MPTL

Multimedia in Physics Teaching and Learning

Supporting Science Learning with Simulations: Contextualized Guidance from LLMs Based on Student Actions

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國立中央大學 National Central University

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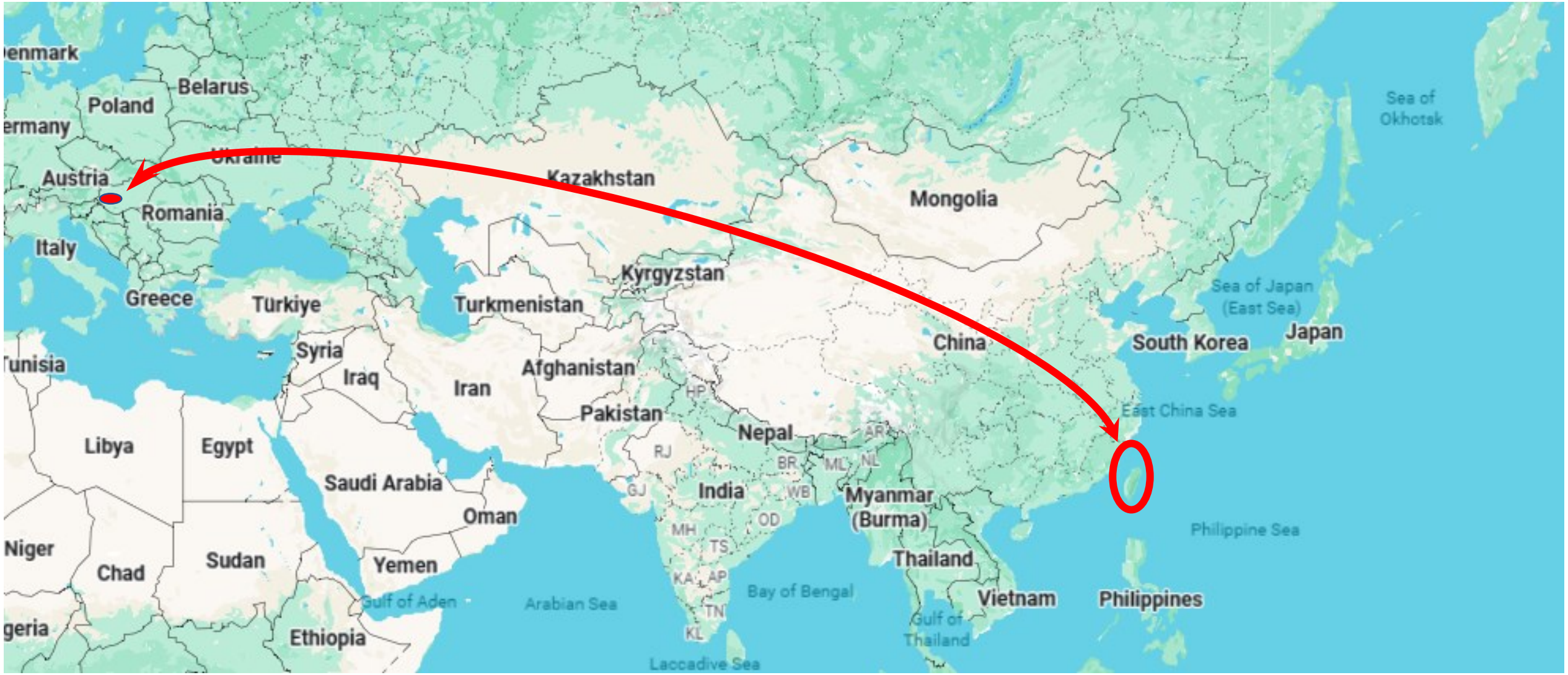
東吳大學 Soochow University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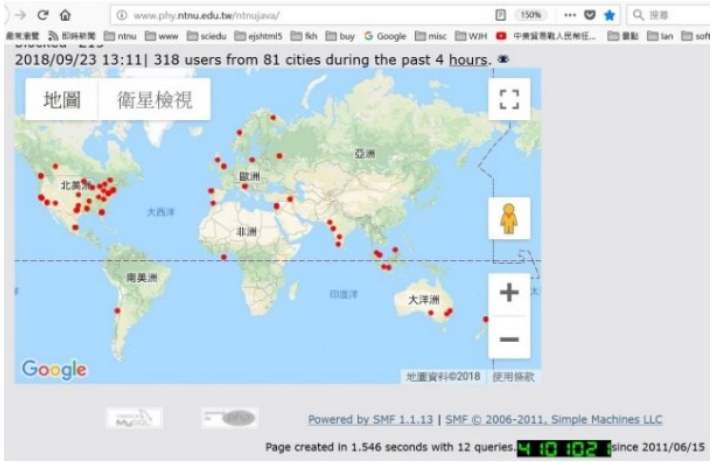
The CoSci Platform

A simulation platform by Chen-Chung Liu, Fu-Kwun Hwang, Francisco Esquembre and colleagues

CoSci

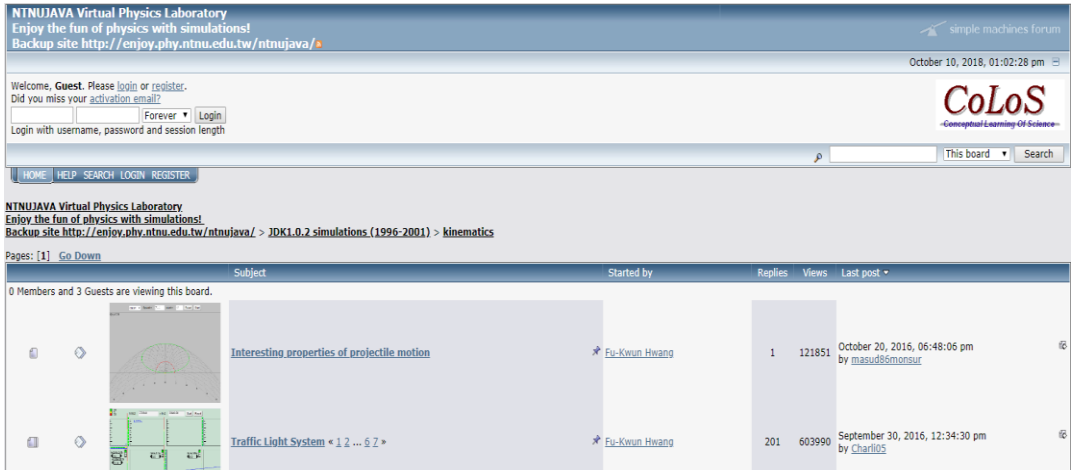
Starting point

- Virtual Physics Lab Since 1996
  - BY Prof. Fu-Kwun Hwang
  - Hundreds of science simulations built with EJS by Professor Francisco Esquembre
  - Collected by MERLOT, National Science Teacher Association, etc.
  - Java-based simulations

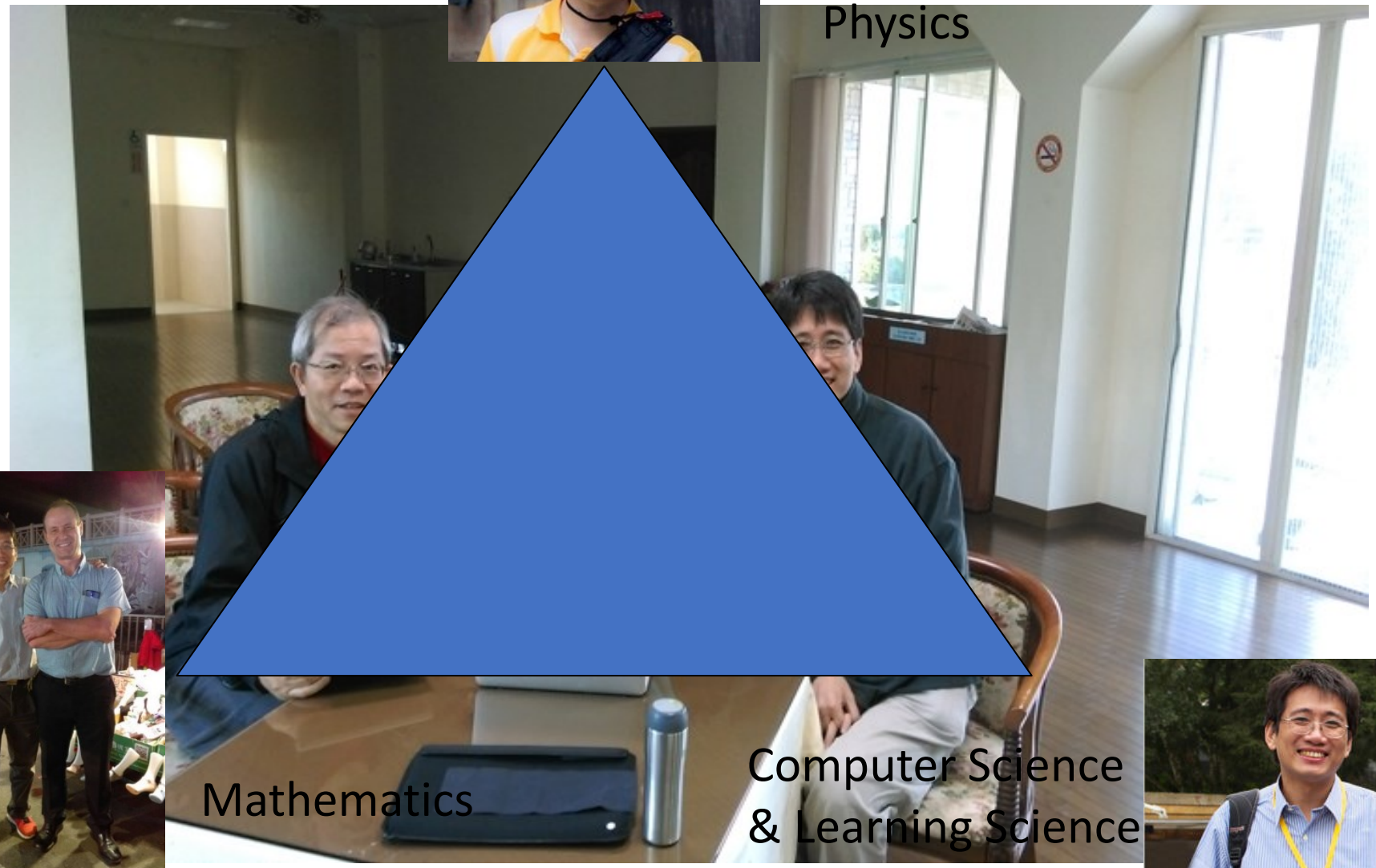


Starting point

- An informal meeting of SIG meeting of e-learning of NSTC, on Pong Hu island, 2011
- JAVA simulations can not be run on Tablets or mobile phones



Launch a ne ect in 2011



Founders and key technician

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NCU, Taiwan

Fu-Kwun Hwang
NTNU, Taiwan

Francisco Esquembre
University of Murcia, Spain

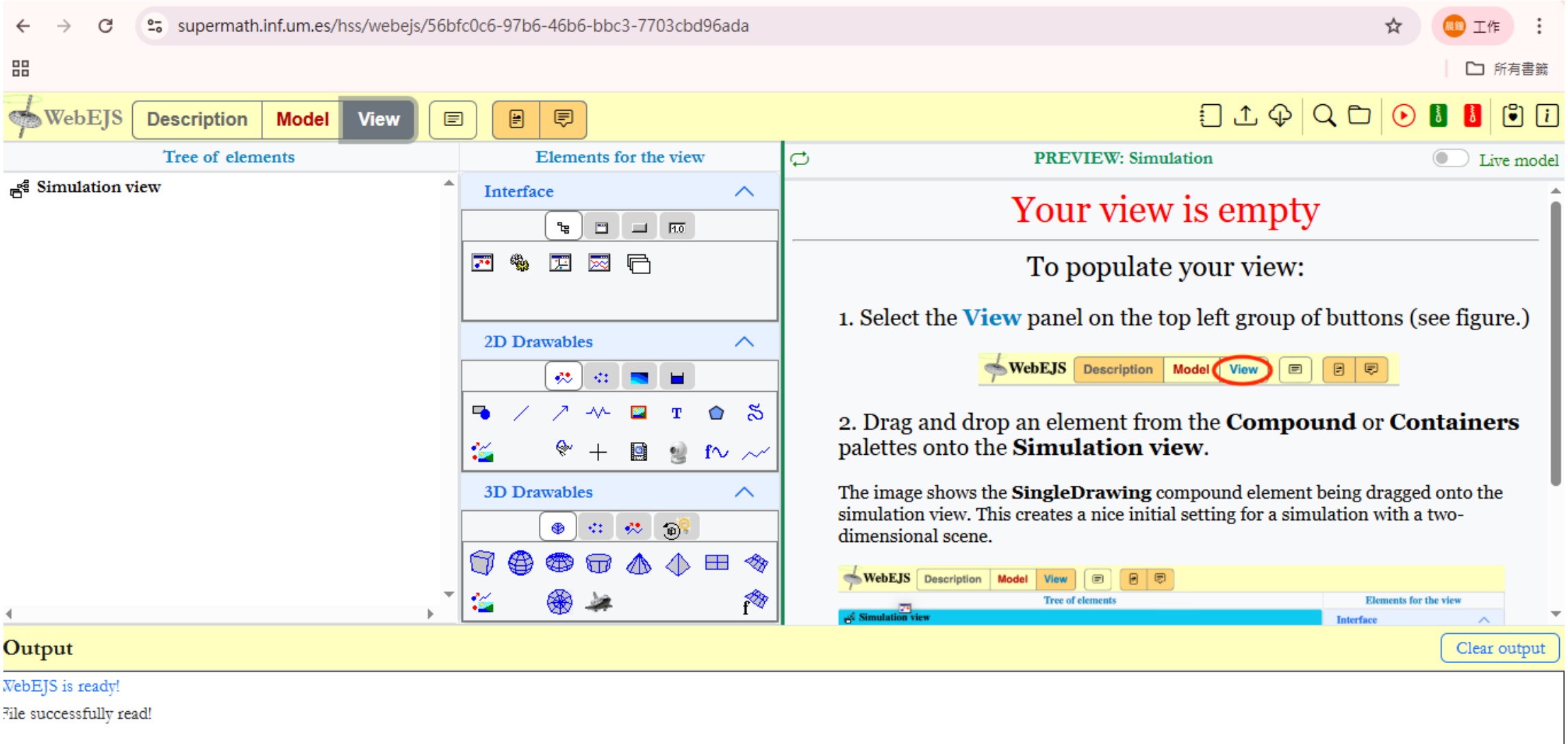
Shih-Hsun Fan Chiang
NCU, Taiwan

Founders and core physics engine

HTML5 version of EJS

A child and subset of EJS/EJSS
Thanks to Paco and Fu-Kwun

WebEJS1.2 By Francisco Esquembre
https://www.um.es/fem/wikis/runwebejs/



Simulation development team

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Chen-Chung Liu
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Jhen-Hao Li

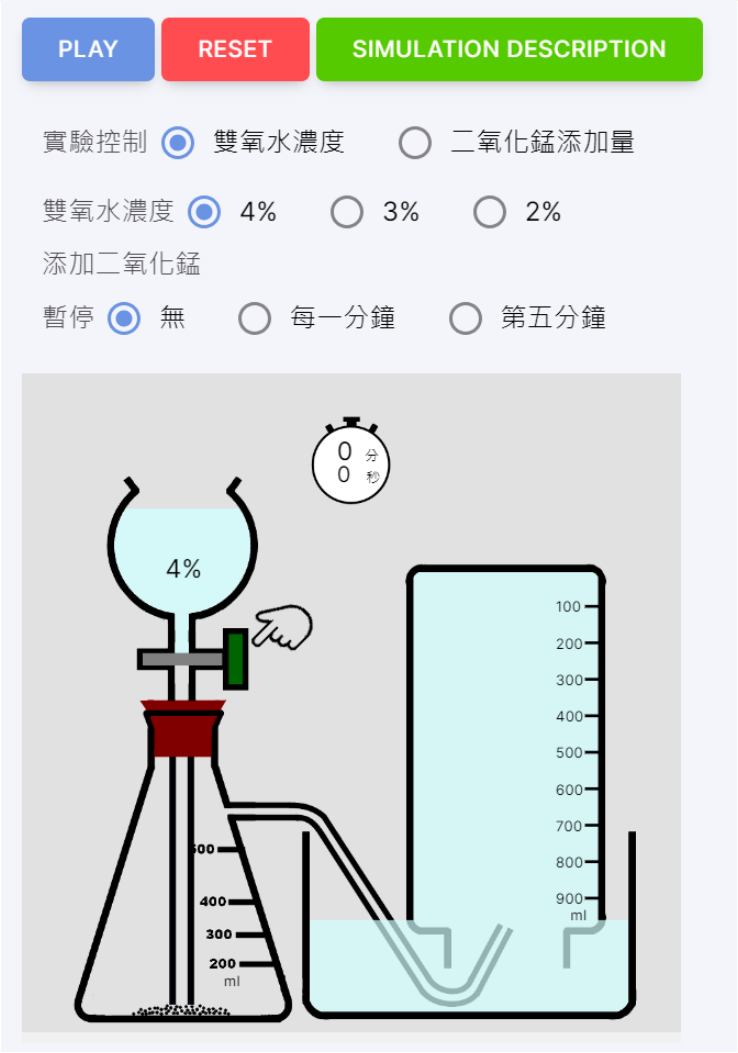
Hsin-Fang Hsieh

Wayne Chuang

Strong Huang

Simulation development team

Simulation Development Team



雙氧水濃度	4.38%	3.28%	2.19%	1.09%
1分鐘	288	190	125	58
2分鐘	213	122	75	13
3分鐘	168	107.1	65	13
4分鐘	83	71	49	13
5分鐘	31	41	35	8.9
6分鐘	13	20	20	8.9
7分鐘	8	8.9	16	8.9
8分鐘	3	8	8	0
9分鐘	3	5	4	0
10分鐘	2	5	4	0
總氧氣量	812	578	401	123.7

