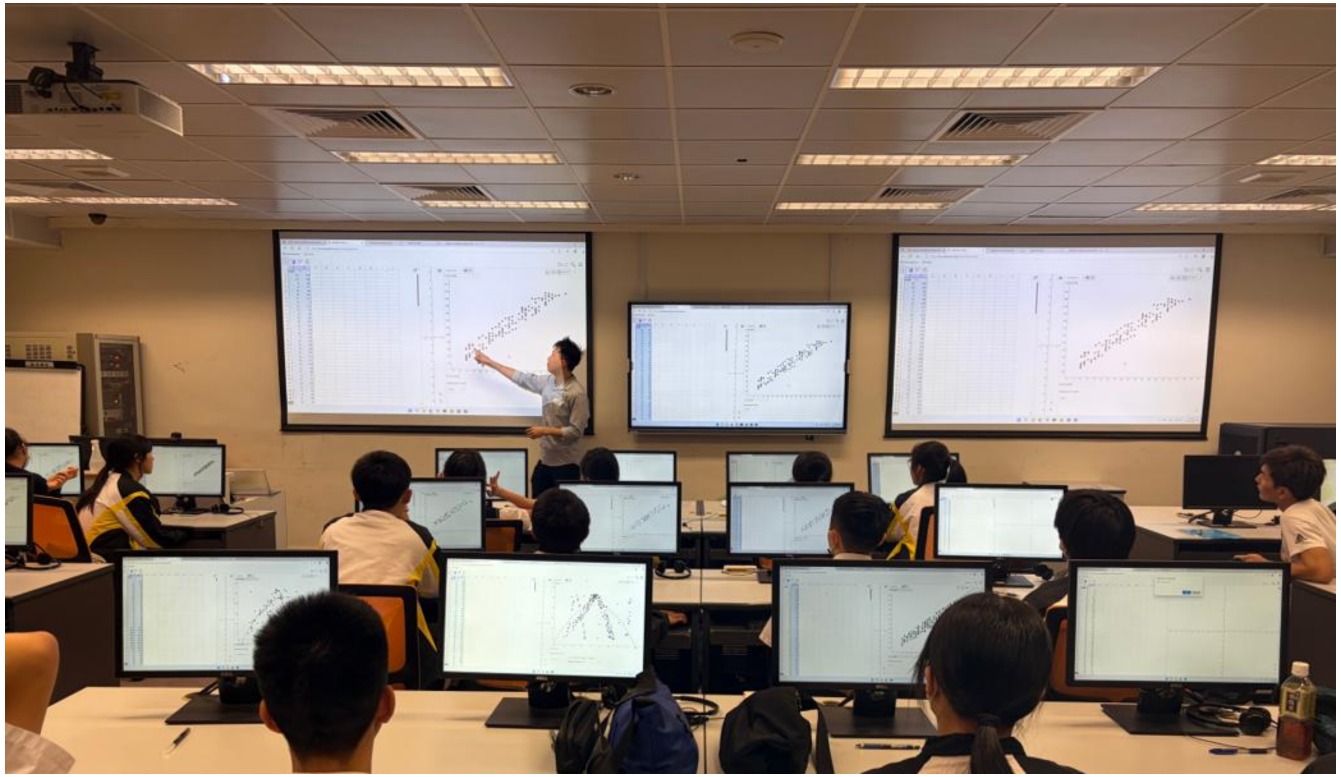
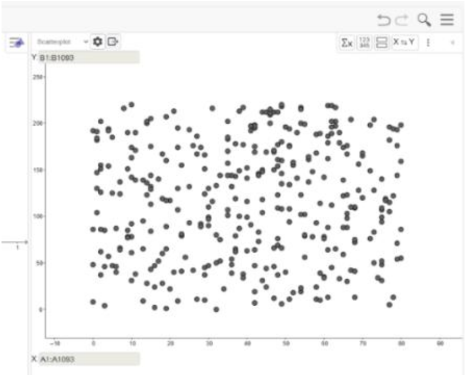
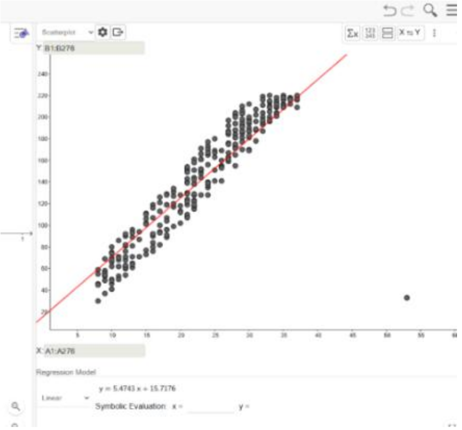
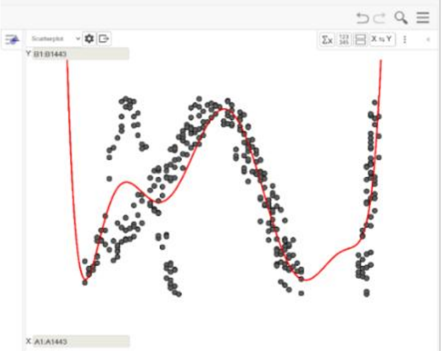
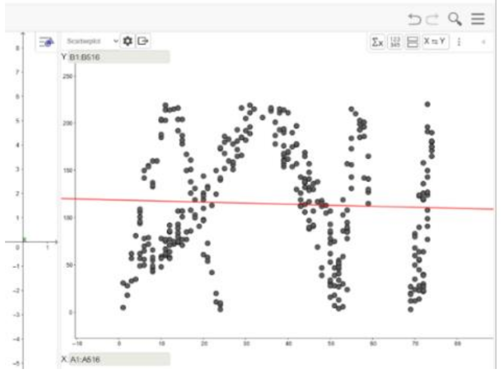
3.3 (Task 3) Reflection on AI model

