Bringing science simulations/games to science classrooms: the pedagogy and orchestration issues

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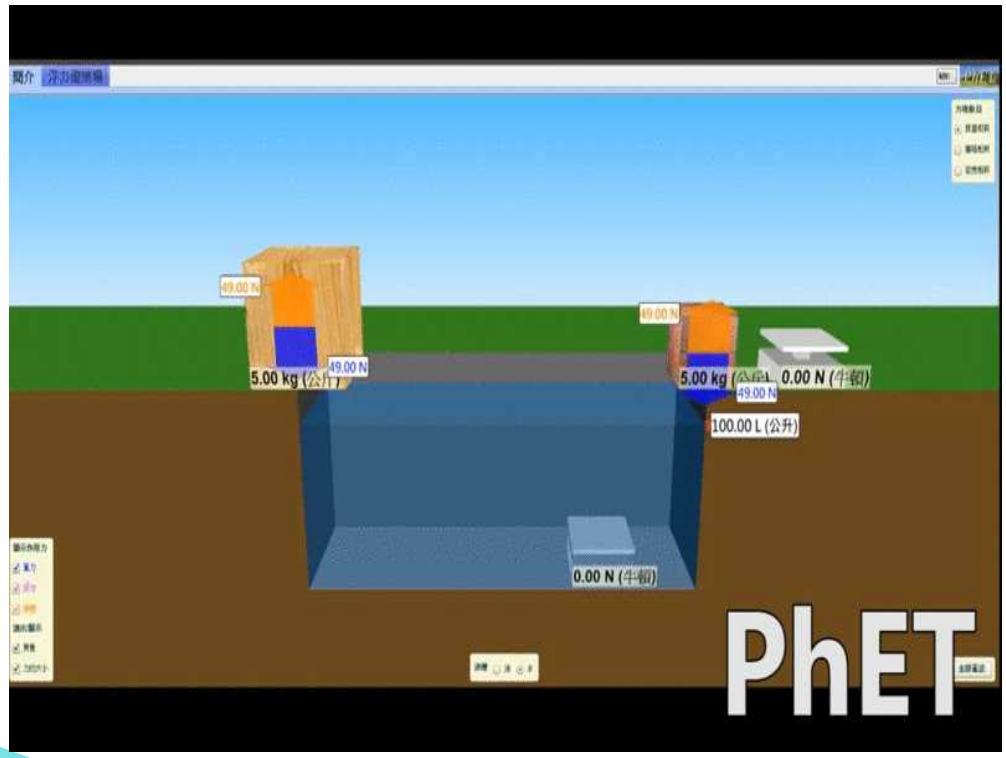
Taiwan

Simulation & Science learning



- Simulate a model of a system or a process
- Visualize some invisible features of science phenomena
- Help students experience scientific discovery process

Simulation & Science learning

- Modeling-based learning
  - Students uses appropriate representation to capture important features of a science phenomenon (Sengupta & Clark, 2016).
  - Students “use, create, share, and evaluate models to explain scientific phenomena (Shen, Lei, Chang, & Namdar, 2014).”

Simulation & Science learning

Jeremy Roschelle, 1992

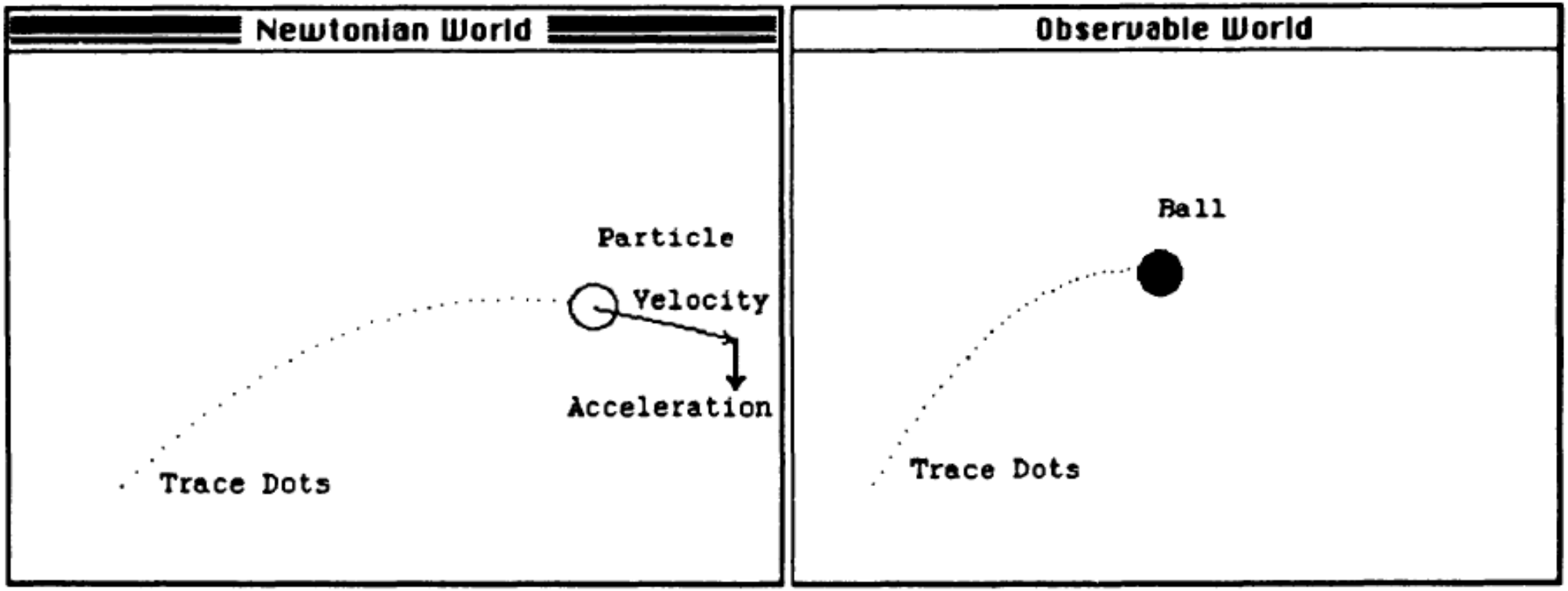


FIGURE 1 The Envisioning Machine (labels added).

Simulation & Science learning

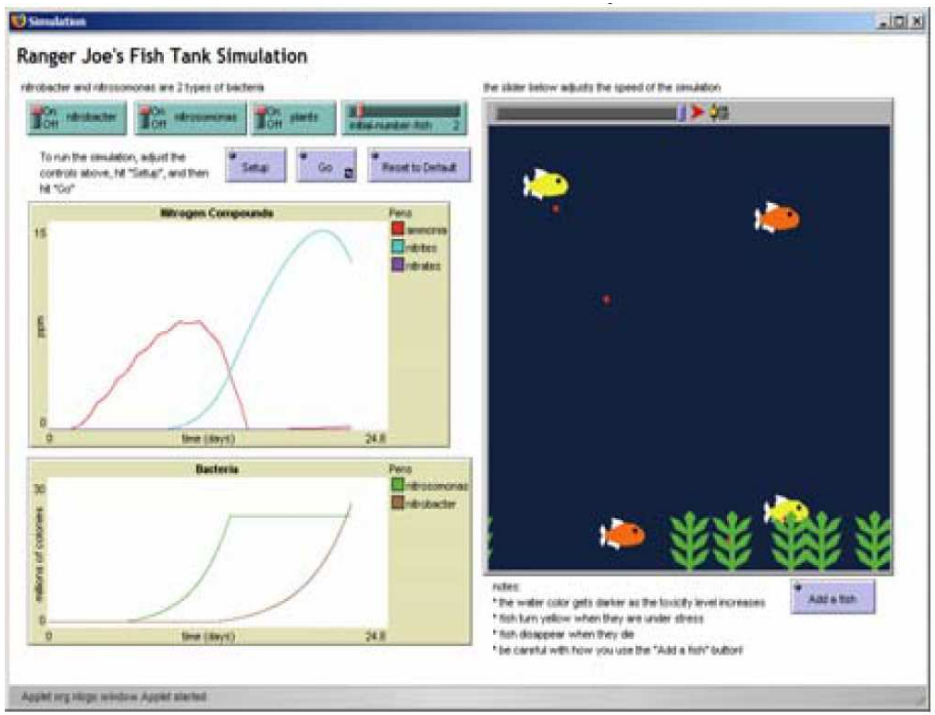
- Problem-solving game
  - Students learn through solving a challenging task in a simulation

```
begin
int count=0;
while(true)
{
  if(TrainPassMe()){
count++;
print (count);
}
 if(count==3){
train0.Break(30);
print "Train0 Break[30]";
print("Train is
stopping");
}
}
```

The program governs the behavior of the track in (3)