一級反應 [編輯]

4 種語言

條目 討論 臺灣正體 閱讀 編輯 檢視歷史 工具

維基百科，自由的百科全書

在化學中，一級反應（英語：First-order reaction），亦稱為一次反應，是指反應級數為1的化學反應。放射性元素衰變就是一級反應的一個例子。

例子 [編輯]

- 五氧化二氮在惰性溶劑四氯化碳中分解為二氧化氮和氧氣的反應： $2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$
- 過氧化氫分解為水和氧氣的反應： $H_2O_2(l) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$
- 硫醯氯分解為二氧化硫和氯氣的反應： $SO_2Cl_2(l) \rightarrow SO_2(g) + Cl_2(g)$
- 偶氮甲烷的分解反應（產物乙烷和氮氣）。
- 有些有機反應也屬於一級反應。例子有單分子消除反應、單分子親核取代反應。

性質 [編輯]

對於反應 $A \rightarrow$ 產物，一級反應是反應速率與反應物 A 的濃度的一次方成正比的基元反應。一級反應包括單分子基元反應。一級反應的速率方程可以寫作：

$$r = -\frac{d[A]}{dt} = k[A]$$

k 是反應的速率常數，其物理意義是單位時間內反應物 A 反應掉的分數，單位為 s^{-1}。

將上式積分，可得一級反應的積分速率方程：

$$\ln[A]_t = -kt + \ln[A]_0$$

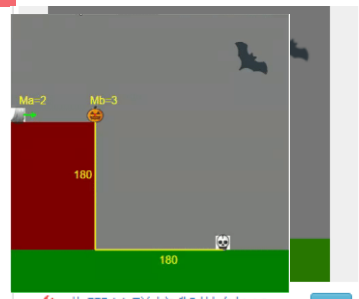
可見一級反應中 $ln[A]_t - t$ 呈直線關係。作 $\ln[A]_t - t$ 圖時，斜率為 $-k$，y - 截距為 $\ln[A]_0$。

一級反應的半衰期為：

$$t_{\frac{1}{2}} = \frac{\ln(2)}{k}$$

可見一級反應的半衰期與反應物的初始濃度無關。

100+ Simulations Since 2012

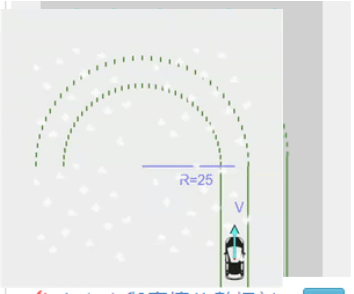


非彈性碰撞與拋射Hfun

projectile motion | non-elastic collision

此程式模擬等速移動的鬼魂在碰撞南瓜後一起落下斷崖的運動過程，任務是讓鬼魂與南瓜落地時命中骷髏頭。

5086 mhchang

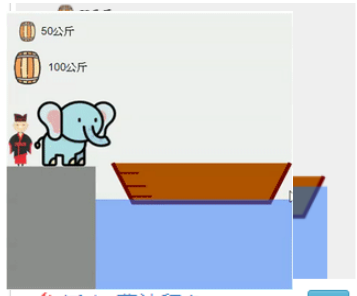


向心力與摩擦係數探討合作

coefficient of static friction | centripetal force

此程式模擬一等速率V(公里/小時)行駛的車輛於直線道行駛進入彎道車輛行駛的軌跡。你知道在天候下行駛時車速該如何控制才安全嗎?

7476 mhchang

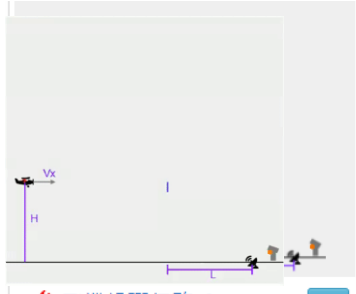


浮力-曹沖秤象

buoyancy | Archimedes' principle

此程式模擬將不同重量的物體放到船上時，船吃水線的變化。你知道模擬中的小象與曹沖分別多重嗎?

7305 mhchang

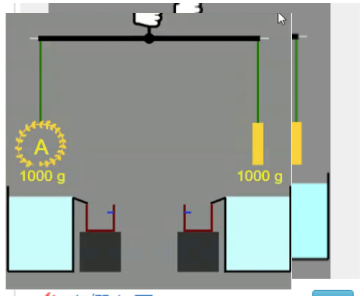


飛機投彈任務-fun

projectile motion | gravitational force

此程式模擬一架椅等速度Vx 飛行的戰機投彈的運動過程，任務是使得砲彈落地時擊重地面雷達站。

7102 mhchang

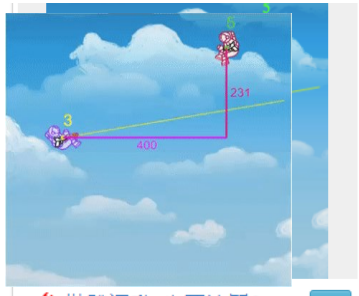


真假皇冠

law of the lever | Archimedes' principle

此程式模擬兩個重量相同但密度不一定相同的物體沉入水中的過程。模擬中有三頂重量相同皇冠，其中有一頂是純金製成的，其他兩頂卻是合金製成，你知道哪個皇冠才是純金的嗎?

4353 mhchang

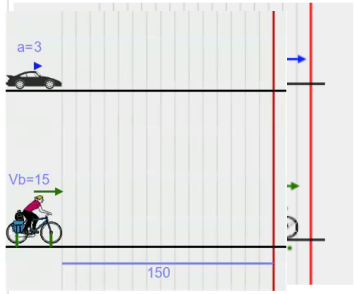


拋體運動-生死決鬥fun

projectile motion

此程式模擬兩位太空人的決鬥過程。你知道該如何設定參數使得紫色太空人射中紅色太空人嗎?

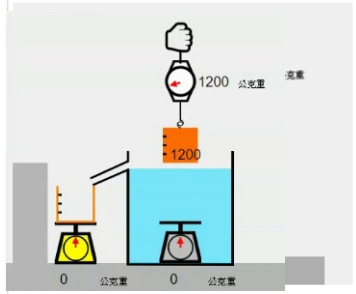
4598 mhchang



等速與等加速度運動-同時

velocity | acceleration

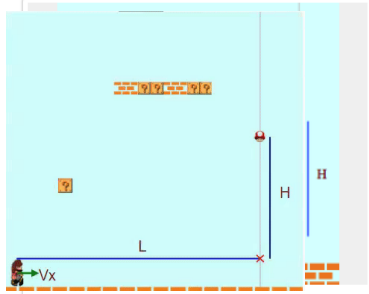
此程式模擬兩種物體的運動，等速度運動的腳踏車與等加速度運動的汽車。任務是讓兩車同時抵達終點。



密度與浮力實驗

buoyancy | Archimedes' principle

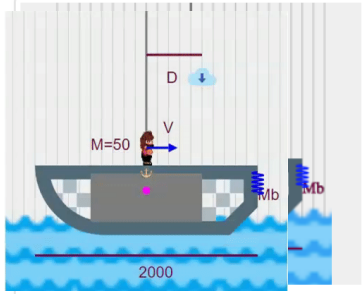
此程式模擬將一個重量為 M 公克，體積為 V 立方公分的橘色方塊慢慢浸入密度為 rhoS (公克/立方公分)的藍色溶液中的過程，以探討浮力概念。



等速與落體合作fun

velocity | acceleration

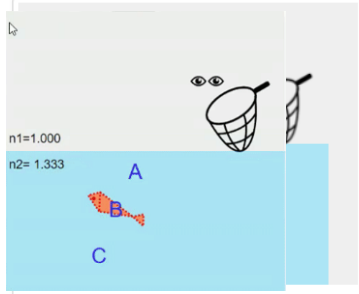
這是一個運用等速度運動與自由落體的概念設計的合作問題解決題目。



質心與動量守恆A-fun

conservation of momentum

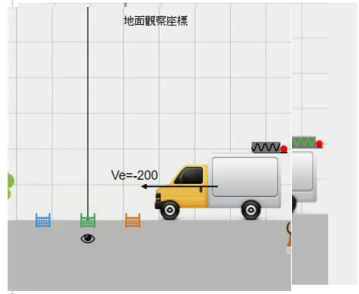
此程式模擬一不受外力的作用的靜止的船上載著馬力歐，假設船與水面間無摩擦力，當馬力歐以等速 V 向船尾移動時，馬力歐與船的運動。



光的折射-捕魚去

refractive index | snell's law

此程式模擬位於空氣中(折射率n1)的人眼由水面上所觀得水裡(折射率n2)的魚的影像。請問該將魚網放在哪裡(A，B，C)可以捉到水裡的魚呢?



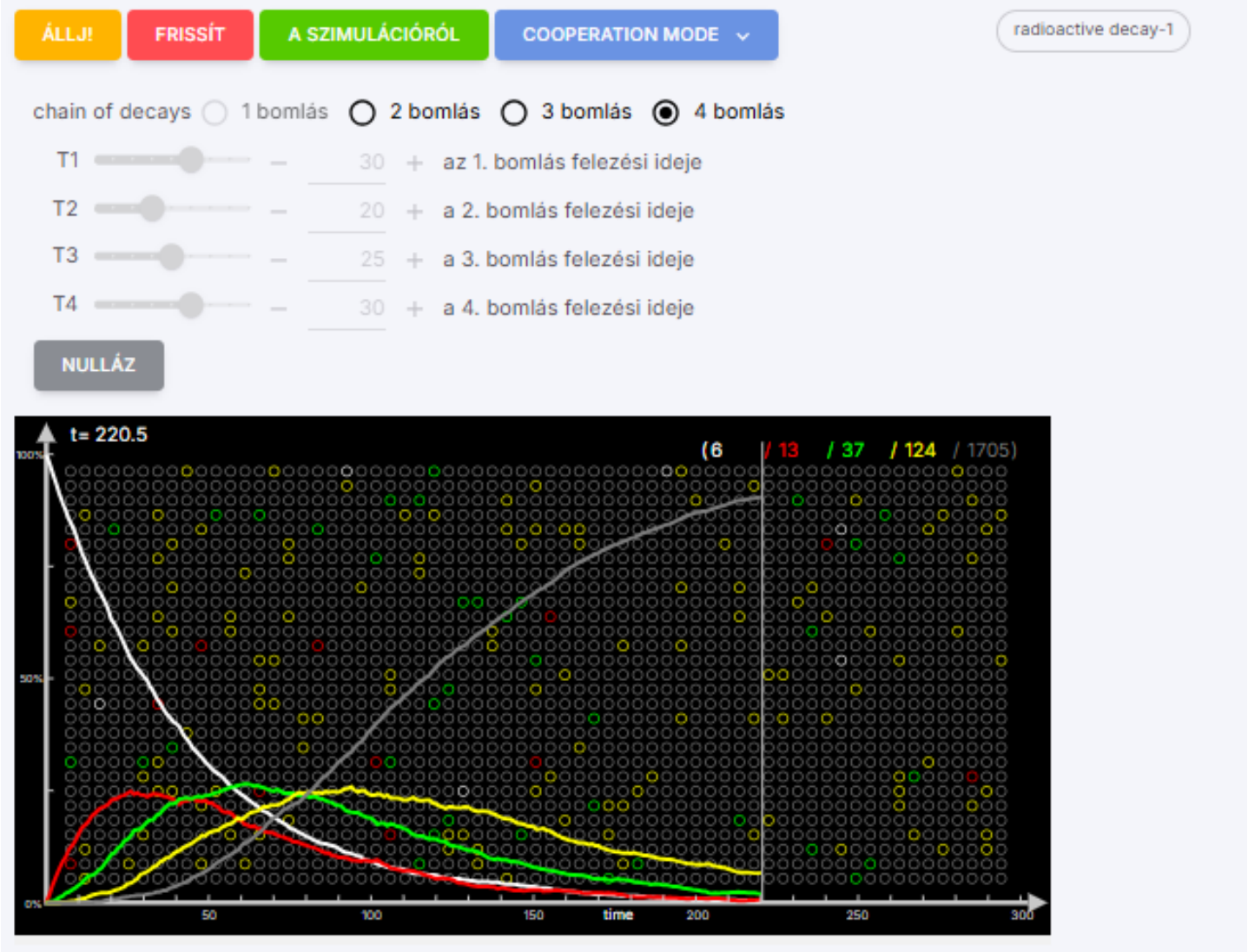
拋體運動-落在哪裡fun

velocity | projectile motion

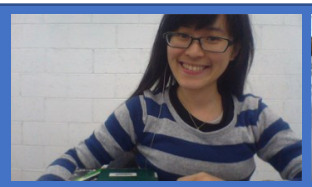
此程式模擬一顆從移動中的貨車屋頂落下/射出的紅球的運動軌跡。

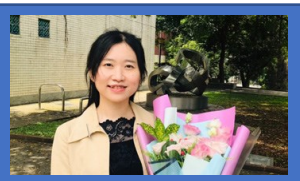
Simulation requested/translated by a Hungarian teacher

- Chinese
- English
- Indonesia
- Thai
- Melayu
- Magyar

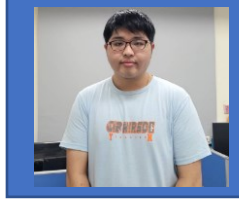


Radioactive decay
https://cosci.tw/run/?name=ky29pA1642424677400





Cai-Ting Wen | Chia-Hui Cheng | Ying-Siou Chen | Chia-Jung Chang | Po-Yao Chao



Pedagogy and system development team

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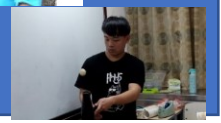
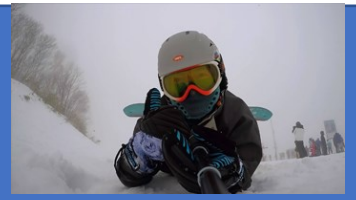
Jhen-Hao Li | Hsin-Fang Hsieh | Wayne Chuang | Strong Huang