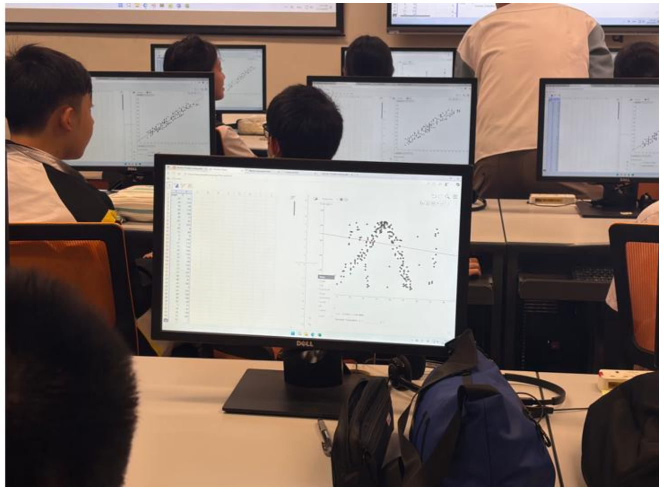
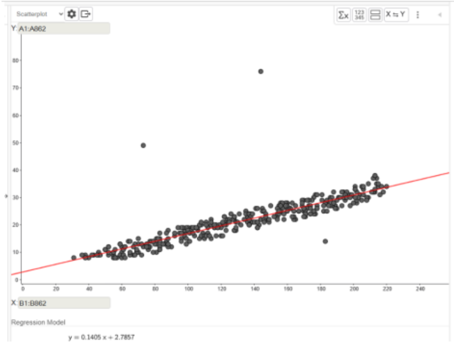
Creating and interpreting the scatter plot and line of best fit

1. What does the line generated in the scatter plot represent?
2. Why don't all points fall exactly on this line?
3. How do you think AI predicts the launch angle of the marble based on the rubbish's x position?
4. Some of the angles predicted by the AI don't hit the target. What factors affect the accuracy of the AI model?
5. How can we improve the accuracy of AI predictions?



Record your changes to parameters, draw scatter plots and fit functions

3.4 Some empirical findings

Students' conception of AI before and after the designed task.

Before the lesson: Inadequate conception of AI	After the lesson: Surface-level of white-boxing	After the lesson: Critical-level of white-boxing
• AI is a software system that knows everything • **Smarter than human; non-human but knowledgeable** • Capable of performing complex calculations • It can help me with homework and engage in conversations • **Capable of resolving questions beyond our understanding** • AI can do something humans do, like walking, some AI know things on the internet and help humans • AI is a machine capable of performing diverse tasks but lacking emotional awareness • A system that observes the surrounding environment and takes actions to achieve goals	• I developed and trained new machine learning models, then observed differences generated by additional examples. • **AI built a model and collected 4,206 data examples.** • How to use AI and collect 382 examples of data. • I learned how to use AI to collect data. • I used AI to analyze and target rubbish • **AI learns from data gathered by repeated experiments** • AI collects data and turns them into learning material	• AI use the existing data, or **find patterns** from these data to **predict the answer** • I used the data to **calculate the average fit number** • AI generates **a line from the input data**, and it use the line to predict the outcomes • There is a reference line from the data, AI finds the predicted angle from the line • AI finds patterns from data to **form rules**, then it uses the rules to predict new data • AI can be **inaccurate since it is summarized from different input data** • If there is incorrect data, it will affect the **model** that AI creates, to impact its predicting accuracy

Ng et al. (2026). Design principles for curricular and instructional innovations toward supporting a computationally enhanced, AI-literate mathematics education. *ZDM-Mathematics Education.*

3.5 More empirical findings

Theme 1: The Learning Process (Focusing on the Core Mechanisms of AI Learning and Training)

- I understood the learning process of AI and how data is applied.
- This helped me grasp the learning principles and model building methods of AI.
- I understood the data concepts and design processes behind AI model programs.
- I learned how AI collects, organizes, and applies data to models.

Theme 2: The Role of Data (Focusing on the Impact of Data on AI)

- AI is not completely accurate; its conclusions are based on different data.
- The more accurate the data acquired by AI, the better the results it can achieve.
- This made me realize that AI learns extremely quickly, and its accuracy is very high when the data is accurate.
- I understood the training process of AI models and recognized the impact of erroneous data during training on the model.

Theme 3: The Capabilities of AI (Speed and Potential)

- I previously thought that AI could only perform creation, calculation, and information retrieval—after learning, I discovered how practical it is.
- I personally experienced the learning speed of AI; AI can process data instantly. The lesson made me realize that AI learns extremely fast.

Some questions and research directions

Curriculum

What knowledge, skills, and attitudes in the AI age?

Tools

What tools (tech and non-tech)?

How to integrate them meaningfully?

Tasks

What problems are worth solving?

What contexts are students interested in?

Teacher professional development

How to support teachers?

Thank you!

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