Simulation & Science learning

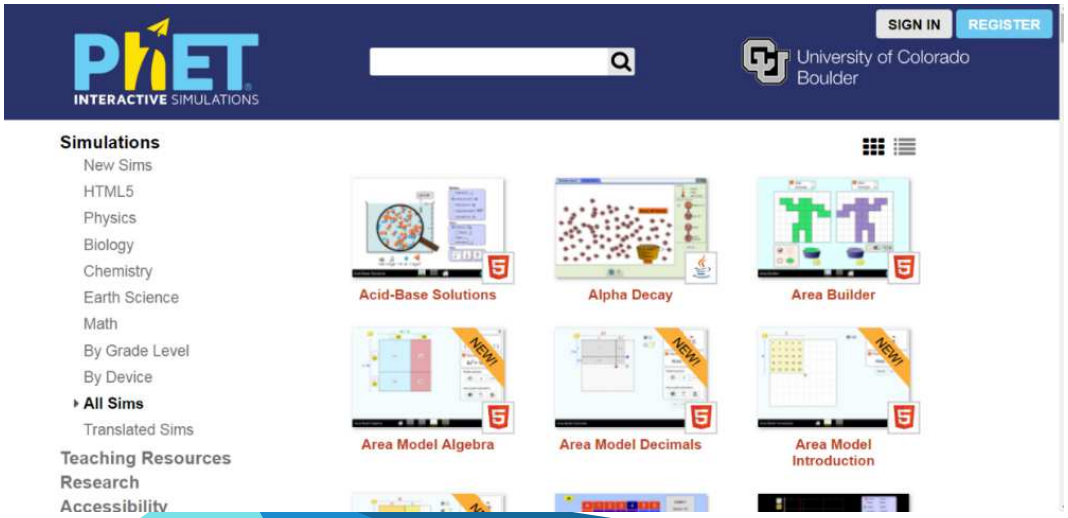
- Problem-solving game
  - Students learn through solving a challenging task in a simulation



Tan & Biswas, 2007

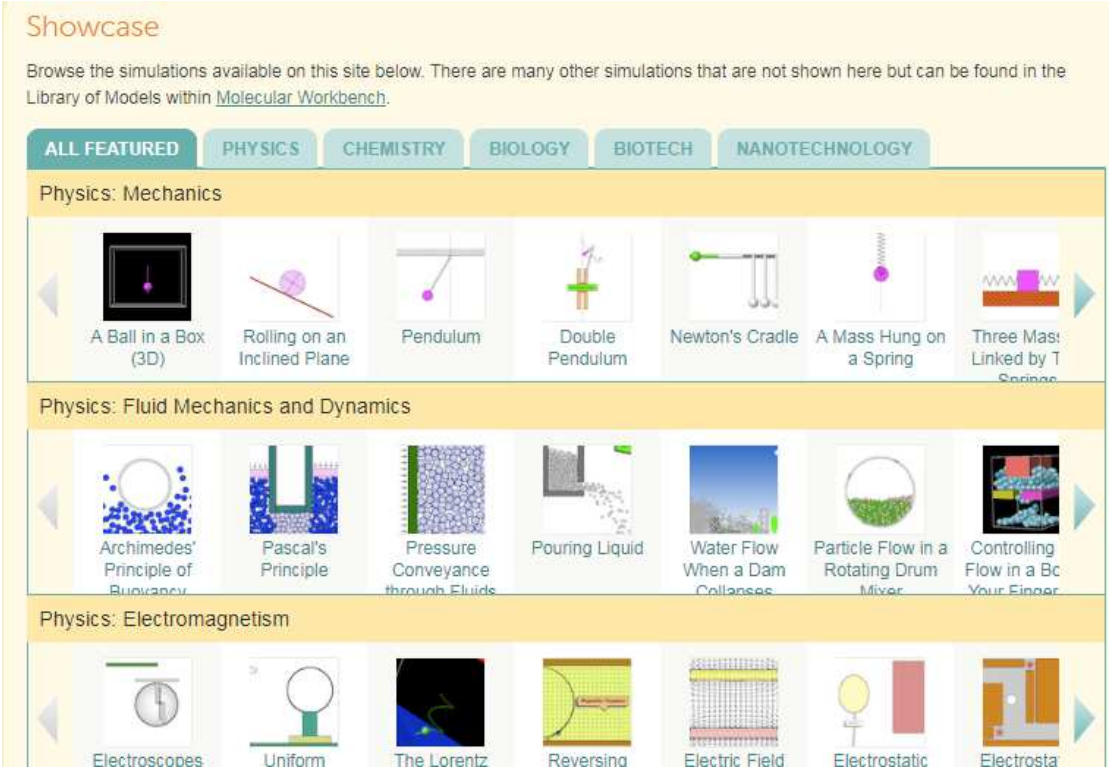
Simulation & Science learning

- PhET (https://phet.colorado.edu/)
  - 150+ high quality simulations for physics, biology, chemistry, earth science…
  - Flash-based, now transferring to HTML5



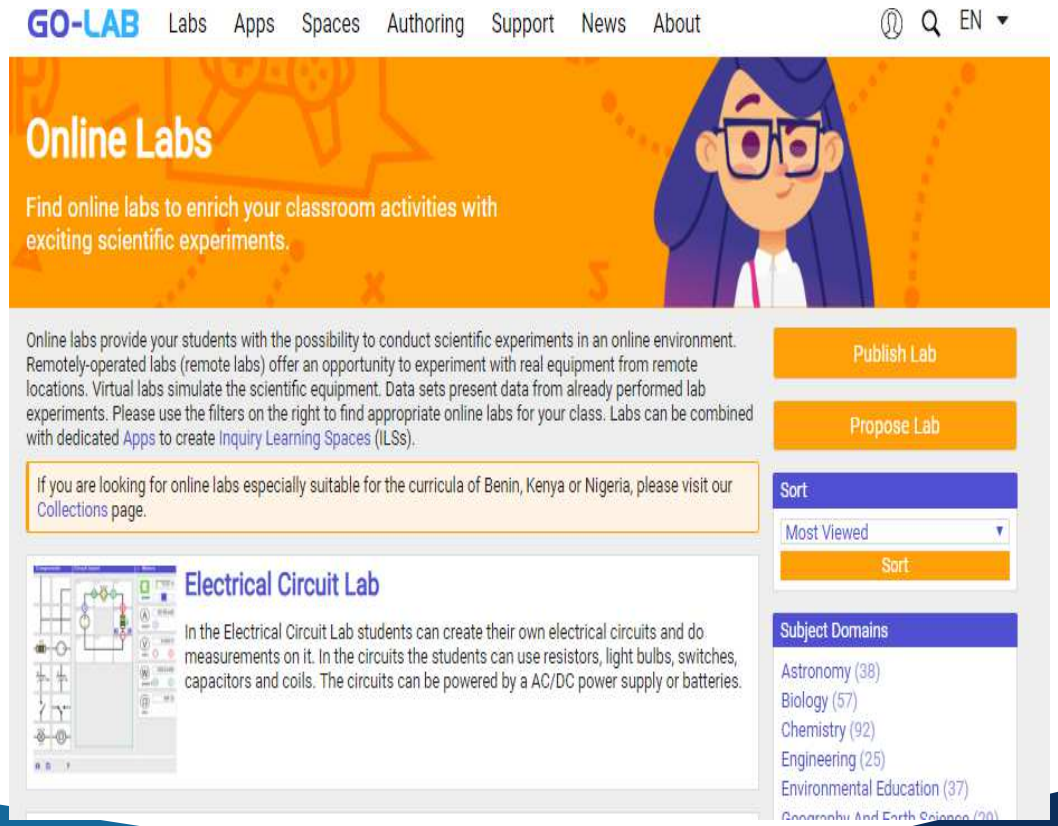
Simulation & Science learning

- Molecular Workbench (http://mw.concord.org/)
  - Java-based simulations for physics, chemistry, biology..,
  - Now transferring to HTML5
  - Simulation development tool
  - Activity development tool