Simulation development team

CoSci



School teachers



Chen-Chung Liu
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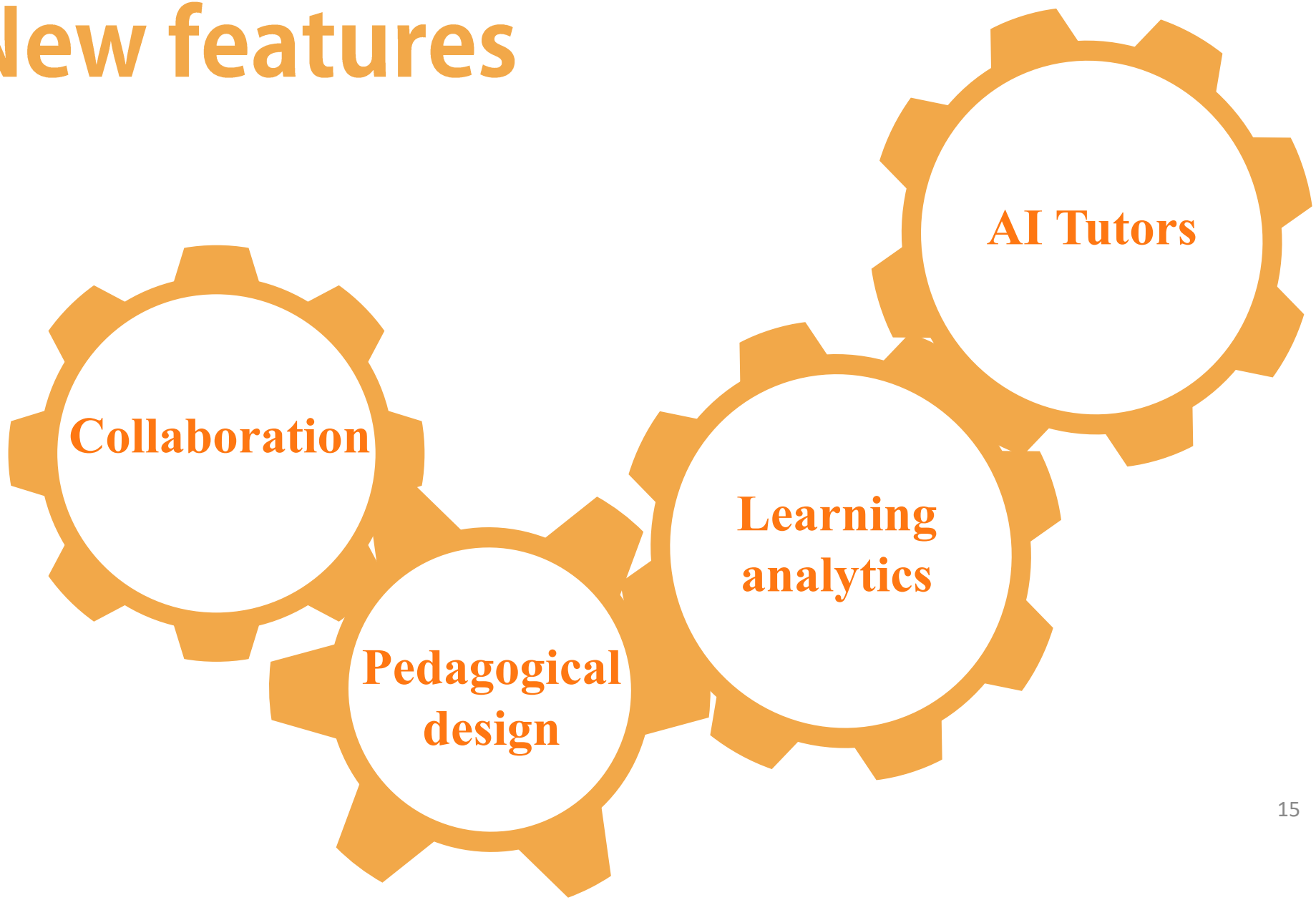
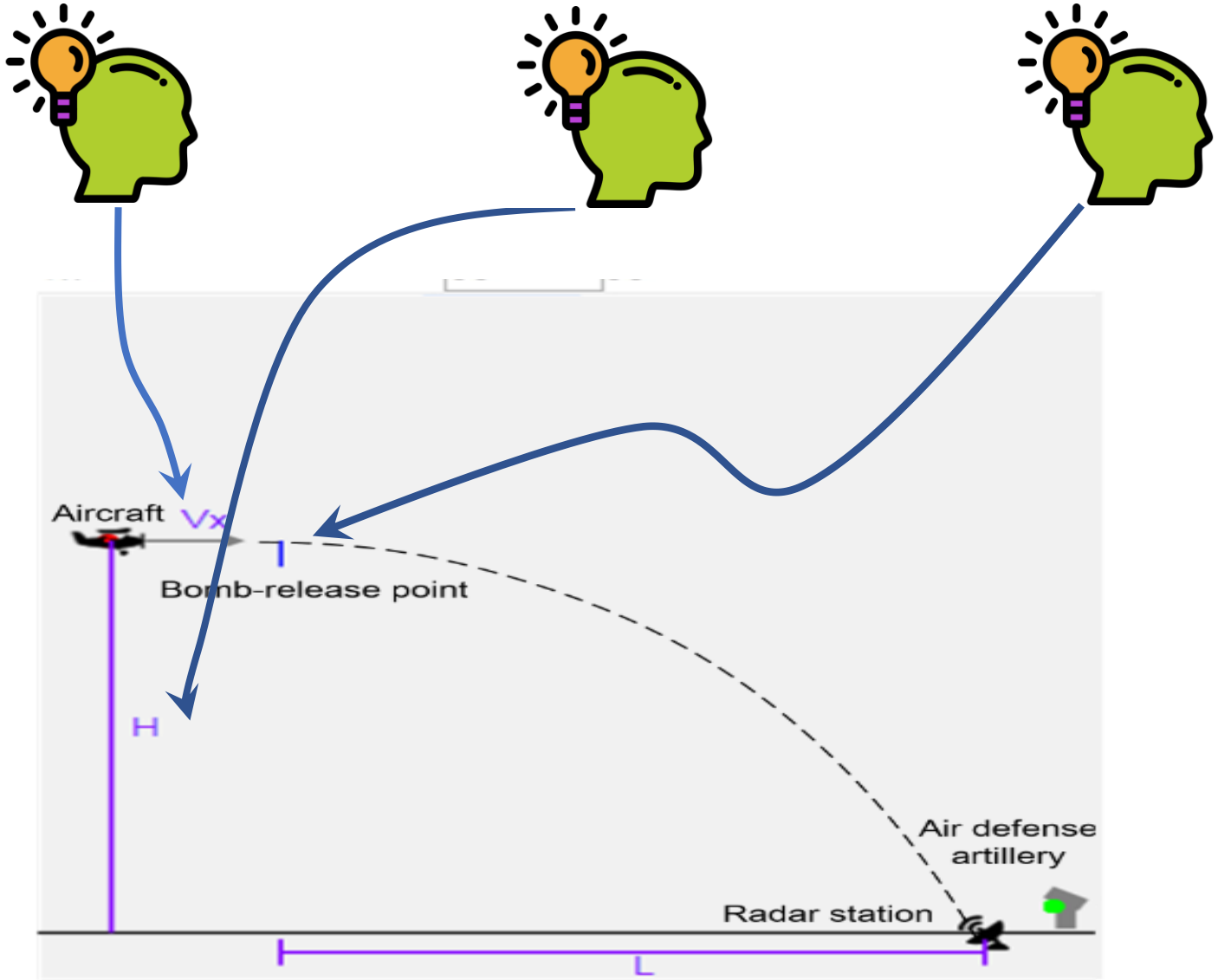
Founders and core physics engine

New features

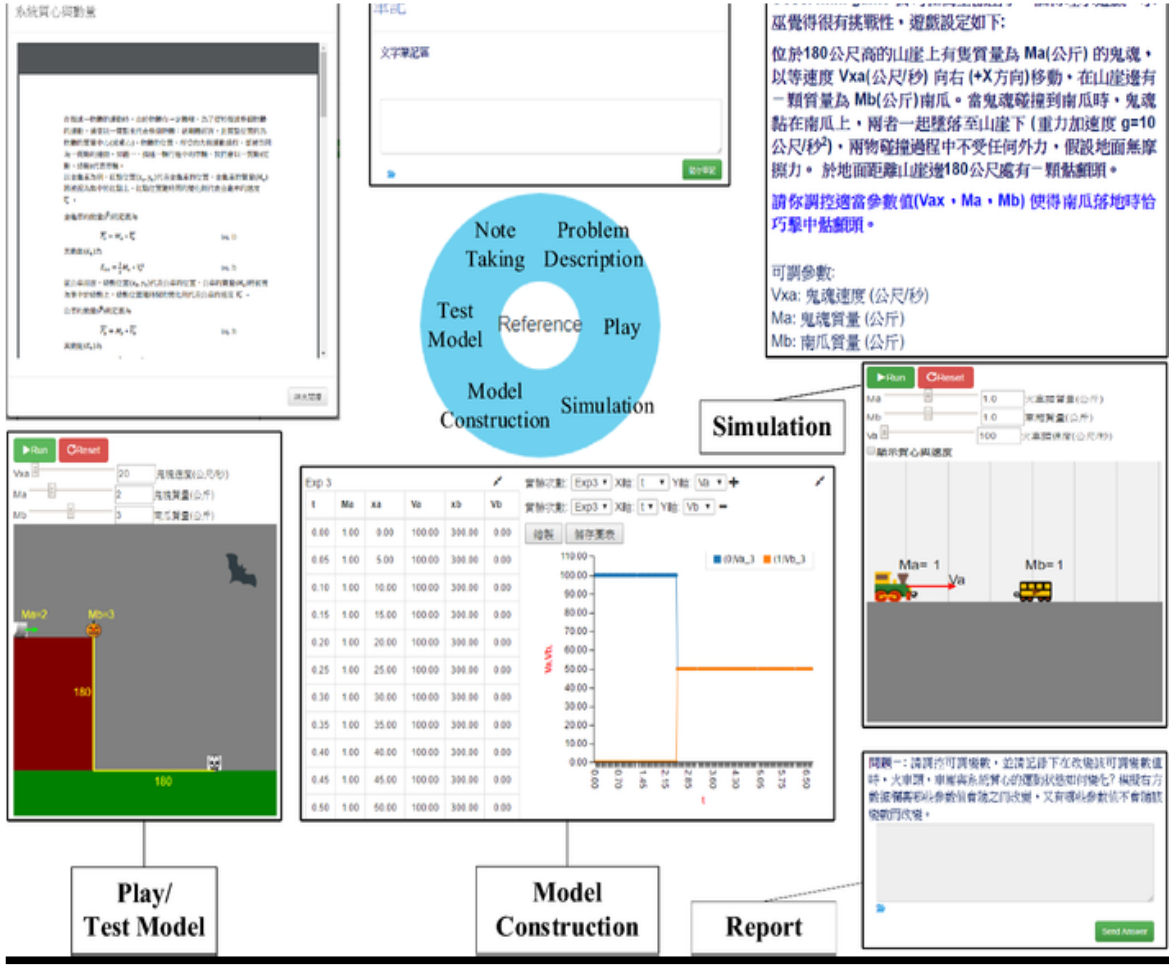


Everyone-is-needed



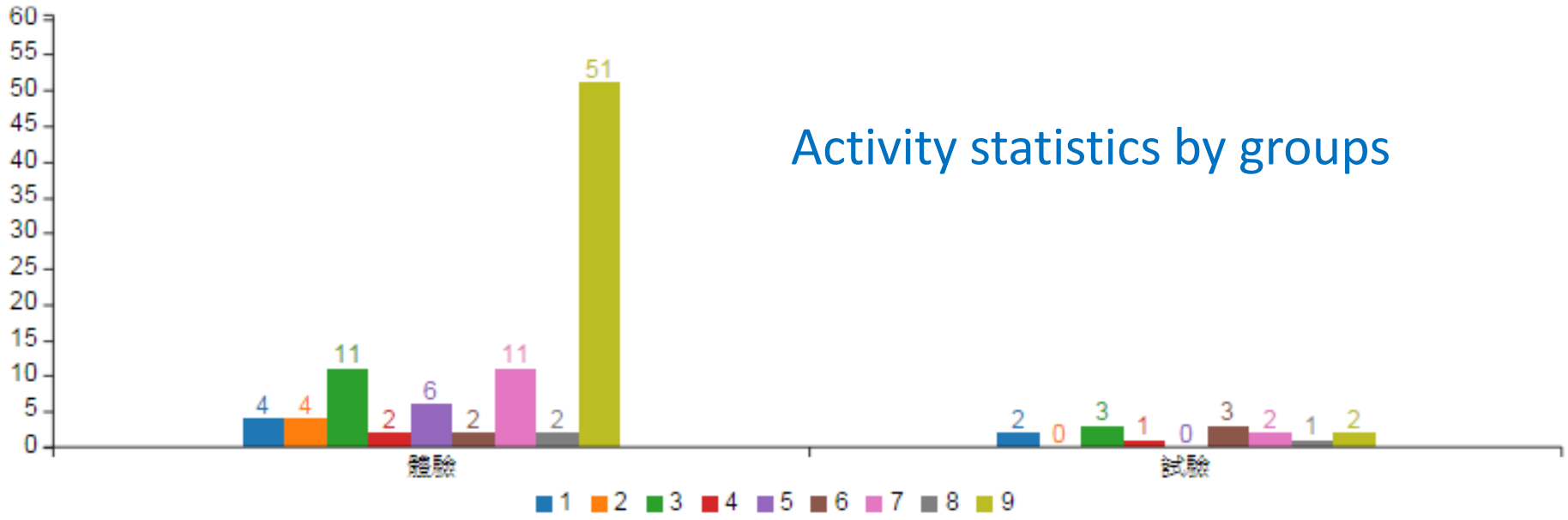
Pedagogical design

Customizable guiding prompts

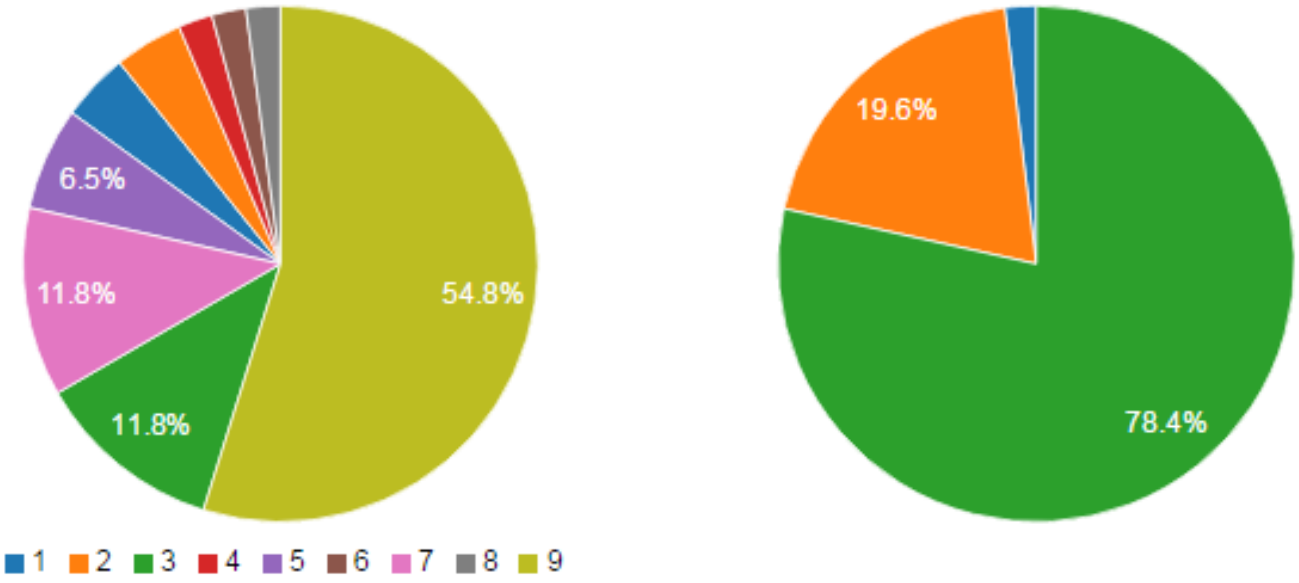


1. Divide complex inquiry into simpler tasks
2. Provide prompt questions in each task
3. Guide student to go through the whole inquiry process

Learning
analytics



Activity statistics by groups



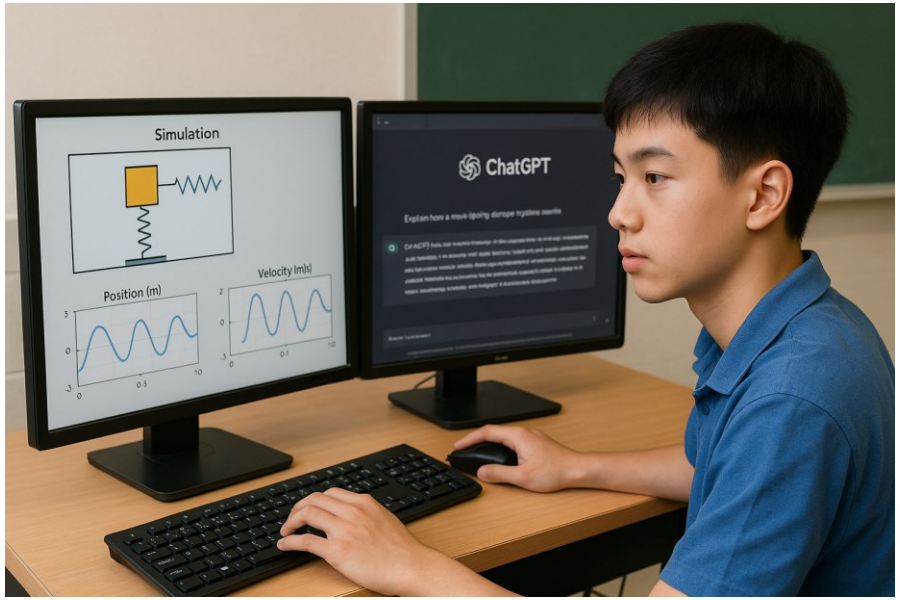
Activity statistics by groups

Member contribution in a group

The AI tutor

How Generative AI can be integrated with simulations to help students learn science?