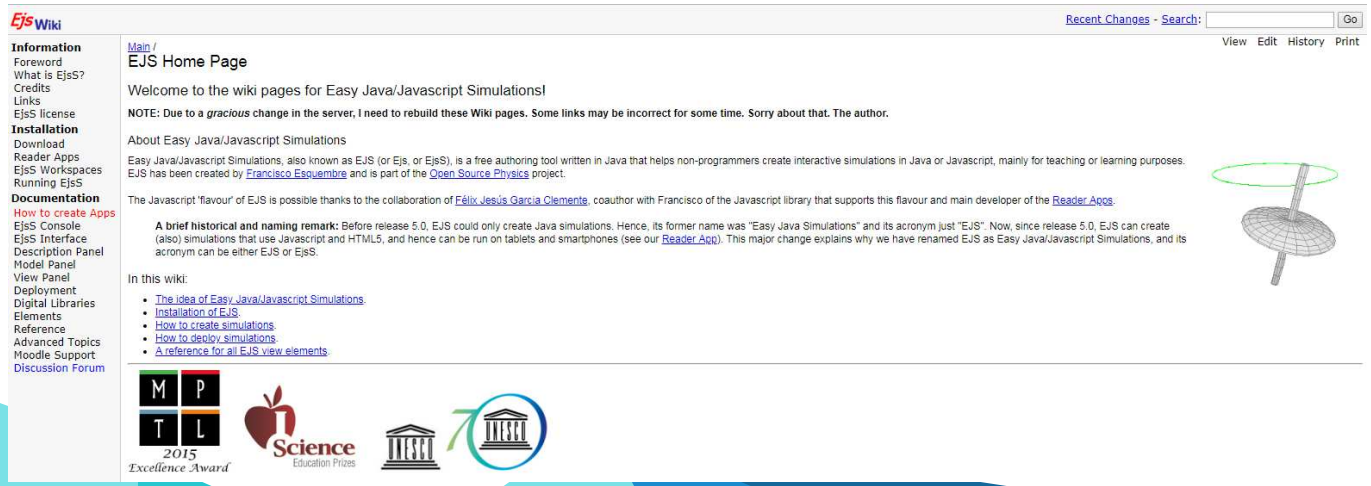
Simulation & Science learning

- Go-Lab (https://www.golabz.eu/labs)
  - An EU exchange platform for simulations.
  - Welcome all contributions from different countries
  - Activity development tool



Simulation & Science learning

- EJS(Easy Java Simulation)
  EJSS(Easy JavaScript Simulation)
  (http://fem.um.es/Ejs/)
  - Application to build science simulations
    (by Prof. Francisco Esquembre)



Simulation & Science learning

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

HTML5

New Simulation Platform

Launch a new project in 2011

Launch a new project in 2011

Fu-Kwun Hwang

Scientist

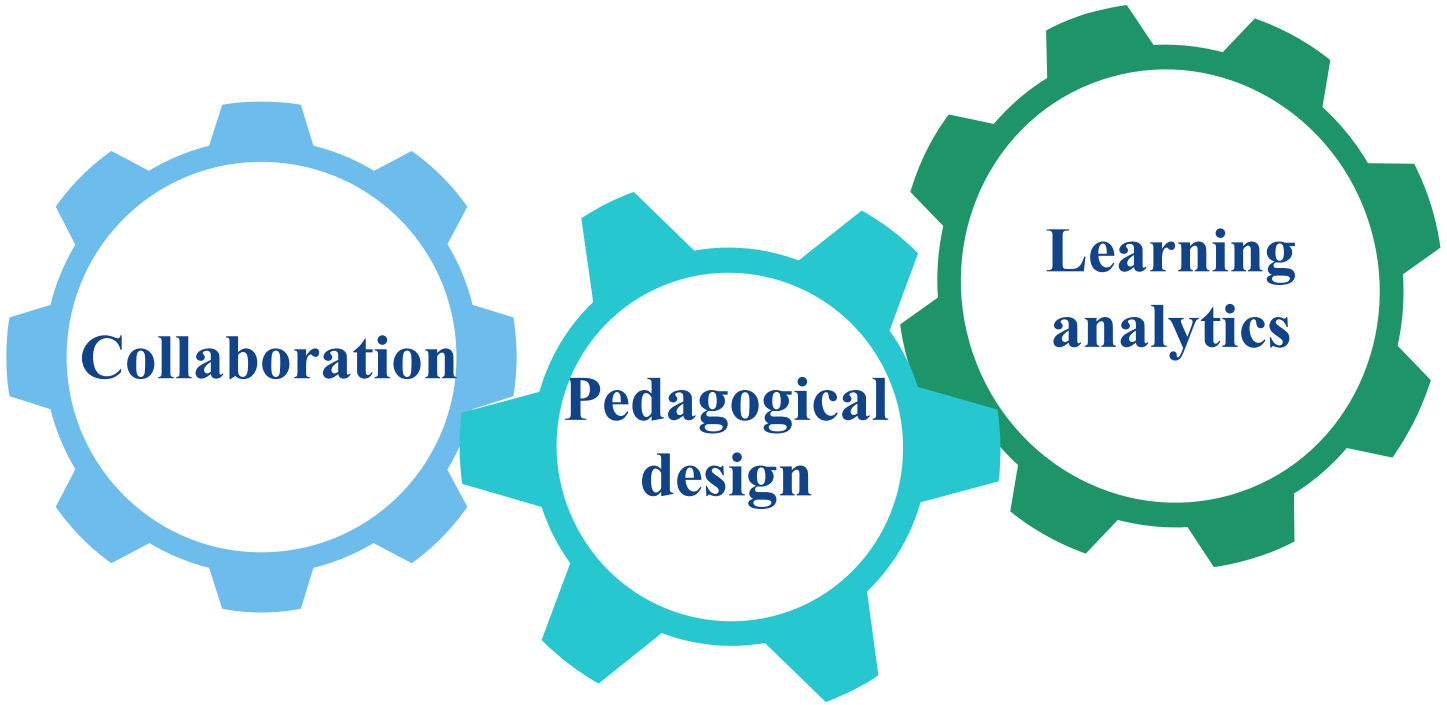
Francisco Esquembre

Chen-Chung Liu

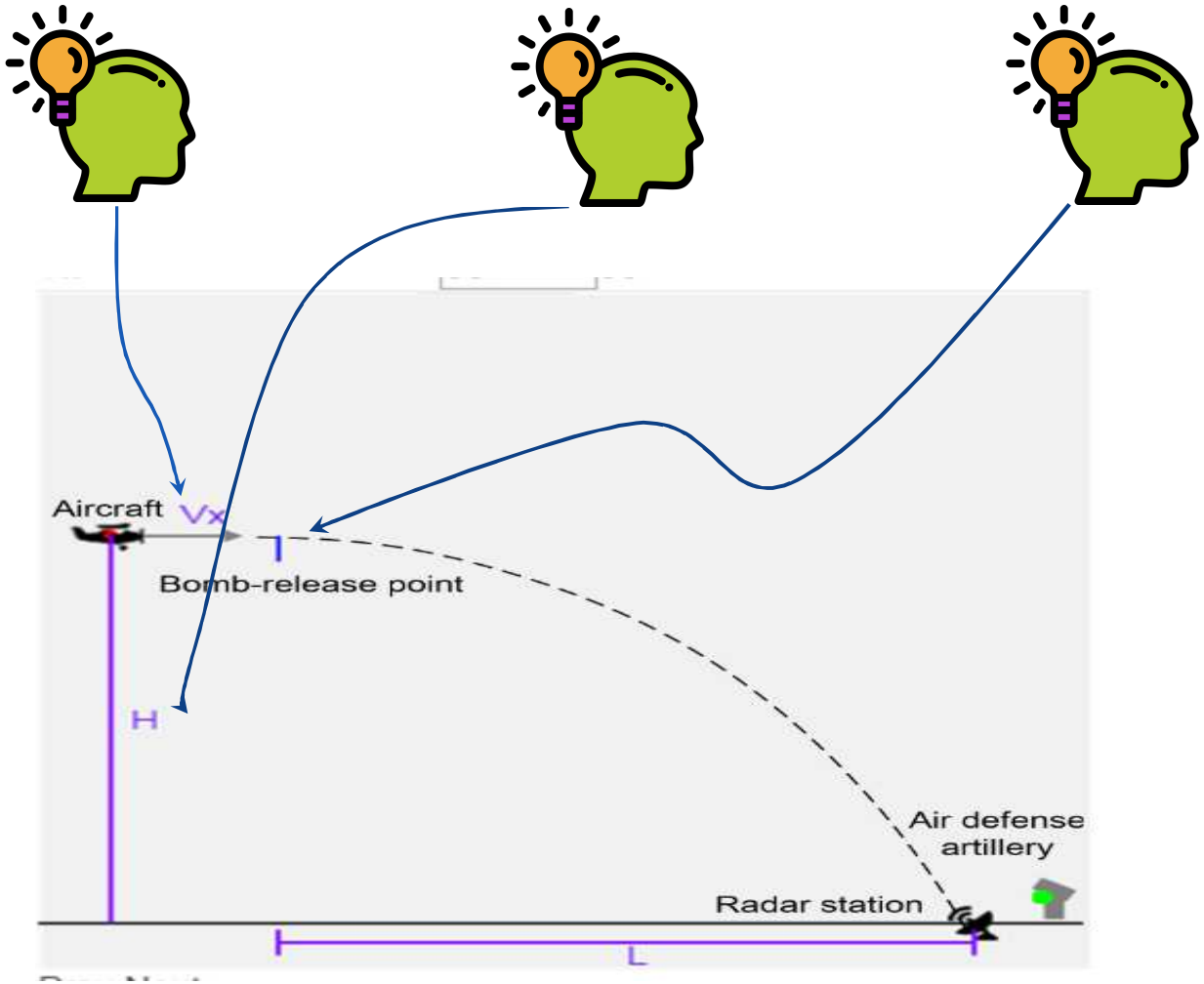
Mathematician

Computer Scientist

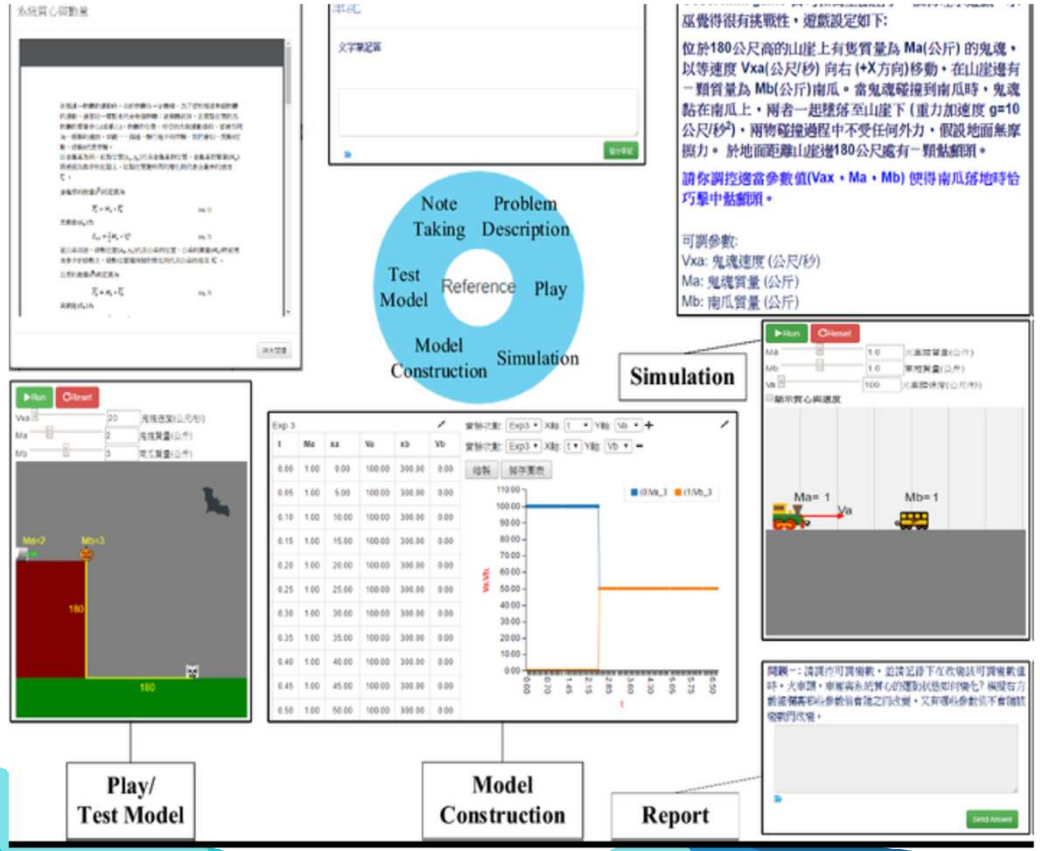
New features



Collaboration



Pedagogical design



1) Select a specific simulation
2) Design a series of learning tasks
3) Provide prompt questions in each task

Learning analytics

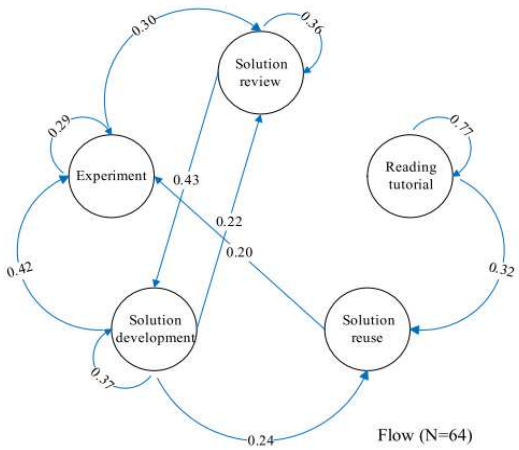
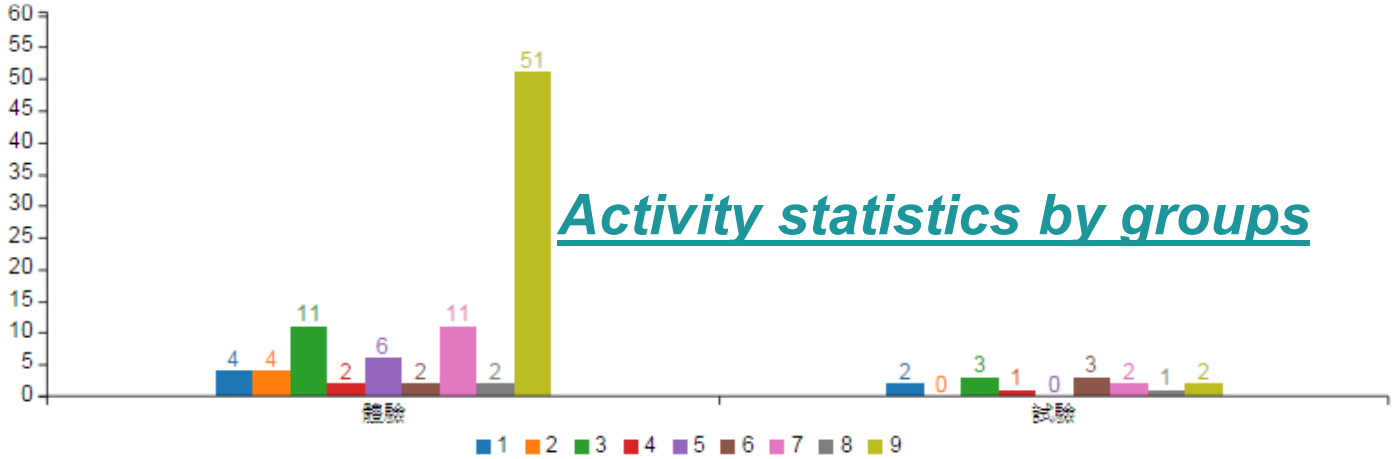
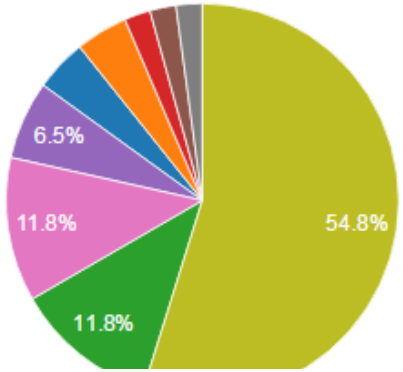


Fig. 5. The problem solving pattern associated with flow experience.

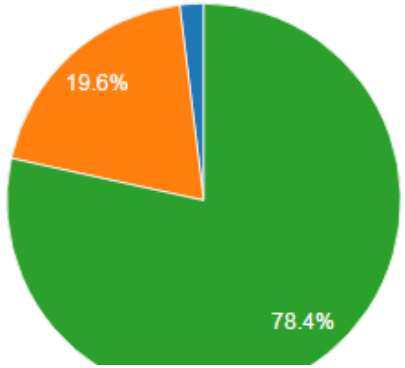
Activity pattern (LSA)



Activity statistics by groups

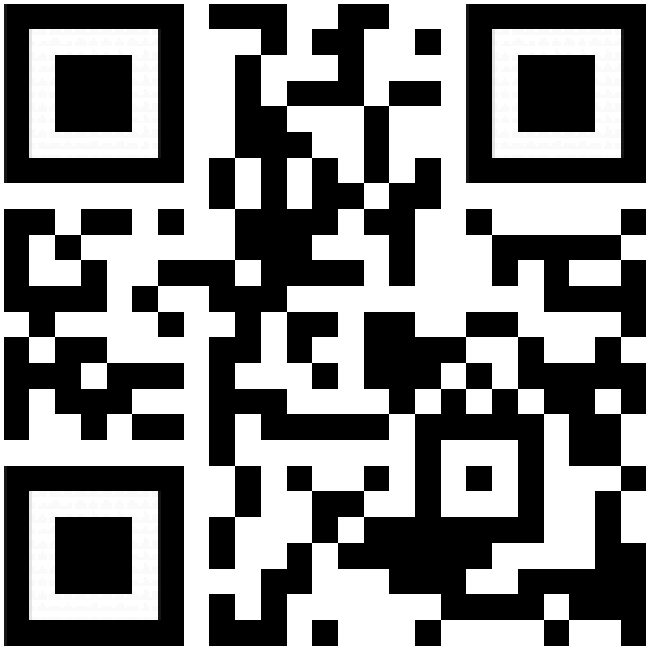


Activity statistics by groups



Member contribution in a group

CoSci



100+ Simulations

A platform supporting scientists, teachers, and students to develop and apply computer simulations for the learning of physics.