The Standalone approach

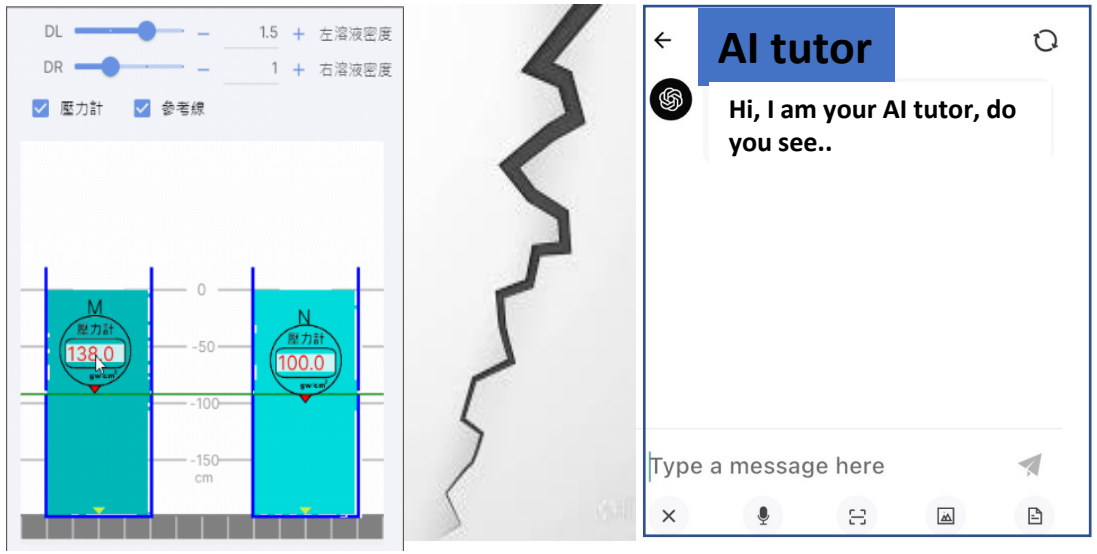


GenAI simulated scenario

- Simulations and GenAI are two standalone systems.
- No teacher pedagogical knowledge involves.
- Students are required to translate what they see in the simulation and need to understand what they need to know.

Focused tutor approach

- Simulations and the AI tutor are still two standalone systems.
- Teacher pedagogical knowledge and the key simulation feature are transcribed into prompts to implement the AI tutor.
- The AI tutor presents the learning task and focus students' attention in a way that is specific enough to orient students



Prompts:
Teachers' pedagogical knowledge and key simulation features

ACT1-Q3

[Student executes the simulation]

[Student executes the simulation]

Student submits answer: The amount of an object's motion.

AI assistant: Your answer is correct. Momentum is indeed the amount of an object's motion.

AI assistant: Do you know that momentum is related to an object's mass and velocity? Let's look at a simulation together! In the simulation, if a person's mass is 50 kilograms and their velocity is 100 cm/s, what would their momentum be?

Student: 5,000

AI assistant: Very good! Do you know how momentum is related to mass and velocity? If you know, please share your thoughts.

Student: p = mv

AI assistant: That's right! The formula for momentum is p = mv, which means that momentum is related to an object's mass and velocity. When mass increases, momentum also increases; when velocity increases, momentum also increases. Can you give an example from daily life to illustrate the change in momentum?

Student: A 1-ton truck moving at a speed of 36 km/h.

AI assistant: Great! So, if the truck's speed increases to 72 km/h, how will its momentum change? You can use the momentum formula to calculate it.

Student: It will double.

AI assistant: Correct! When the speed doubles, the momentum also doubles. This example nicely demonstrates the proportional relationship between momentum and velocity. Do you have any other thoughts or questions about momentum?

Figure 7. Excerpt displaying how the AI assistant interacted with a student with the simulation and life example

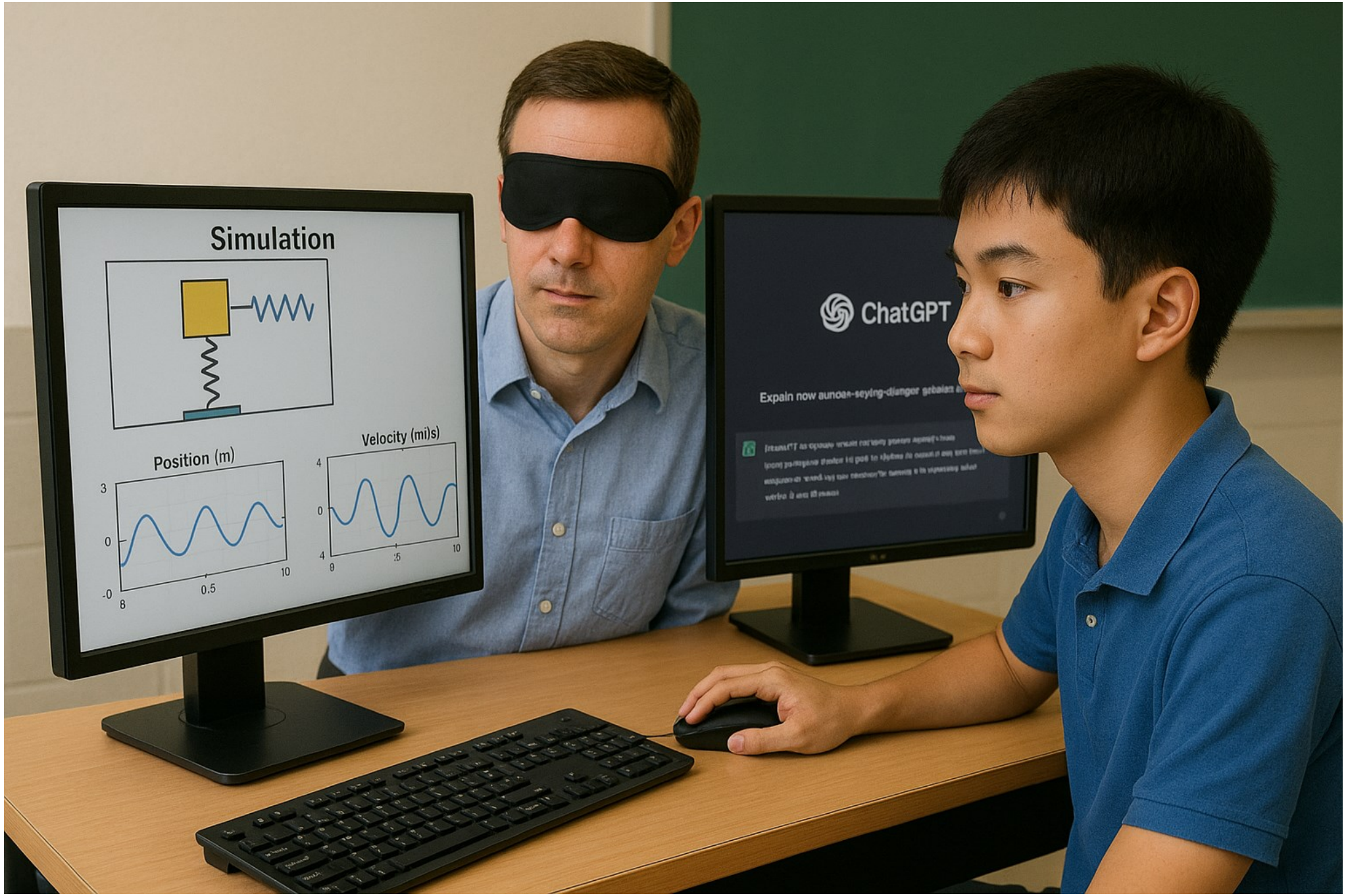
Focused tutor approach

Control group learned with the same system.
-- text descriptions of the science concepts were provided
-- without the access to the AI tutor

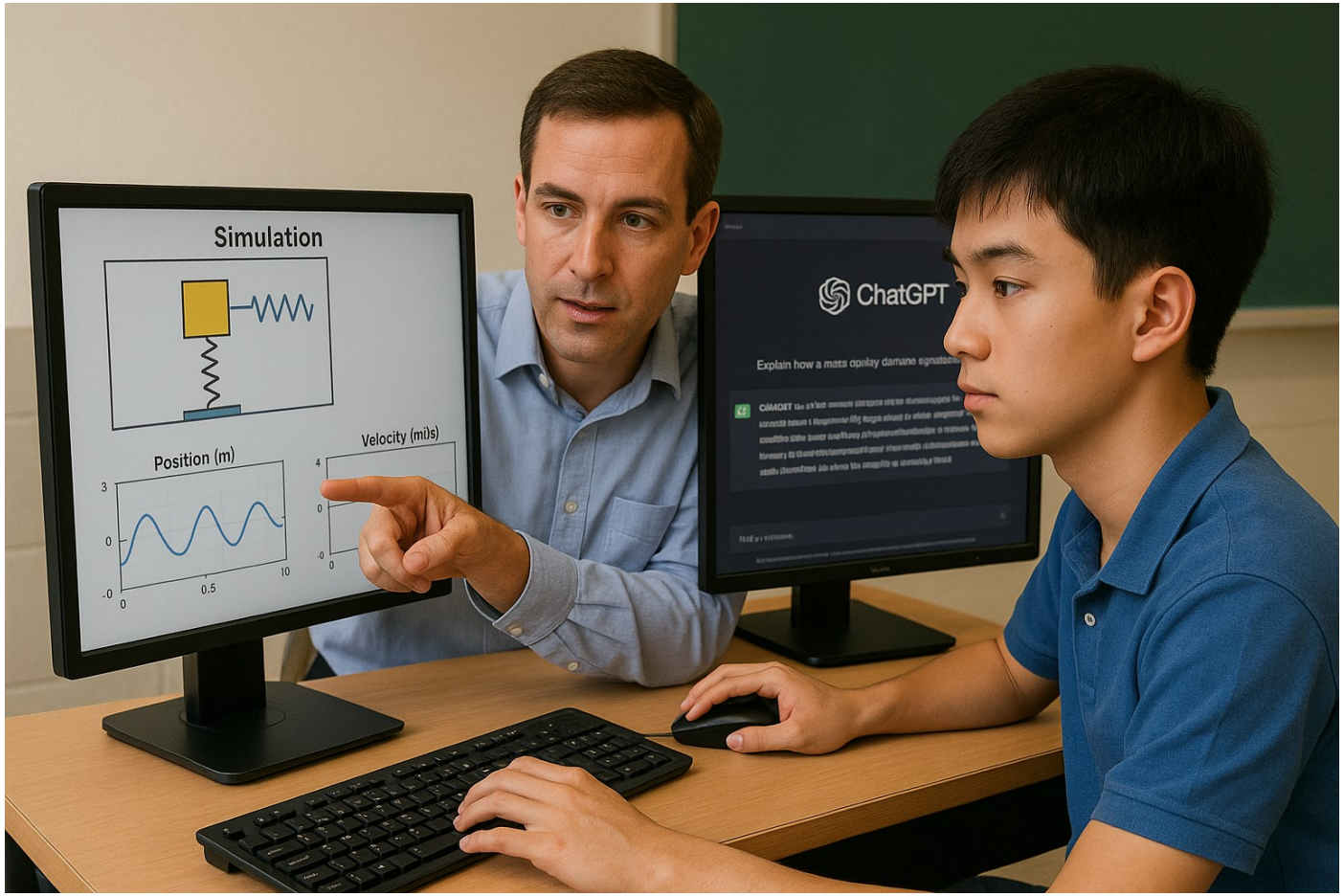
	N	Adjusted mean	Std. error	F	p
Control	29	10.86	.37	6.05	.02*
Experimental	33	12.12	.35		

Table 5. The ANCOVA analysis of the science conceptual post-test score with the pre-test score as the covariate
* < .05

However, the tutor is not aware of the simulation context and students' moves in learning science!



GenAI simulated scenario



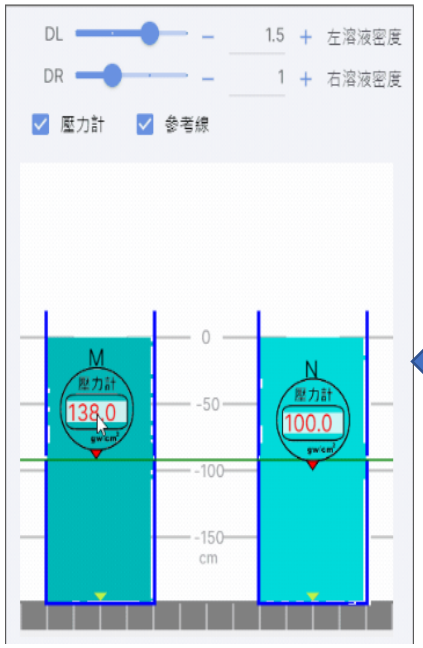
GenAI simulated scenario

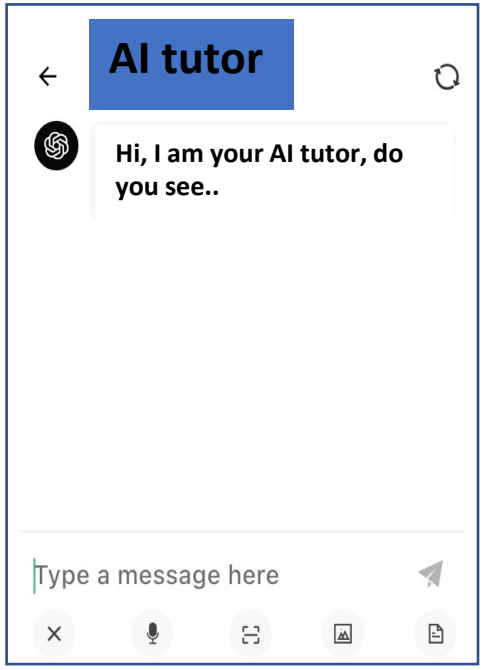
Cognitive apprenticeship stresses the critical role of the tutor in the context to (Collins et al., 1991):

a. Observe students' actions
b. Help students reflect on the learning process
c. Model the problem solving process
d. Engage students in articulation