https://CoSci.TW/

CoSci

PLAY Simulation

Teachers
Students

Learning Activity

Teachers
Students

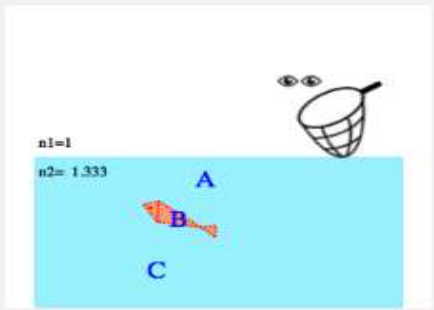
Design Simulation

Scientist

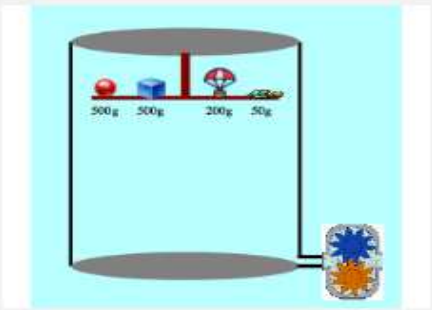
Worksheets List

Teachers

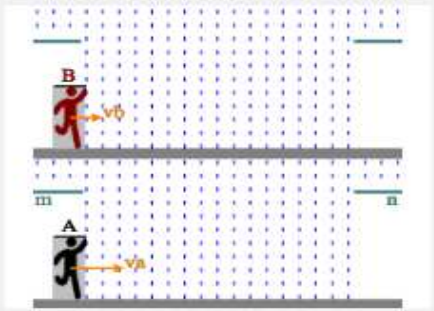
Featured Simulations



光的折射-捕... 19061



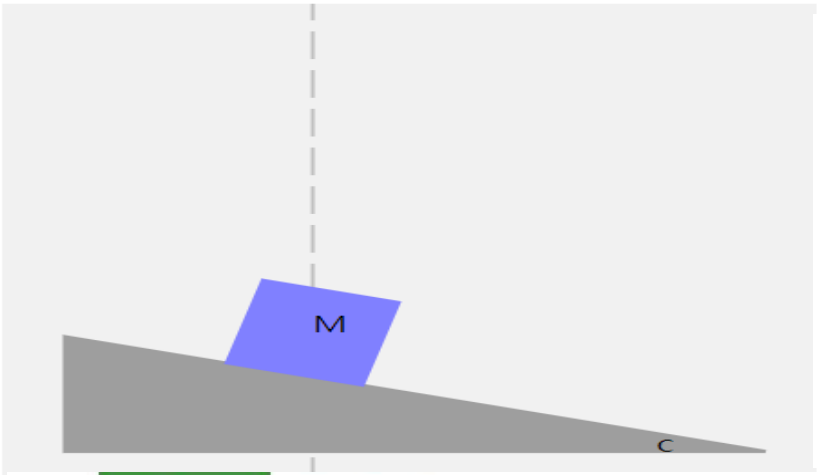
自由落體-... 12653



淋到多少雨? 20888

滑車接拋體-... 12479

CoSci



Interface

2D Drawables

2D Drawables Set

+ Var Table New Tab 2

Variable	Initial value	Type	Dimension	Comments	Unit	Decimal digits	
t	0	double				0.00	Del
dt	0.05	double				0.00	Del
d	400	double				0.00	Del
M	1	double		方塊質量	公斤	0.00	Del
us	0.53	double		斜面與方塊的靜摩係數		0.00	Del
c	15	double		斜面仰角	度	0.00	Del
theta	c*Math.PI/180	double				0.00	Del
S	d/4	double				0.00	Del
x0	d*Math.cos(theta)	double				0.00	Del
v0	d*Math.sin(theta)	double				0.00	Del

20 FPS 1 SPD Auto Start

Normal | Evol Page

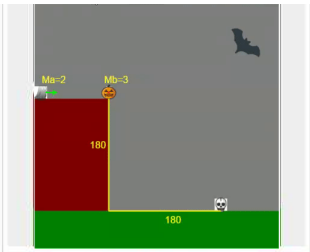
Independent Var t ∞ Increment dt ∞ Prelim code

State		Rate
d S	/dt =	vs
d vs	/dt =	a*25

Add Column

0.00001 ∞ Advanced Events

100+ Simulations

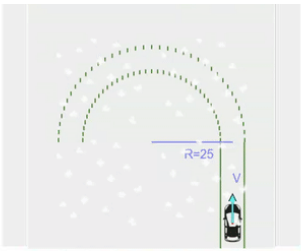


非彈性碰撞與拋射Hfun

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

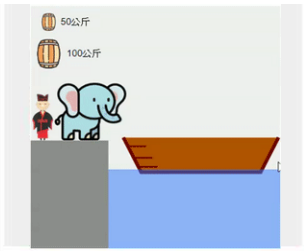


向心力與摩擦係數探討合作

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

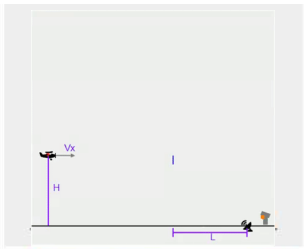


浮力-曹沖秤象

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

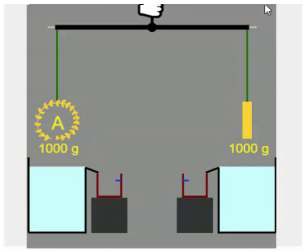


飛機投彈任務-fun

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

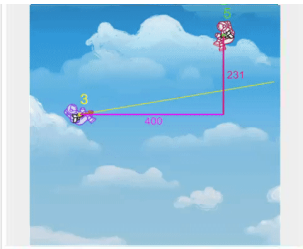


真假皇冠

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

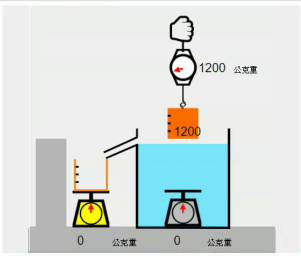
此程式模擬兩位太空人的決鬥過程。你知道該如何設定參數使得紫色太空人射中紅色太空人嗎?

4598 mhchang

等速與等加速度運動-同時

velocity | acceleration

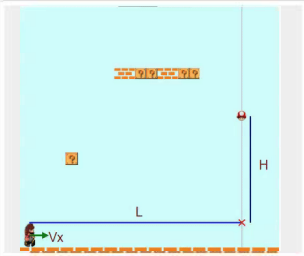
此程式模擬兩種物體的運動，等速度運動的腳踏車與等加速度運動的汽車。任務是讓兩車同時抵達終點。



密度與浮力實驗

buoyancy | Archimedes' principle

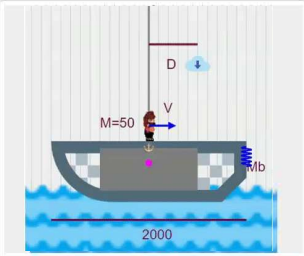
此程式模擬將一個重量為 M 公克，體積為 V 立方公分的橘色方塊慢慢浸入密度為 rhoS (公克/立方公分)的藍色溶液中的過程，以探討浮力概念。



等速與落體合作fun

velocity | acceleration

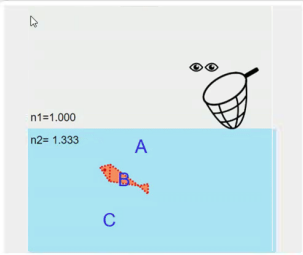
這是一個運用等速度運動與自由落體的概念設計的合作問題解決題目。



質心與動量守恆A-fun

conservation of momentum

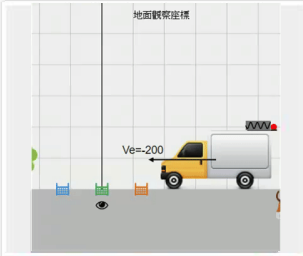
此程式模擬一不受外力的作用的靜止的船上載著馬力歐，假設船與水面間無摩擦力，當馬力歐以等速 V 向船尾移動時，馬力歐與船的運動。



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?



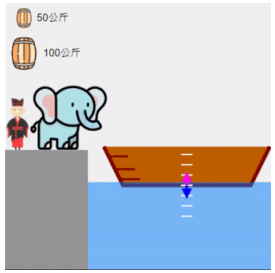
拋體運動-落在哪裡fun

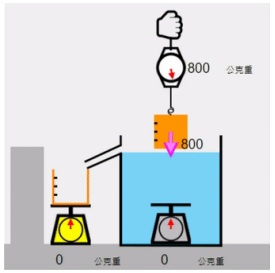
velocity | projectile motion

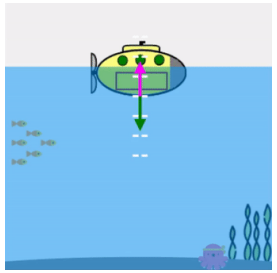
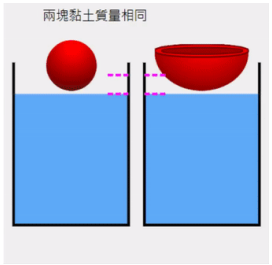
此程式模擬一顆從移動中的貨車屋頂落下/射出的紅球的運動軌跡。

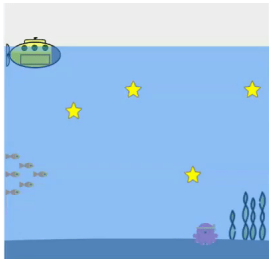
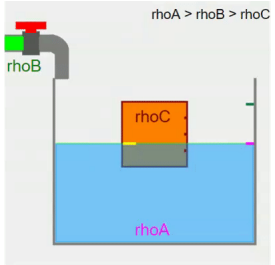
100+ Simulations

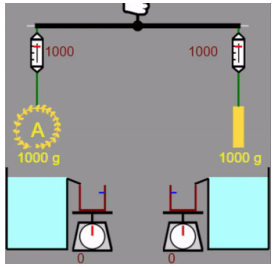
Buoyancy



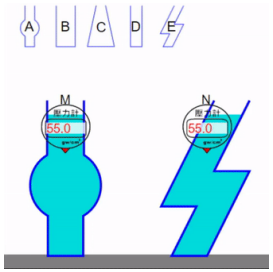


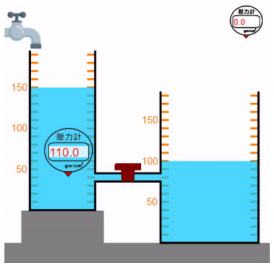



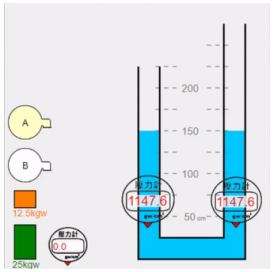



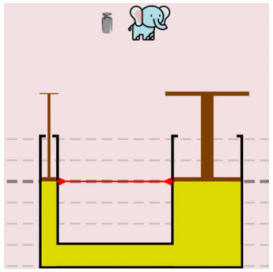
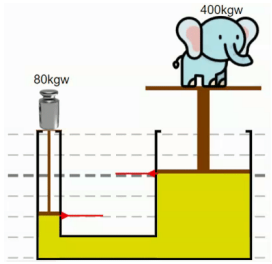


Pressure



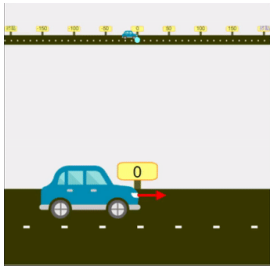


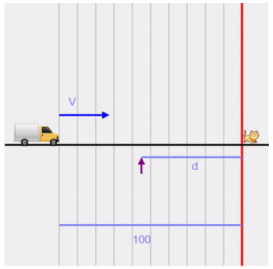


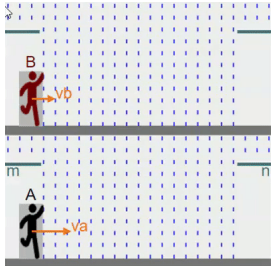



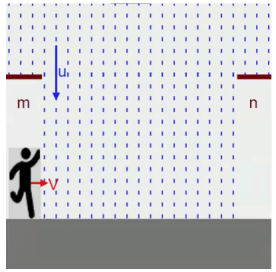
100+ Simulations

Velocity & Acceleration

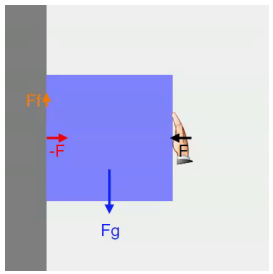


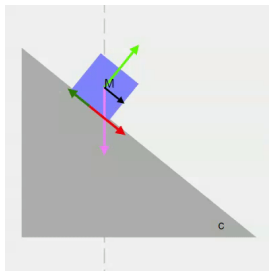


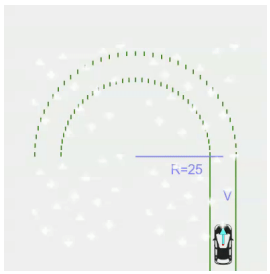


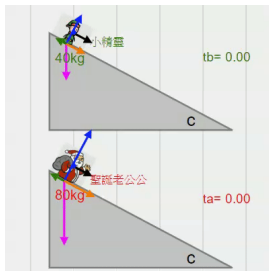


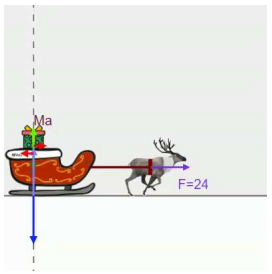
Friction

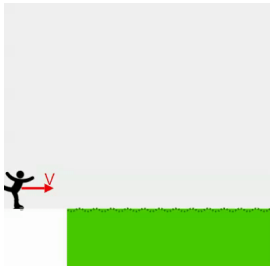






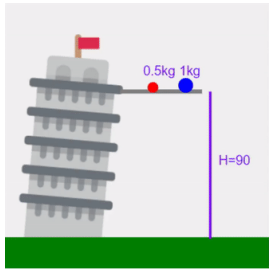


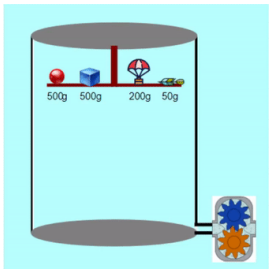


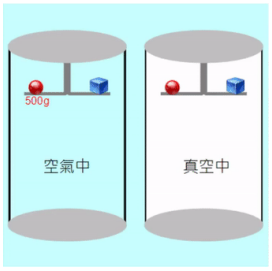


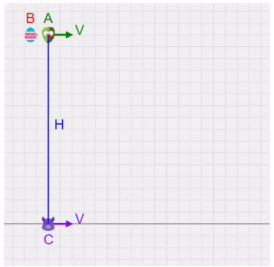
100+ Simulations

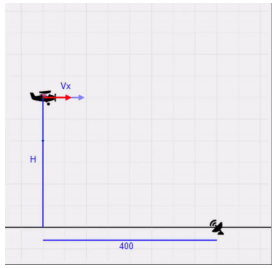
Free falling / Projectile

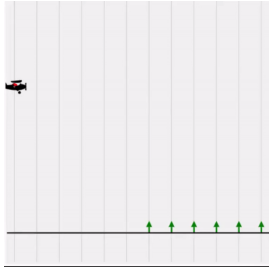
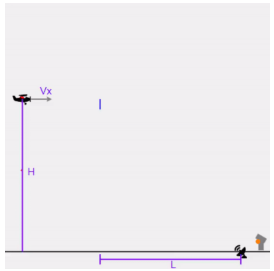


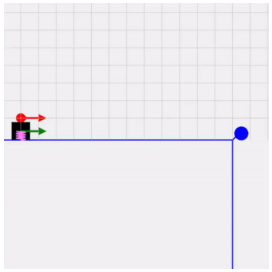
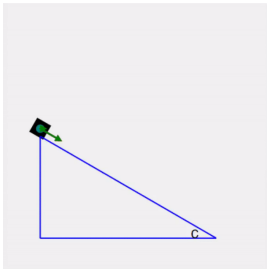