The Cognitive Apprenticeship Tutor

The Cognitive Apprenticeship Approach

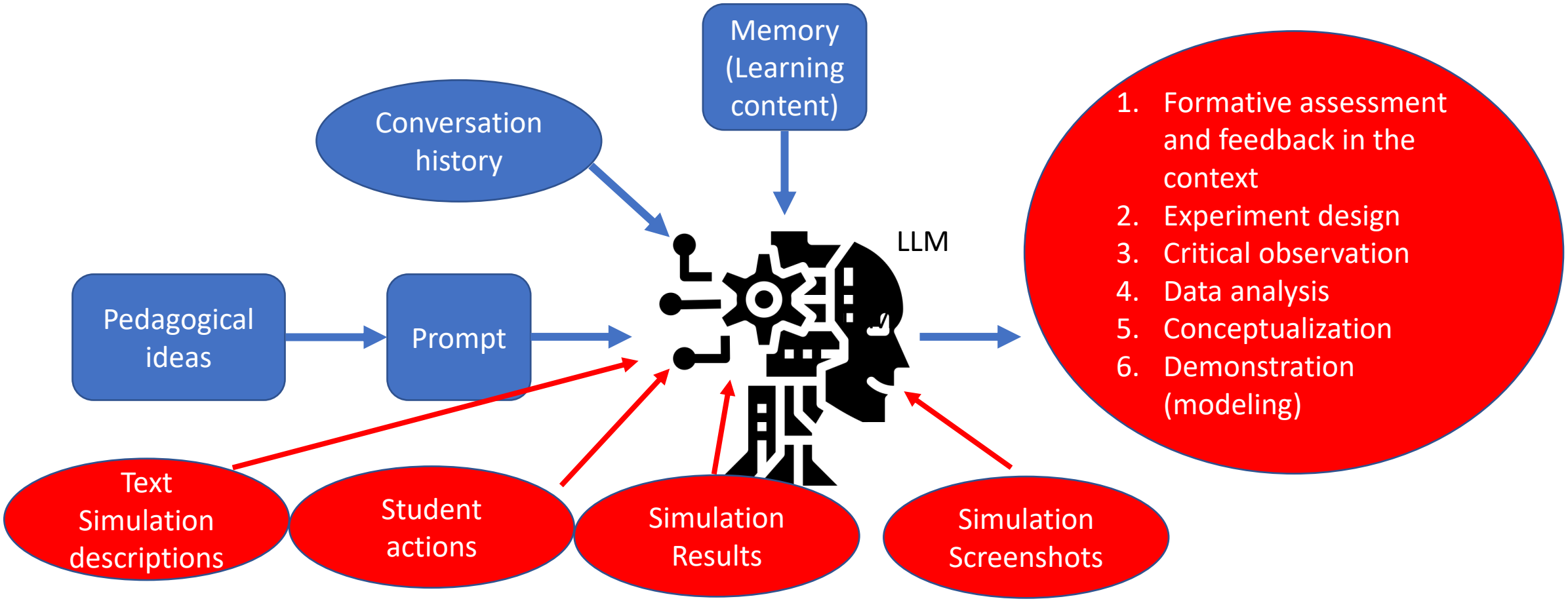




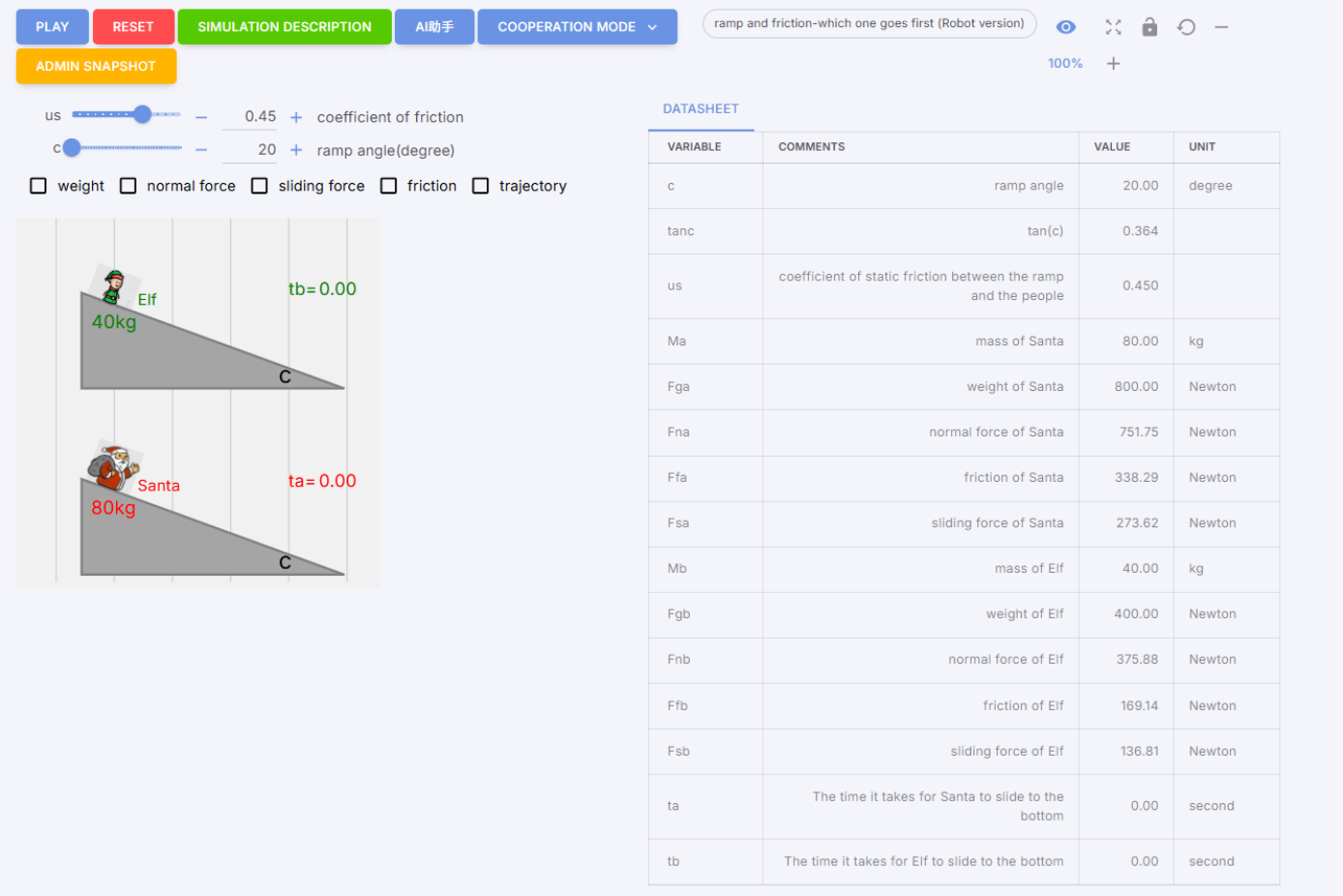
Prompts:
Teachers' pedagogical knowledge
Computational simulation model

- Building bridge between the AI tutor and the simulation.
-
- AI tutor understand the simulation and students' actions and the results of the actions.
- Teacher pedagogical knowledge are transcribed into prompts to implement the AI tutor.

Cognitive Apprenticeship (CA) Tutors
supporting reflection-in-action in context



Demonstration https://reurl.cc/x3WR5e

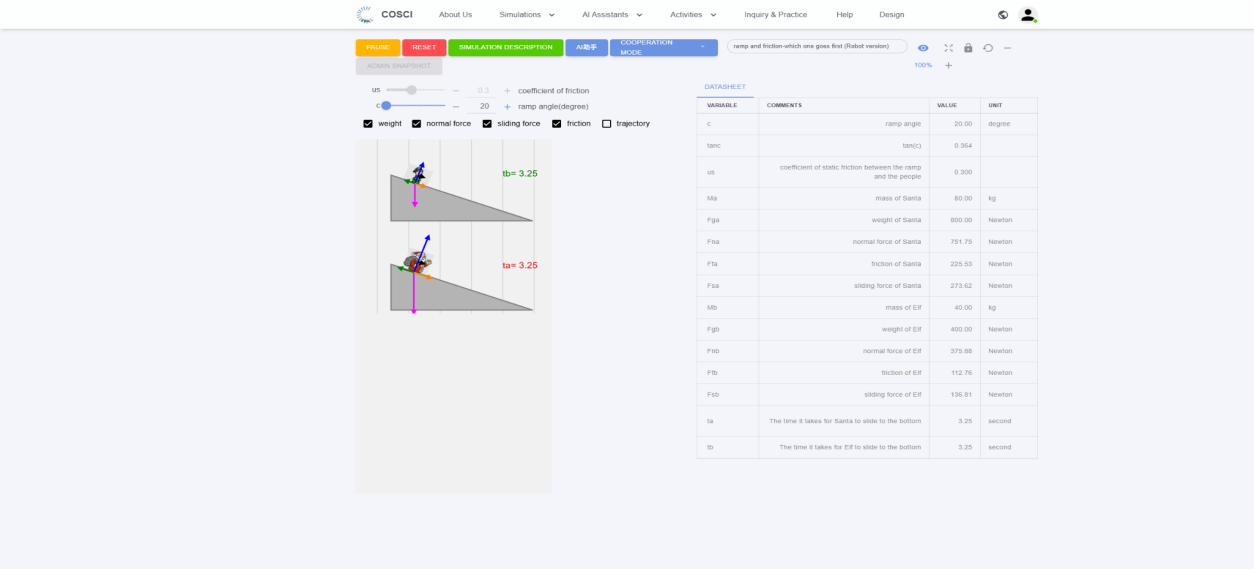


VARIABLE	COMMENTS	VALUE	UNIT
c	ramp angle	20.00	degree
tanc	tan(c)	0.364	
us	coefficient of static friction between the ramp and the people	0.450	
Ma	mass of Santa	80.00	kg
Fga	weight of Santa	800.00	Newton
Fna	normal force of Santa	751.75	Newton
Ffa	friction of Santa	338.29	Newton
Fsa	sliding force of Santa	273.62	Newton
Mb	mass of Elf	40.00	kg
Fgb	weight of Elf	400.00	Newton
Fnb	normal force of Elf	375.88	Newton
Ffb	friction of Elf	169.14	Newton
Fsb	sliding force of Elf	136.81	Newton
ta	The time it takes for Santa to slide to the bottom	0.00	second
tb	The time it takes for Elf to slide to the bottom	0.00	second

Registration and logging in CoSci required!

- Tutor: In this experiment, which forces do you think affect Santa and the elf as they slide down? For example, how might gravity, friction, and normal force influence their sliding?(2)

- Me: I don't know! can you explain it with the simulation?(3)
- Tutor: Let me demonstrate it with the simulation.



COSCI About Us Simulations AI Assistants Activities Inquiry & Practice Help Design

PAUSE RESET SIMULATION DESCRIPTION AI助手 COOPERATION MODE

ramp and friction-which one goes first (Robot version)

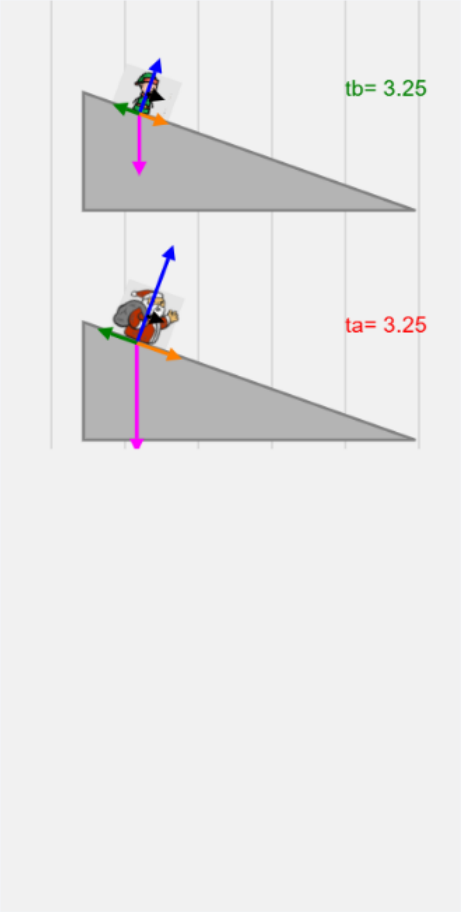
ADMIN SNAPSHOT

100%

us 0.3 coefficient of friction

c 20 ramp angle(degree)

weight normal force sliding force friction trajectory



DATASHEET

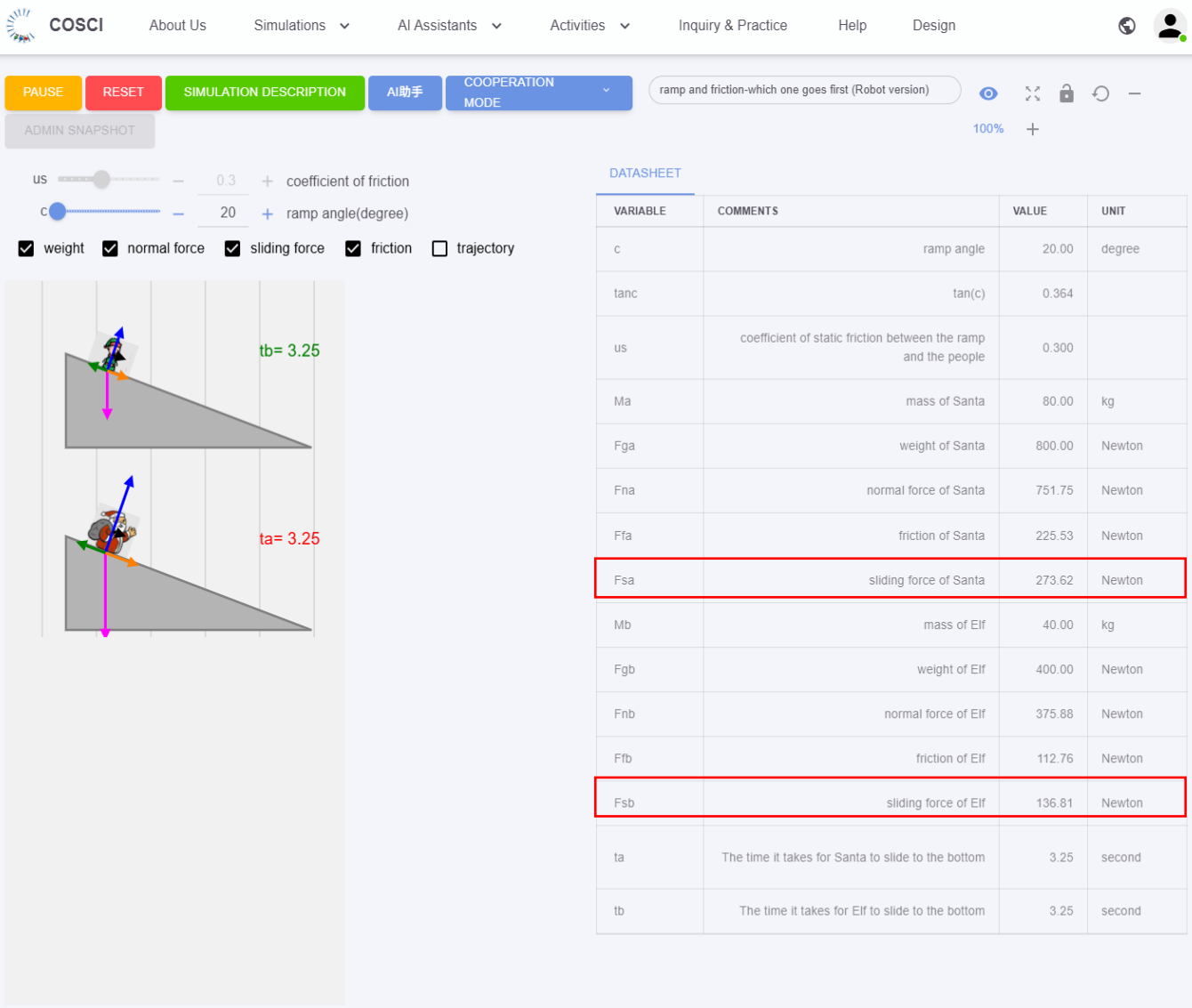
VARIABLE	COMMENTS	VALUE	UNIT
c	ramp angle	20.00	degree
tanc	tan(c)	0.364	
us	coefficient of static friction between the ramp and the people	0.300	
Ma	mass of Santa	80.00	kg
Fga	weight of Santa	800.00	Newton
Fna	normal force of Santa	751.75	Newton
Ffa	friction of Santa	225.53	Newton
Fsa	sliding force of Santa	273.62	Newton
Mb	mass of Elf	40.00	kg
Fgb	weight of Elf	400.00	Newton
Fnb	normal force of Elf	375.88	Newton
Ffb	friction of Elf	112.76	Newton
Fsb	sliding force of Elf	136.81	Newton
ta	The time it takes for Santa to slide to the bottom	3.25	second
tb	The time it takes for Elf to slide to the bottom	3.25	second

Cognitive apprenticeship: demonstration

- Tutor: Looking at the simulation, what do you notice about the forces acting on Santa and the elf? How do you think gravity, friction, and normal force play a role in their sliding? Let's discuss how these forces interact to affect the sliding behavior.(4)

- Me: How can I know the sliding force?(5)
- Tutor: The sliding force is the component of the gravitational force that pulls an object down the slope. It's calculated as the gravitational force times the sine of the slope angle, or mg sinθ. This is what causes the object to accelerate down the slope. Does that help clarify?(5)

- Me: Where I can find the magnitude of the sliding force in the simulation?(6)
- Tutor: You can find the magnitude of the sliding force in the datasheet on the right side of the simulation. Look for the rows labeled 'sliding force of Santa' and 'sliding force of Elf' to see their respective values. Let me know if you find it!(6)



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ta	The time it takes for Santa to slide to the bottom	3.25	second
tb	The time it takes for Elf to slide to the bottom	3.25	second

Cognitive apprenticeship: guidance in the context

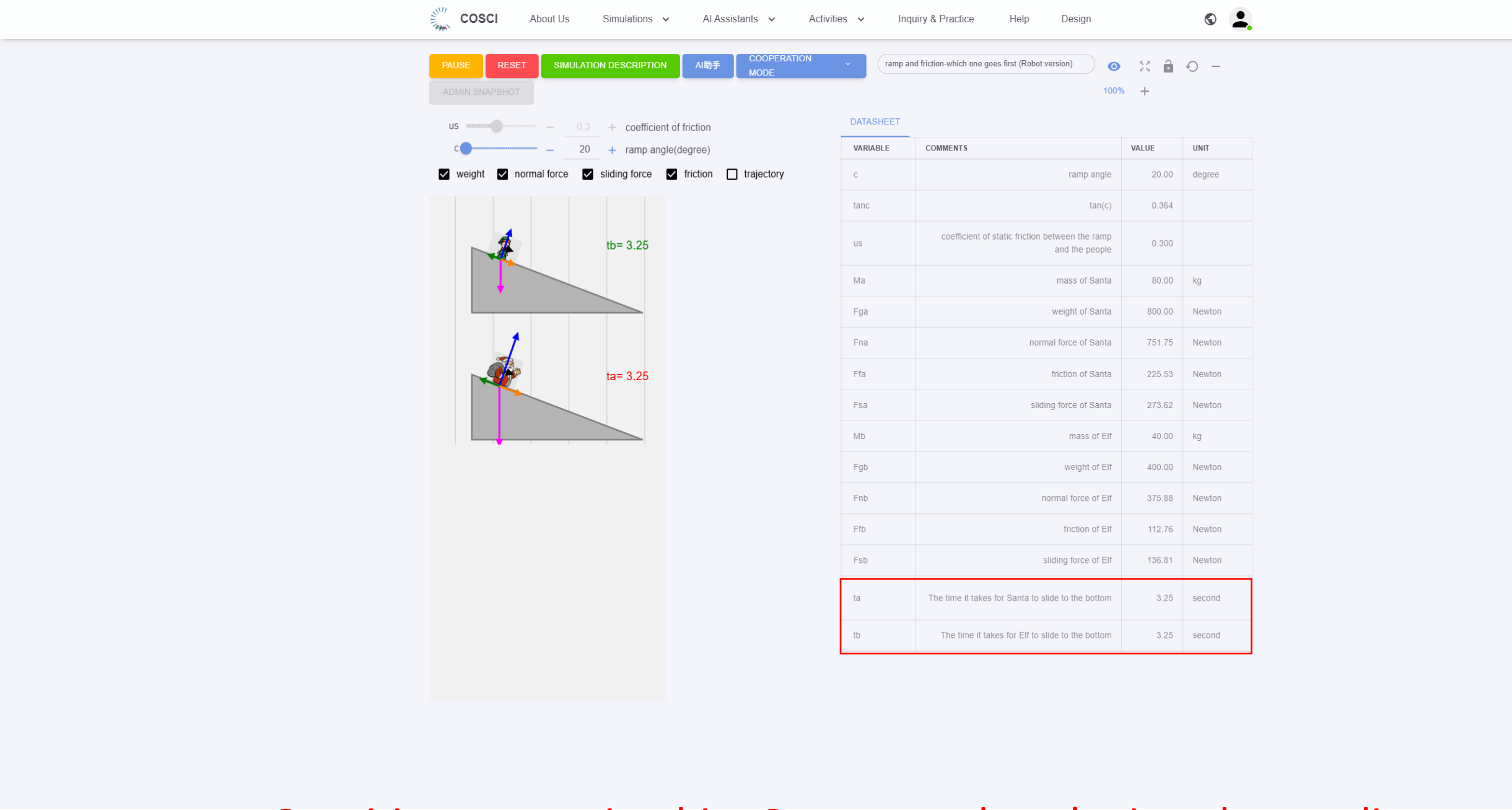
Demonstration

- Me: oh I see !! And where I can find the friction in the simulation? (7)
- You can find the magnitude of the friction force in the datasheet on the right side of the simulation. Look for the rows labeled 'friction of Santa' and 'friction of Elf' to see their respective values. Let me know if you find it!(7)
- So, I think the Santa will slide down more quickly than the elf.(8)
- Actually, both Santa and the elf slide down at the same rate in the simulation. Why do you think mass would cause Santa to slide faster than the elf? Let's explore this further.(8)