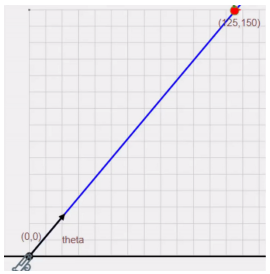


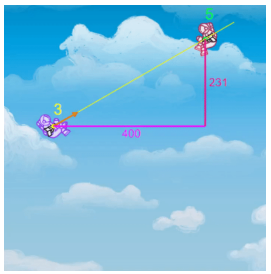



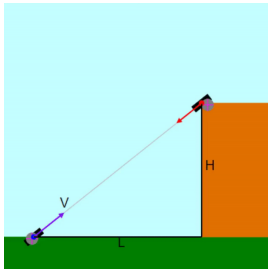


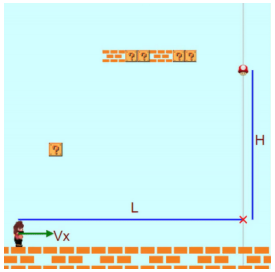





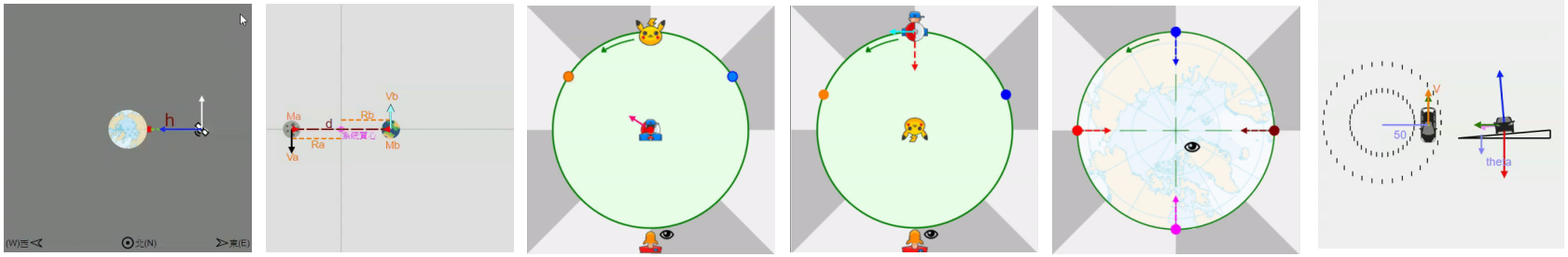




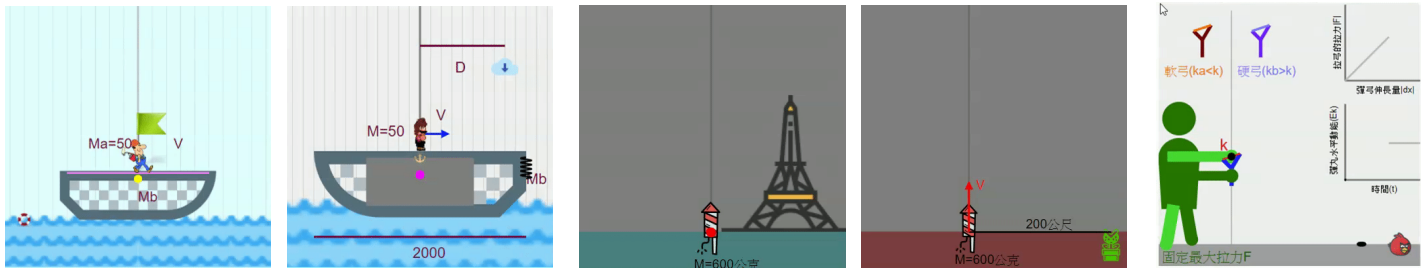


100+ Simulations

Circular motion

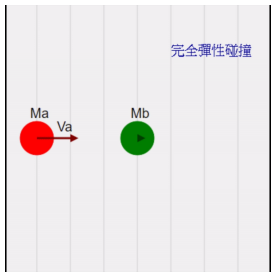


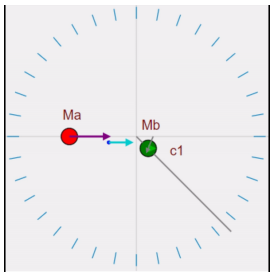
Momentum and Energy

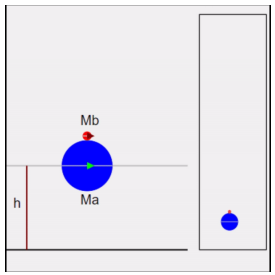


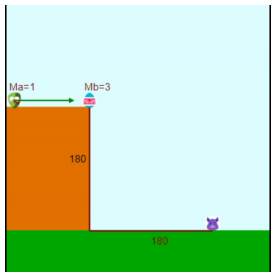
100+ Simulations

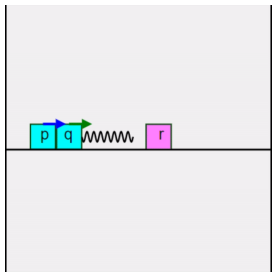
Collision

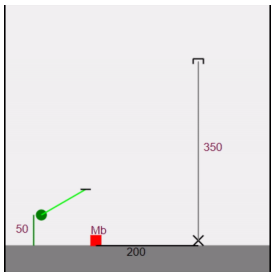


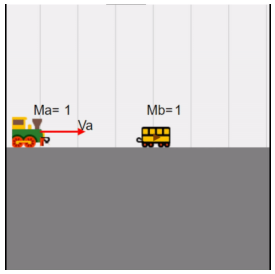


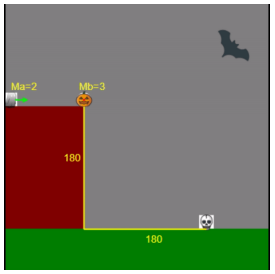


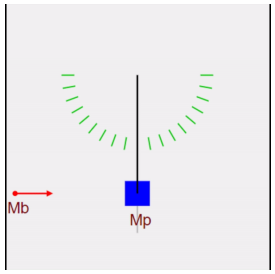






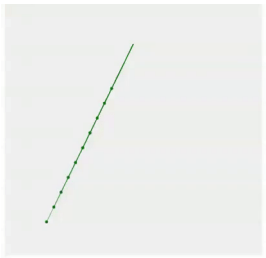
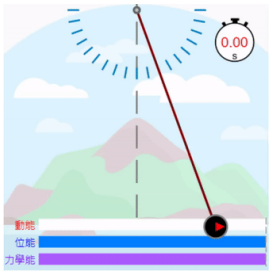


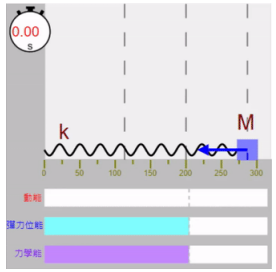




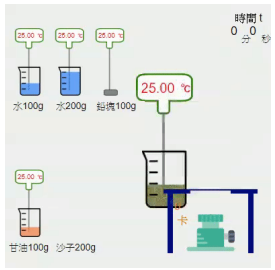
100+ Simulations

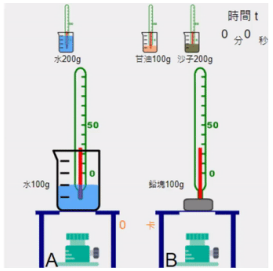
Harmonic motion

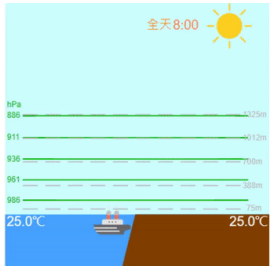



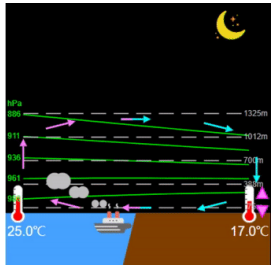


Thermodynamics



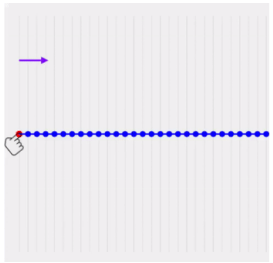
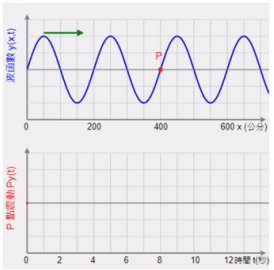


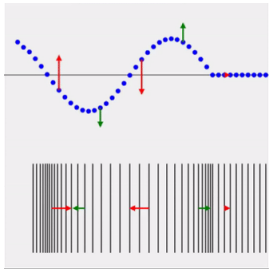
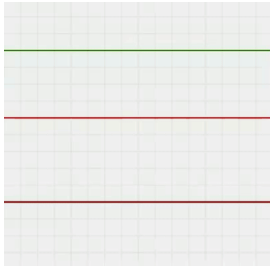
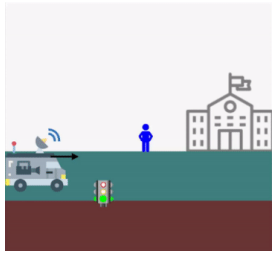




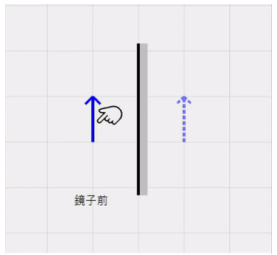
100+ Simulations

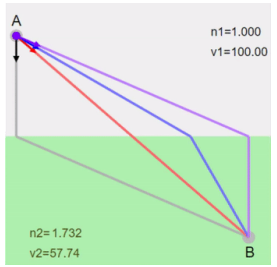
Waves

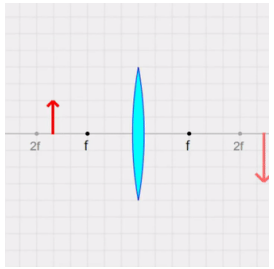



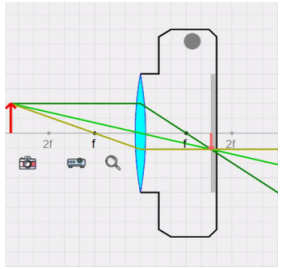




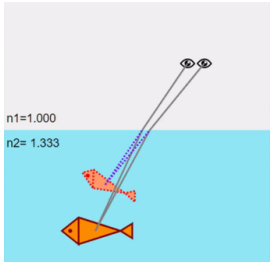
Optics











100+ Simulations

Electromagnetic

Pedagogical Design

Pedagogical design

- Simply providing simulations does not guarantee positive learning effect
  - Students do not know how to interact with simulations (Holzinger, Kickmeier-Rust, Wassertheurer, and Hessinger, 2009).
  - Interact with simulations on a superficial and playful level (Mayer, 2004; Swaak & de Jong, 2001)

➔ Students need different levels of supports in using simulations.