Demonstration

- Me: So, how can I verify this with the simulation?(9)
- Tutor: To verify, look at the datasheet in the simulation for 'ta' (time for Santa) and 'tb' (time for the elf). Run the simulation and check if these times are the same. This will show that they slide at the same rate. Let me know what you find!(9)

- ……



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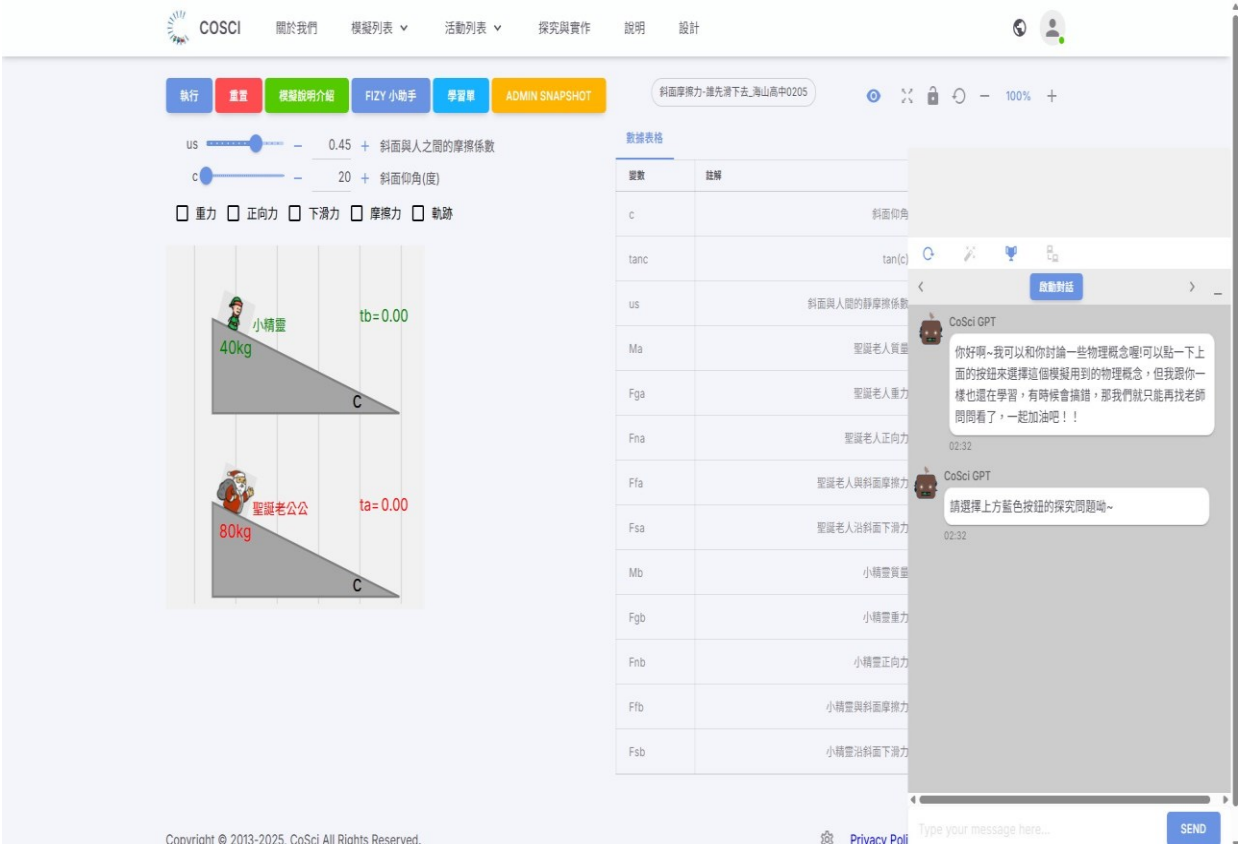
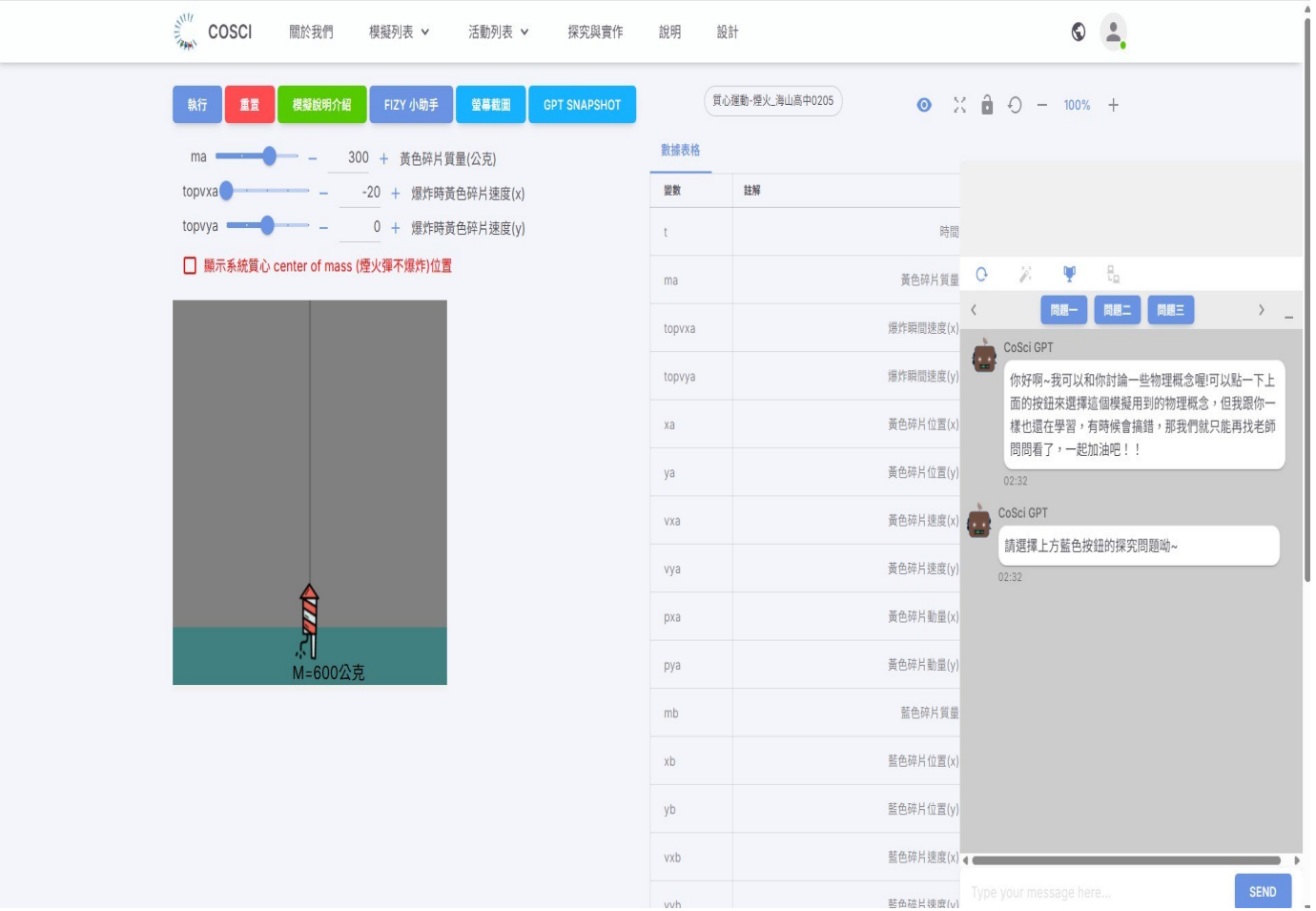
Cognitive apprenticeship: Correct students’ misunderstanding

Comparison of Standalone tutor and CA tutor



- Standalone tutor
  - Acting as ChatGPT with background knowledge of the simulation
  - The background knowledge of the simulation (friction, forces acting on a block on a slide) were given to GPT4o
  - The tutor responded to students' questions based on the knowledge given.

Comparison of Standalone tutor and CA tutor



- CA tutor knows the context of the simulation and students
  - Proactively guiding students in the use of the simulation
  - Monitoring students actions and the simulation
  - Discussing with students the simulations
  - Evaluating students' understanding
  - Demonstrating the simulation

Learning gains

Group	*N*	Pre-test		Post-test		*MD*	*t*	*df*	*p*
		M	*SD*	*M*	*SD*				
Standalone tutor	22	3.77	3.32	7.27	4.60	3.50	4.071**	21	0.001
CA tutor	22	2.73	2.60	6.61	3.86	3.88	3.906**	21	0.001

**p<.01

Evaluation of student understanding by human and AI

- Sources:
  - Students' actions and verbal feedback

- Human tagging of Knowledge construction evidence
  - Knowledge transformation
  - Knowledge telling/ following/restate/acknowledge
  - Asking information
  - Critical thinking

Evaluation of student understanding by human and AI

- AI's Chain of Thought before providing feedback to students
  - Student understanding of the concept
  - Mis-conception
  - Pedagogical strategy
  - Reasoning
  - Approach

L0. Unknown
L1. Observation-driven
L2. Concept germination
L3. Basic connection
L4. Robust understanding

Discourse and action analysis

		Standalone tutor		CA tutor					
Group	*N*	*M*	*SD*	*M*	*SD*	*MD*	*t*	*df*	*p*
Asking questions	22	8.55	6.07	6.18	5.54	-2.37	-1.24	21	0.23
Knowledge following	22	0.05	0.21	2.18	1.56	2.13	6.33***	21	<.001
Knowledge telling	22	0.05	0.21	7.14	4.09	7.09	8.06***	21	<.001
Knowledge acknowledgement	22	0	0	0.82	0.91	0.82	4.23***	21	<.001
Knowledge restate	22	0.09	0.29	1.45	1.65	1.36	3.69**	21	0.001
Knowledge transformation	22	0.32	0.48	3.41	2.68	3.09	5.29***	21	<.001
Critical thinking	22	0.05	0.21	0.59	1.22	0.54	2.32*	21	0.03
Ignore/Unfocused	22	1.5	4.17	3.64	3.49	2.14	1.82	21	0.083

Comparison of knowledge transformation when interacting with the passive and CA tutors

Relation between knowledge construction discourse and learning outcomes

	Knowledge transformation	Knowledge telling	Knowledge following	Knowledge acknowledgement	Knowledge restate	Critical thinking	Ignoring / Unfocus	Asking information
	r=.58	r=0.14	r=0.05	r=-0.25	r=-0.15	r=-0.07	r=-0.004	r=-0.02
Post-test	p<.01	p=0.54	p=0.82	p=0.25	p=0.51	p=0.77	p=0.98	p=0.92
	r=.62	r=0.001	r=0.09	r=-0.30	r=-0.14	r=0.04	r=-0.17	r=0.18
Learning gain	p<.01	p=0.99	p=0.67	p=0.17	p=0.54	p=0.85	p=0.44	p=0.41

Correlation between knowledge transformation discourses and learning outcomes

Relation between AI formative evaluation and and learning outcomes

	L0	L1	L2	L3	L4
Post-test	r=-0.10	r=0.05	r=0.35	r=0.24	r=0.41
	p=0.68	p=0.81	p=0.11	p=0.28	p=0.06
Learning Gain	r=0.20	r=0.06	r=0.29	r=0.21	r=0.25
	p=0.36	p=0.78	p=0.19	p=0.35	p=0.27

Correlation between AI evaluations and learning outcomes

Summary

Technically

- LLM can provide in-context feedback for students when context information and student actions were included.
- GenAI's formative assessment may reflect higher-level learning outcome.

Knowledge Construction

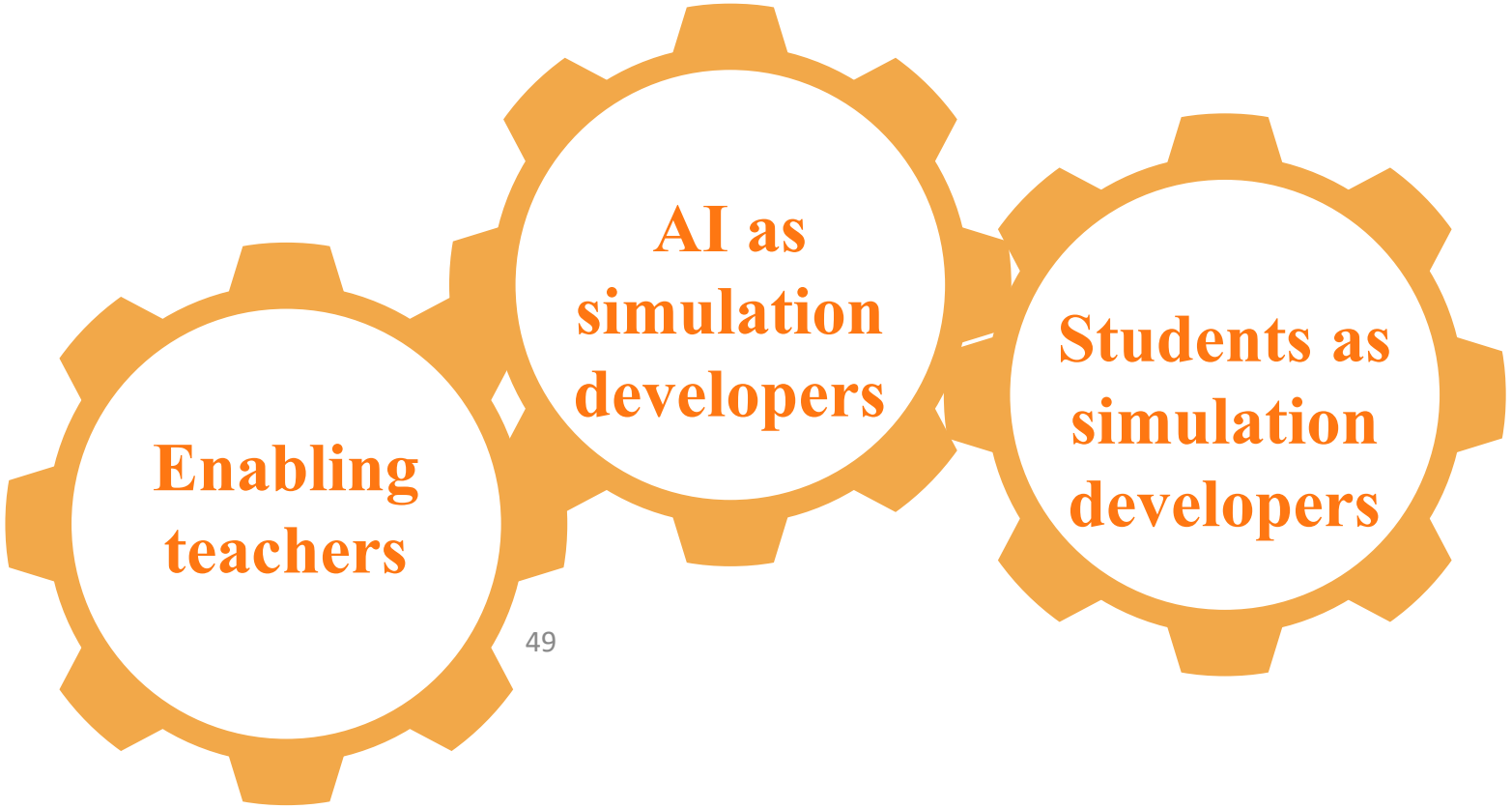
- Students demonstrated more knowledge construction evidences with CA tutor than the passive tutor.
- Generative AI guided in completing the learning task through the predefined questions and in achieving a higher score for conceptual questions.

Points of consideration

- Agency Transference
- AI isn’t free—it costs money and impacts the environment.

- Teachers in the loop!
- Think with Theoretical Depth!
- Do it right before others get it wrong!

Future works

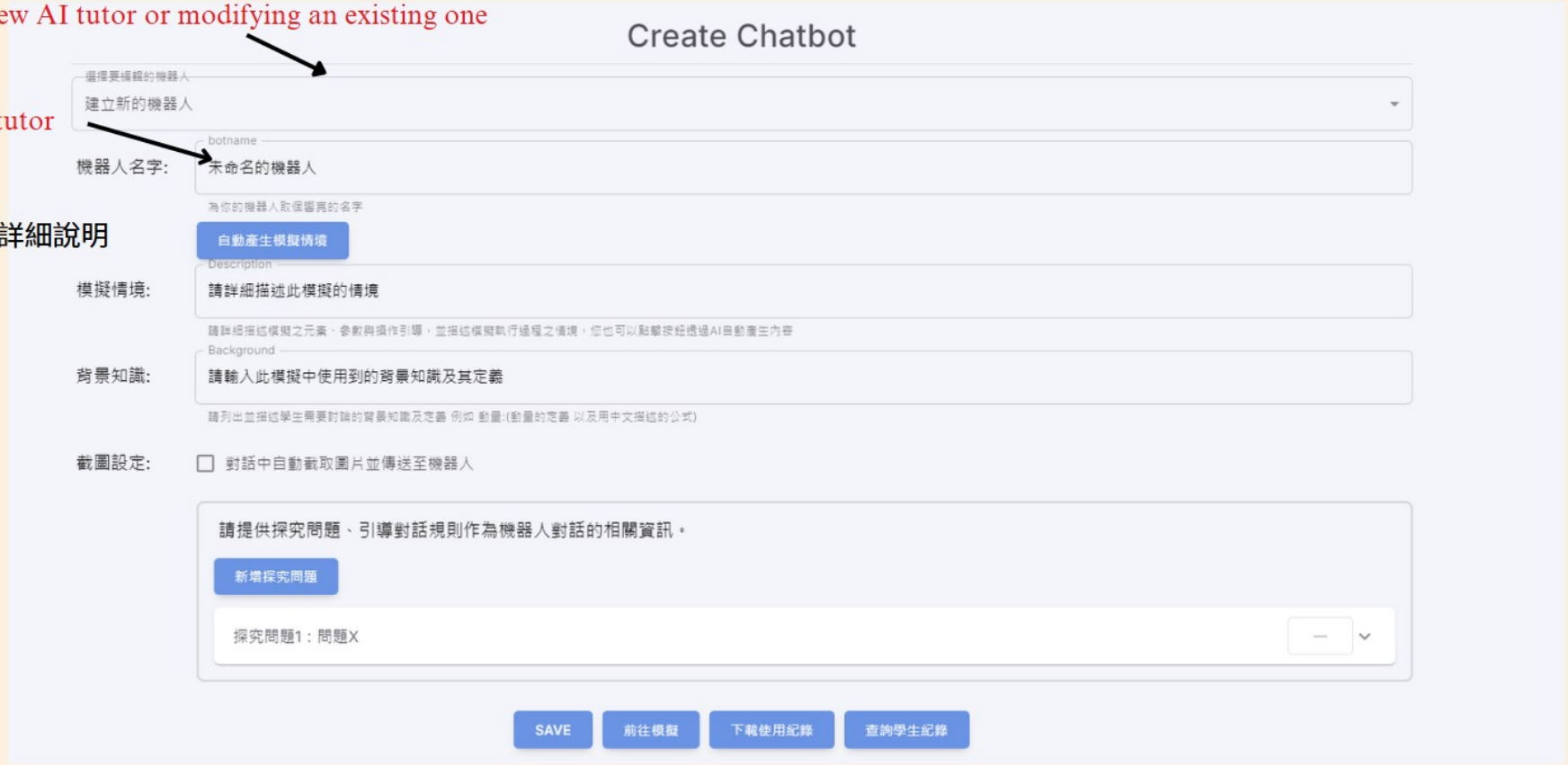


AI tutor development tools for teachers

1.Creating a new AI tutor or modifying an existing one

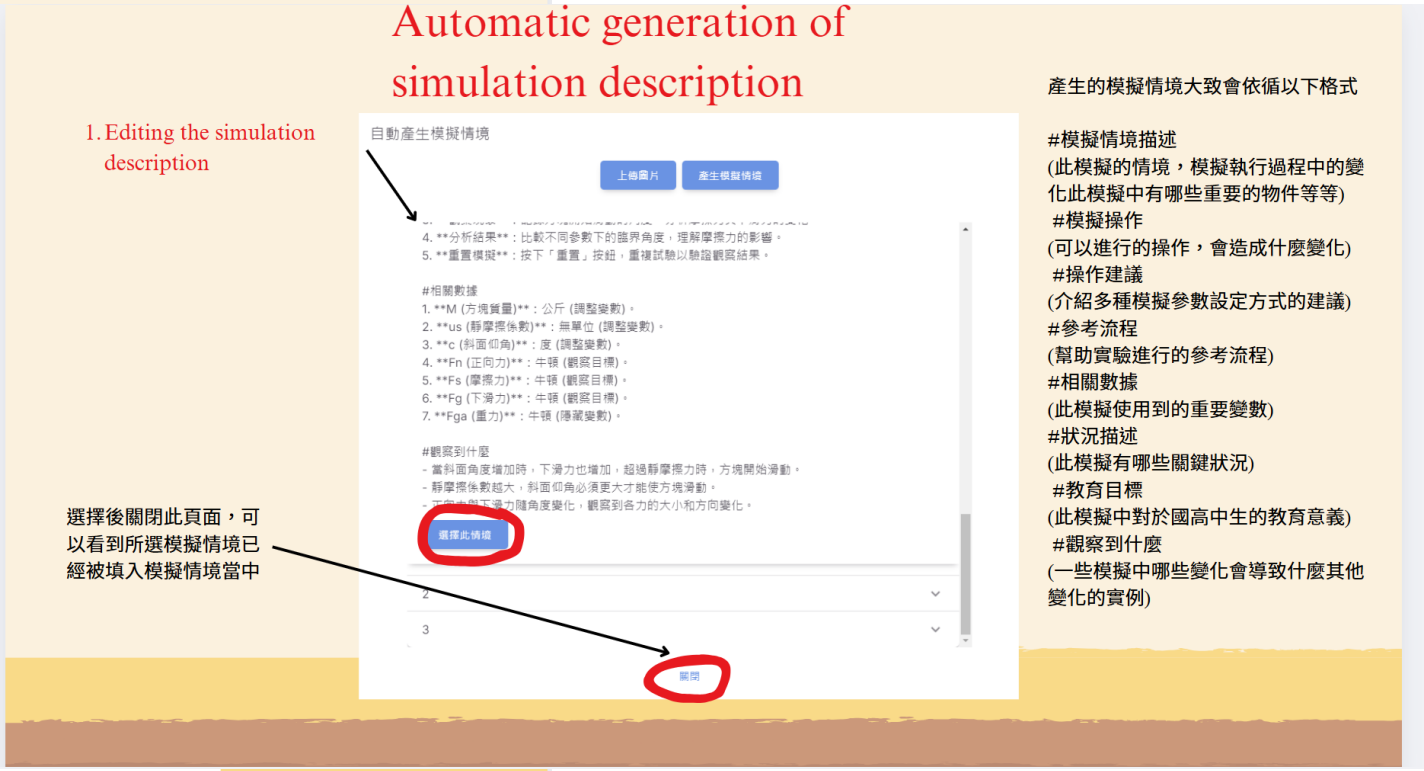
2. Name of the tutor

其餘欄位後方詳細說明



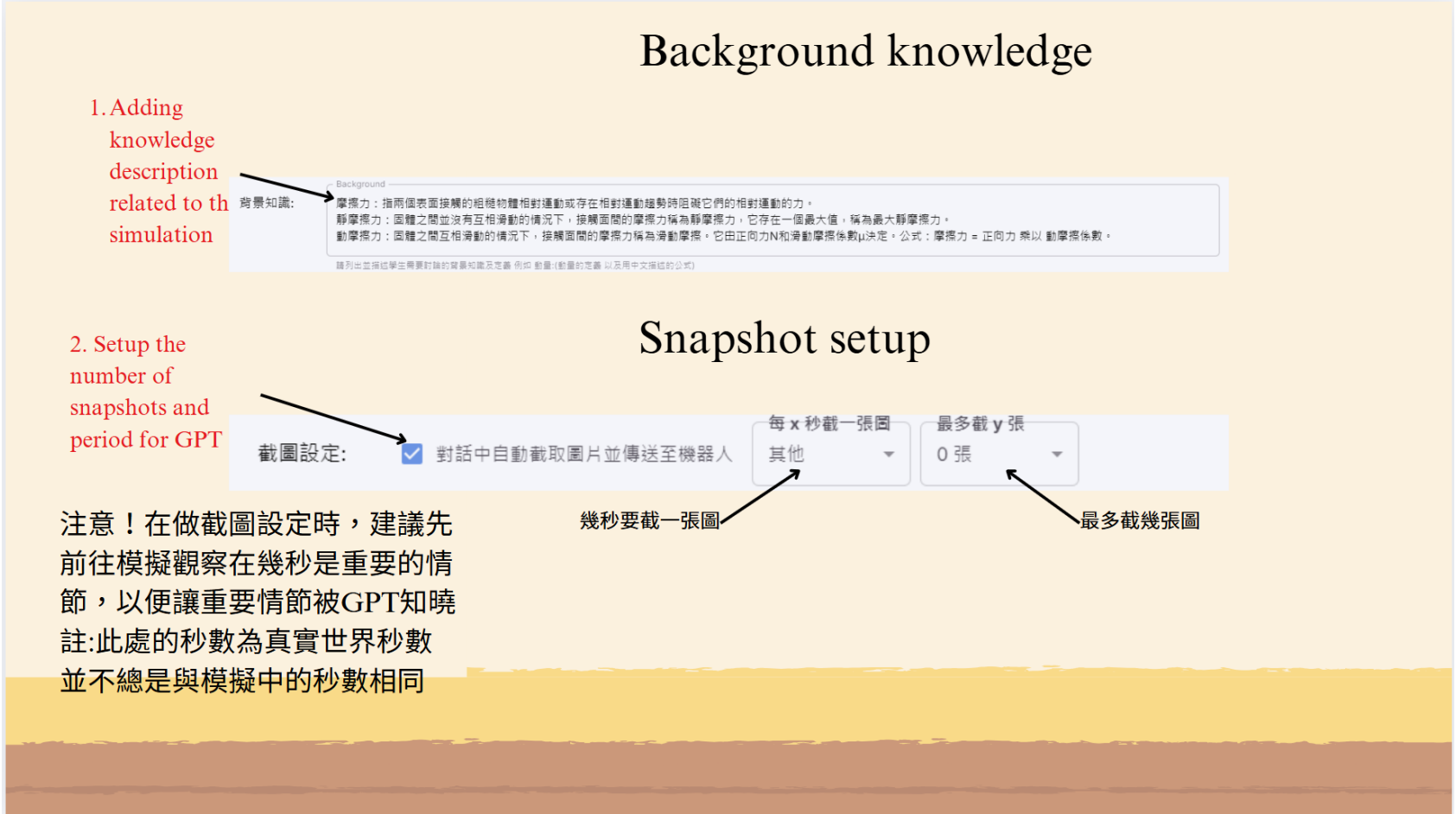
AI tutor development tools for teachers

- Generating simulation description from CoSci JSON file



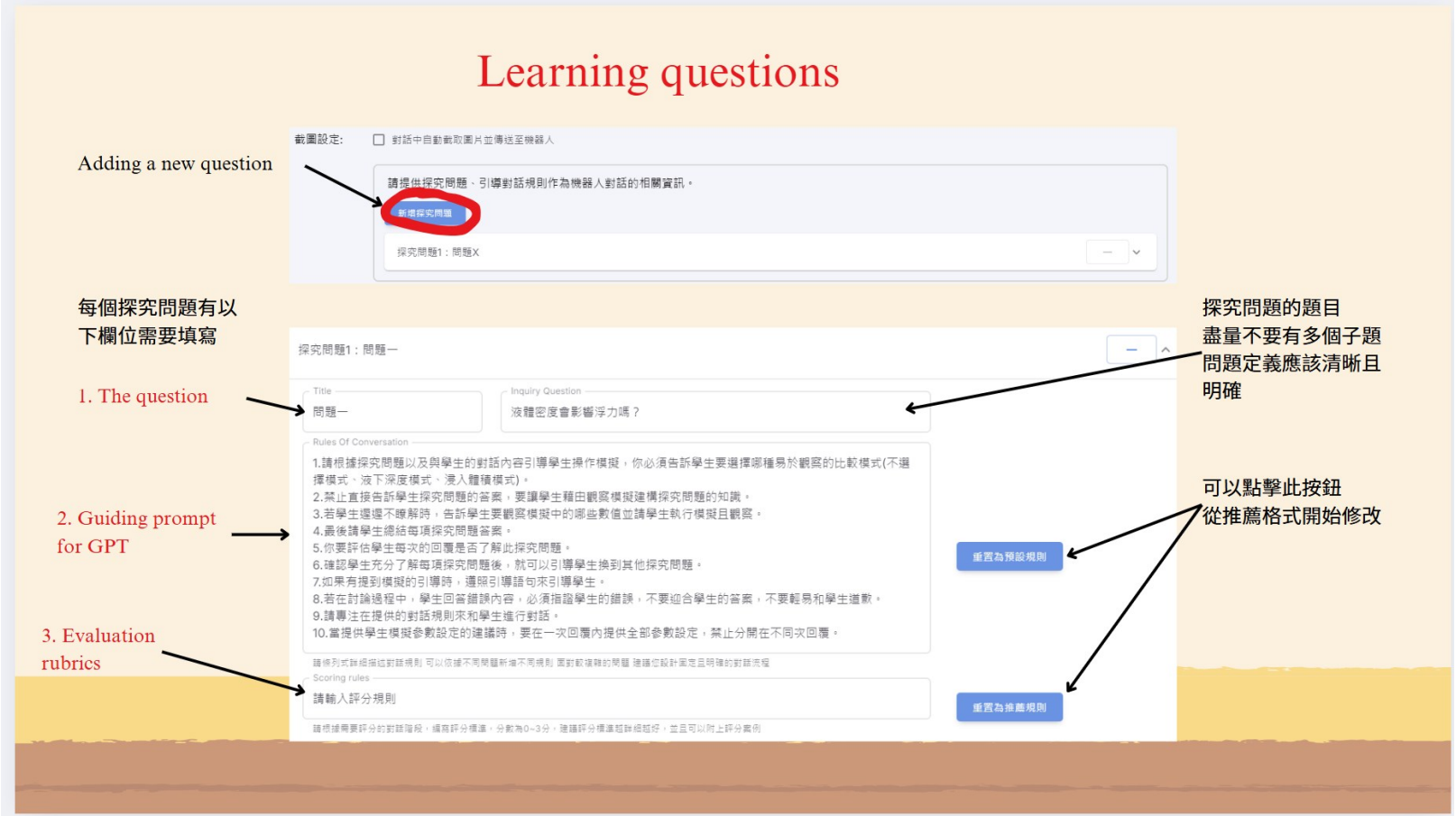
AI tutor development tools for teachers

- Adding background knowledge and snapshots for GPT



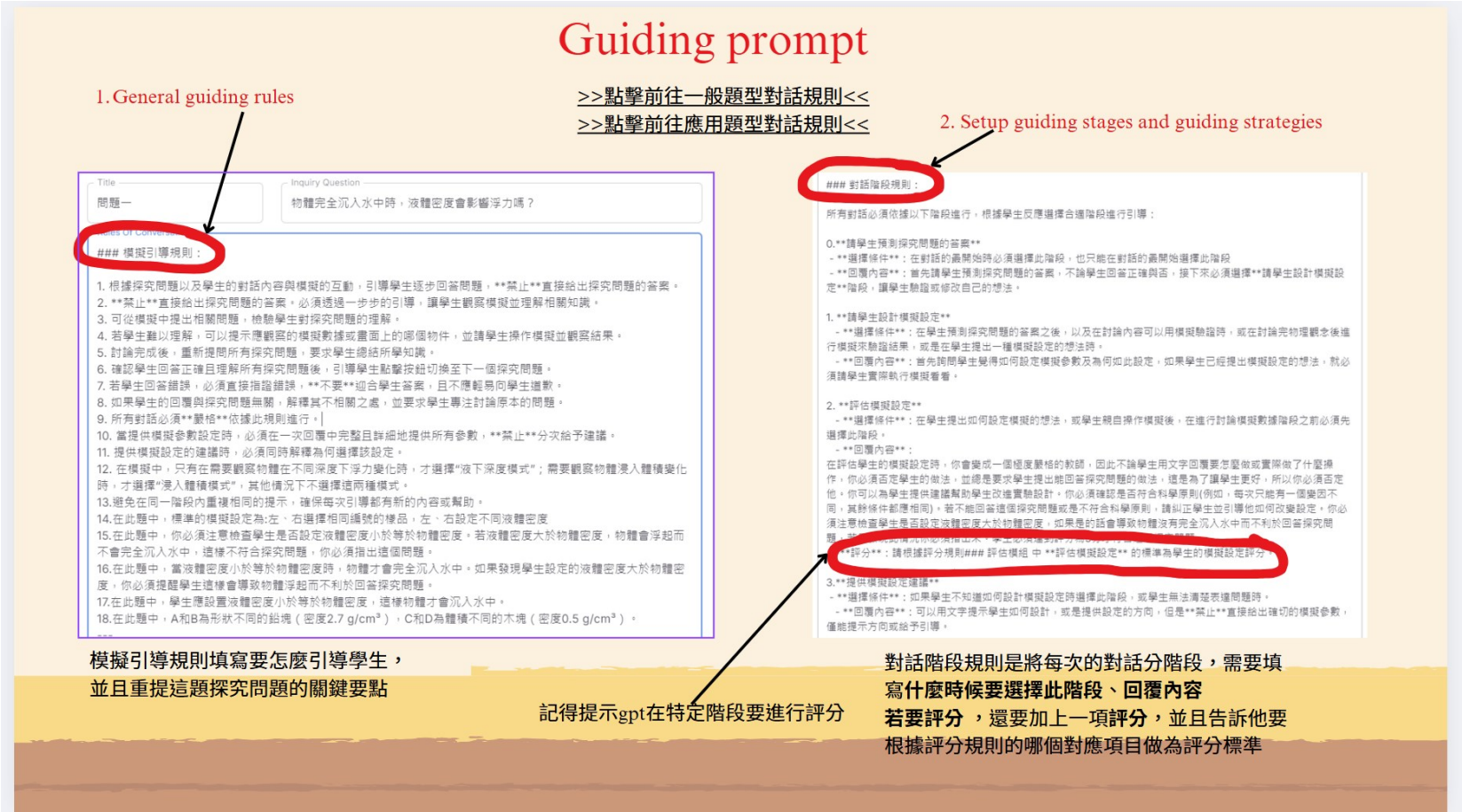
AI tutor development tools for teachers

- Adding learning questions



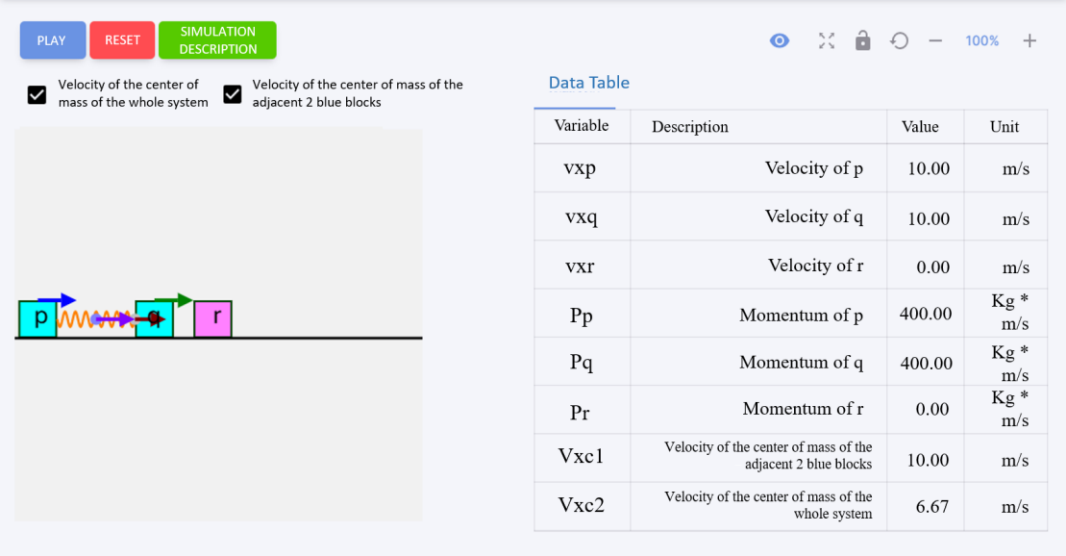
AI tutor development tools for teachers

- Setup guiding prompts

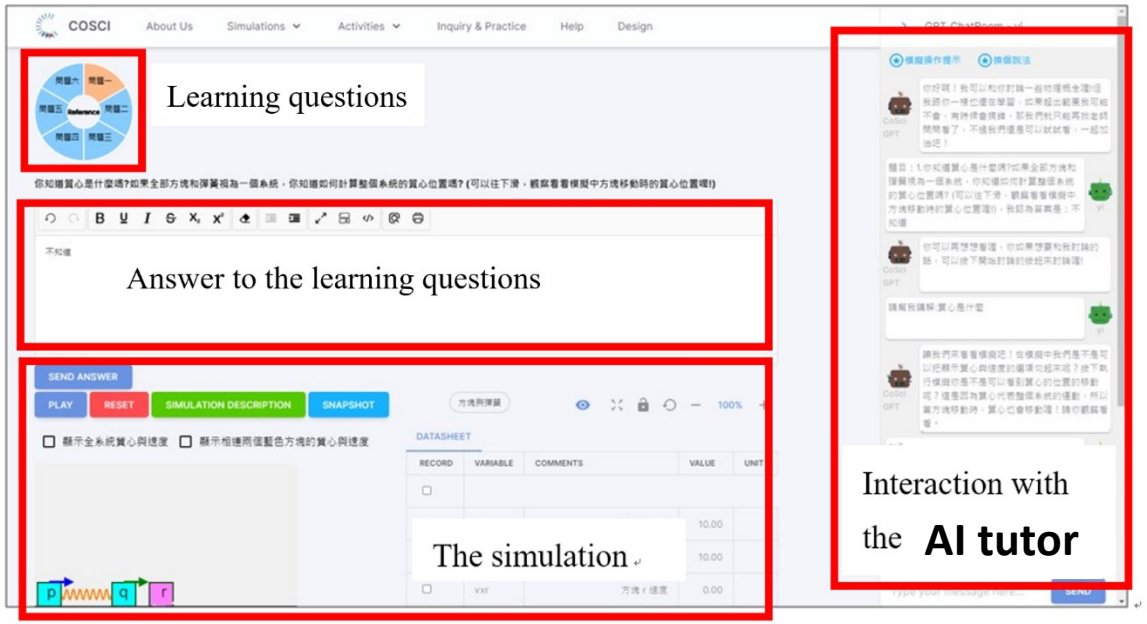


Focused tutor approach

- Combining pedagogical designs with focused tutor approach
  - The guidance for the use of simulations is embedded in the prompts to the LLM



Variable	Description	Value	Unit
vxp	Velocity of p	10.00	m/s
vxq	Velocity of q	10.00	m/s
vxr	Velocity of r	0.00	m/s
Pp	Momentum of p	400.00	Kg * m/s
Pq	Momentum of q	400.00	Kg * m/s
Pr	Momentum of r	0.00	Kg * m/s
Vxc1	Velocity of the center of mass of the adjacent 2 blue blocks	10.00	m/s
Vxc2	Velocity of the center of mass of the whole system	6.67	m/s



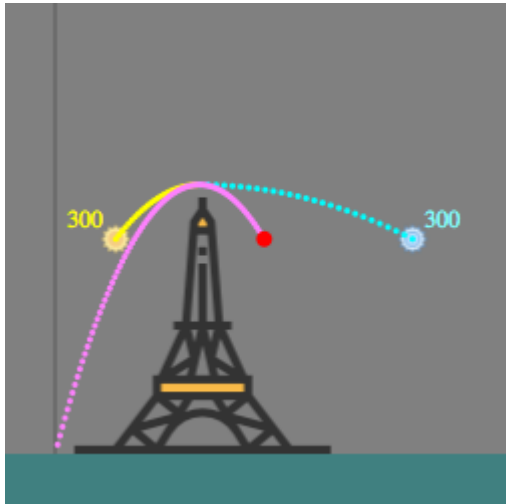
Transcribing the computational model to text description

{JSON}

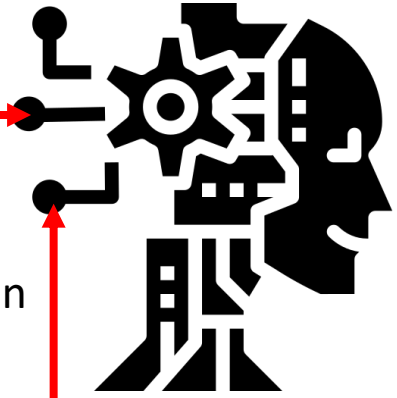
JavaScript Object Notation

1. Visual objects
2. Variables
3. Variable evolution model (1st order derivation)
4. Variable dependency (Javascript)

Computational model of simulation



Critical states and visual outlook



LLM

- Simulation Scenario
- Simulation Operations
- Operation Suggestions
- Learning Objectives
- State Descriptions
- Suggested Procedure
- Relevant Data
- Critical Phenomena

	Modified from GPT output	Final Version
Simulation Scenario Description	This simulation presents a 600-gram firework shell ~~in the process of moving through the air~~ launched into the sky at an initial speed of 60 m/s, influenced only by gravity. At the peak of its ascent, the shell explodes into two fragments (yellow and blue) and falls back down. Assuming the explosion is affected only by internal forces and the system experiences no external forces, the total momentum is conserved. In the simulation, students can adjust the mass and velocity of the yellow fragment (horizontal velocity topvxa and vertical velocity topvya), and observe the trajectories of both fragments and the system's center of mass. The simulation includes the following elements: 1. **Firework Shell**: Initial mass of 600 grams; explodes at the peak. 2. **Yellow Fragment**: Mass is adjustable; students can set horizontal and vertical velocities. 3. **Blue Fragment**: Mass and velocity are computed by the system according to conservation of	This simulation presents a 600-gram firework shell launched into the sky at an initial speed of 60 m/s, influenced only by gravity. At the peak of its ascent, the shell explodes into two fragments (yellow and blue) and falls back down. Assuming the explosion is affected only by internal forces and the system experiences no external forces, the total momentum is conserved. In the simulation, students can adjust the mass and velocity of the yellow fragment (horizontal velocity topvxa and vertical velocity topvya), and observe the trajectories of both fragments and the system's center of mass. The simulation includes the following elements: 1. **Firework Shell**: Initial mass of 600 grams; explodes at the peak. 2. **Yellow Fragment**: Mass is adjustable; students can set horizontal and vertical velocities. 3. **Blue Fragment**: Mass and velocity are computed by the system according to conservation of momentum.

Simulation Operations	Students can perform the following actions: 1. **Select Throwing Mode**: 2. Vertical Throw Mode: Firework launched vertically at 60 m/s. 3. Oblique Throw Mode: Firework launched at a 75° angle at 60 m/s. 2. **Adjust Parameters**: 3. Adjust yellow fragment mass (ma): range 100 to 400 grams. 4. Set the yellow fragment's velocity at explosion (topvxa and topvya): both range -20 to 20 m/s. 5. Choose whether to ~~check the box~~ show center of mass position and trajectory. 3. **Run Simulation**: Click "Run" to start the simulation. 4. **Reset Simulation**: Click "Reset" to return to the initial state. Simulation Effects: - In vertical throw mode, the firework ascends straight up; in oblique throw mode, it follows a parabolic path.	Students can perform the following actions: 1. **Select Launch Mode**: ○ Vertical Throw Mode: Firework launched vertically at 60 m/s. ○ Oblique Throw Mode: Firework launched at a 75° angle at 60 m/s. 2. **Adjust Parameters**: ○ Adjust yellow fragment mass (ma): range 100 to 400 grams. ○ Set the yellow fragment's velocity at explosion (topvxa and topvya): both range -20 to 20 m/s. ○ Choose whether to show center of mass position and trajectory. 3. **Run Simulation**: Click "Run" to start the simulation. 4. **Reset Simulation**: Click "Reset" to return to the initial state. Simulation Effects: - In vertical mode, the firework ascends straight up; in oblique mode, it follows a parabolic path. - The firework explodes at the peak

Case study

Respond	From this simulation, which aspect demonstrated the directionality of momentum, and how does this aff
gptImg	http://140.115.53.212:3030/uploads/GPT_chatroom/77ae7bad-d80c-4d79-97fe-7d41b0e6673f.
Chat	I think momentum describes the position. Knowledge transformation
Respond	Actually, momentum doesn't simply describe position; it's the product of mass and velocity. How
gptImg	http://140.115.53.212:3030/uploads/GPT_chatroom/77ae7bad-d80c-4d79-97fe-7d41b0e6673f.
Chat	In the two previous experiments, when the yellow fragment moved forward, its x-value was posi
Respond	Great observation! This indeed demonstrates momentum's directionality. Then, why does the mom
gptImg	http://140.115.53.212:3030/uploads/GPT_chatroom/77ae7bad-d80c-4d79-97fe-7d41b0e6673f.
Chat	Is it because the direction of force is the same? Knowledge telling
Respond	Momentum' s direction aligns with velocity, but the direction of the force isn't always identical.
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Chat	In the previous experiment, why wasn't the y-momentum of the yellow fragment equal to its ma
Respond	Let' s revisit that again—momentum should indeed equal mass multiplied by velocity. Could you
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Chat	Shouldn't it be -2000? Why is it -8100? Critical thinking
Respond	The y-direction momentum of the yellow fragment is calculated as mass (100 g) multiplied by veloci
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play	{"sync":true,"action":"play"}
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Respond	Based on your simulation results, the yellow fragment has a mass of 100 g and a velocity of -61 m
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Chat	Yes. Knowledge acknowledgement
Respond	Now, could you summarize in your own words what momentum and the system' s center of ma
gptImg	http://140.115.53.212:3030/uploads/GPT_chatroom/3b0fa679-b347-48bd-93eb-c9ad1137be80.pn
Chat	I'm still not quite clear about the system' s center of mass. Asking Information
Respond	The center of mass can be viewed as the balance point of mass in a system. To calculate it, multiply each

student_understanding: The student may have observed the directional nature of momentum **(Level 1:**

student understanding: The student may have misunderstood velocity data or the calculation process **(Level 2: Concept germination)** ,
misconceptions: The student might believe their momentum calculation result is incorrect.

student understanding: The student needs

student understanding: The student can interpret

student understanding: The student needs clearer understanding of how the center of mass is calculated and interpreted. **(Level 2: Concept germination)** ,
misconceptions: The student may not yet see how mass distribution affects the position of the center of mass.
pedagogical strategy:
immediate goal: Help the student clearly understand the concept of the center of mass. ,
reasoning: Using calculations and examples helps students visualize the center of mass position.
approach: Provide simple examples and relatable everyday phenomena to facilitate understanding.

Table 1. The four types of prompts for the GPT-3.5 based on the experiential learning model

Feedback for students	System prompts to the GPT-3.5 model	Example generated feedback
Simulation-related prompts	The description of the simulation including variables and relations, the context of the simulation and instructions on using the simulation were given in the prompt. The prompt asks the AI assistant to guide students to set up the simulation to observe important science features, ask students questions about their observation, and provide explanations for the science phenomenon.	"Let's take a look at the simulation! In the simulation, can we use a data table to know the mass and speed of the blocks? Can you run the simulation and then tell me what the momentum Pr of block r will be after the collision?" "Do you know that momentum is related to an object's mass and velocity? Let's look at a simulation together! In the simulation, if the character's mass is 50 kilograms and the speed is 100 cm/s, what is the character's momentum?"
Conceptual prompts	The conceptual descriptions and some examples of the learning questions were given in the prompt, and the AI assistant was asked to guide students to understand the concepts associated with the learning question	"In a closed system, if there is no external force acting on it, the total momentum of the system remains constant. For example, in a collision without external forces, the total momentum before and after the collision remains unchanged. Or in the case of rocket propulsion, when fuel and gases are ejected, the rocket gains positive momentum, but the total momentum of the entire system remains unchanged."
Mathematical prompts	The mathematical model of scientific concepts or problems were given in the prompt and the AI assistant guided students to understand the mathematical model or apply the model to solve the given problem	"After the collision, the velocity of block r Vr is 10 m/sec, so what is the velocity of block q Vq'? The pink block r was hit by block q with the same mass M from the right with a velocity Vq=10 m/sec. Considering the conservation of momentum before and after the collision for blocks r and q, the total momentum for blocks q and r remains constant. Before the collision, the total momentum for blocks r and q is p=M*Vq+M*Vr=M*10 since Vr=0. Right after the collision, the total momentum is p=M×Vq′+M×Vr′= M×Vq′+ M*10 as Vr'=10 from the observation of the simulation. So, the sum of momentum is p=M*10=M*Vq'+M*10. We can then conclude that Vq′=0, indicating that the velocities of the two blocks swap after the collision. Do you understand?"
Evaluative prompts	The model answer of the question was given in the prompt and the AI assistant was asked to compare students' answers with the model answer, give students feedback, and invite them to discuss with the AI assistant.	"Your answer is partially correct, but there are some areas that need to be revised. The center of mass of a system represents the average position of the entire system's mass. It can be calculated by multiplying the mass of each object by its distance to the system's center of mass and then dividing by the total mass of the system. If you want to discuss this with me, you can press the 'Start Discussion' button to talk.