Orchestration

> *“ Leveraging multiple resources and extrinsic constraints including time, curriculum relevance, discipline constraints, and assessment constraints. ”*

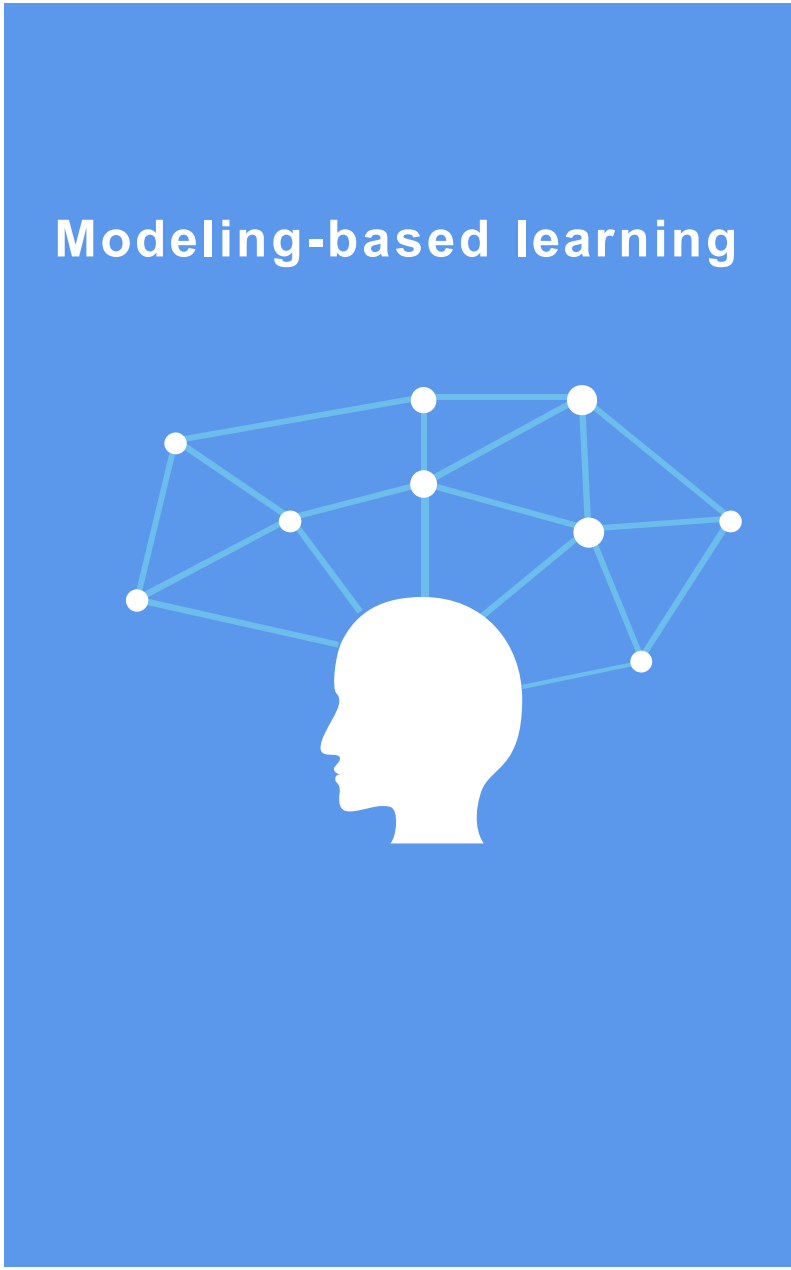
(From The special issue in Computers & Education 2013 by Pierre Dillenbourg)

simple and feasible

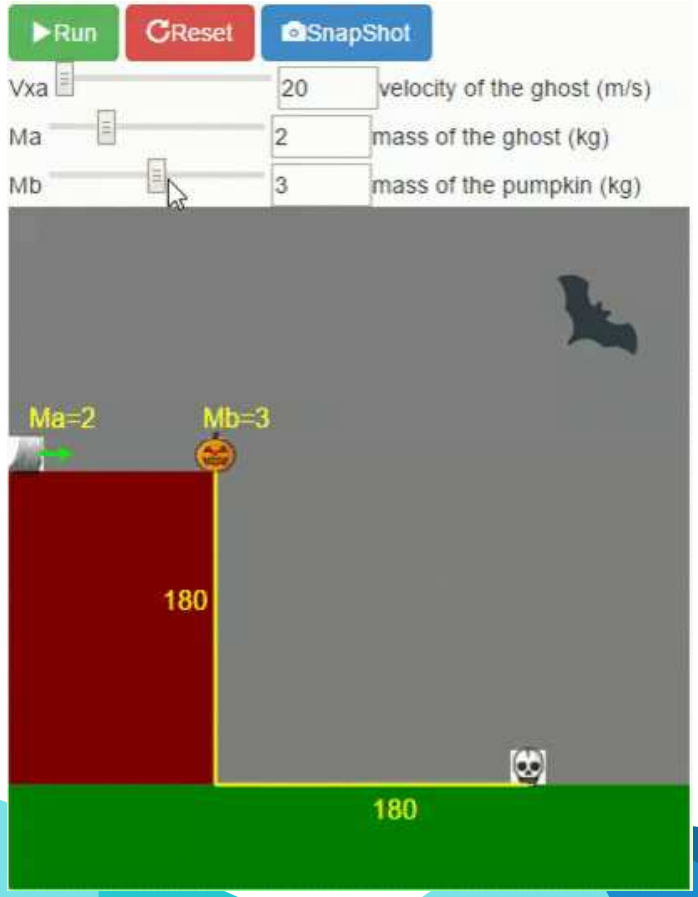
Pedagogies using simulations

- Modeling-based learning with games
- Guided inquiry with simulations
- Critique on the inquiry with simulations
- Light-weight inquiry in classrooms

Modeling-based learning with games



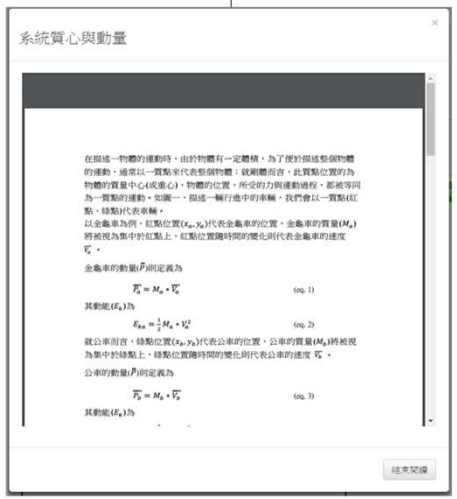
Problem-solving simulation game



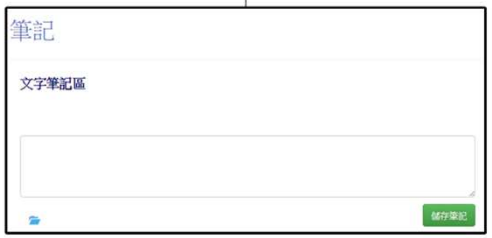
Momentum + Collision

High school students constructed the model of collision of two objects.

Reference Material



Note taking



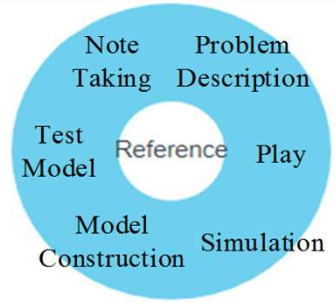
Problem Description

Cosci mini game 公司在萬聖節出了一個物理小遊戲，小巫覺得很有挑戰性，遊戲設定如下:

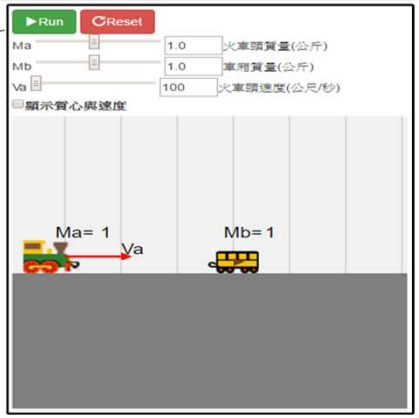
位於180公尺高的山崖上有隻質量為 **Ma**(公斤) 的鬼魂，以等速度 **Vxa**(公尺/秒) 向右 (+X方向)移動，在山崖邊有一顆質量為 **Mb**(公斤)南瓜。當鬼魂碰撞到南瓜時，鬼魂黏在南瓜上，兩者一起墜落至山崖下 (重力加速度 **g=10** 公尺/秒^2)，兩物碰撞過程中不受任何外力，假設地面無摩擦力。 於地面距離山崖邊180公尺處有一顆骷顱頭。

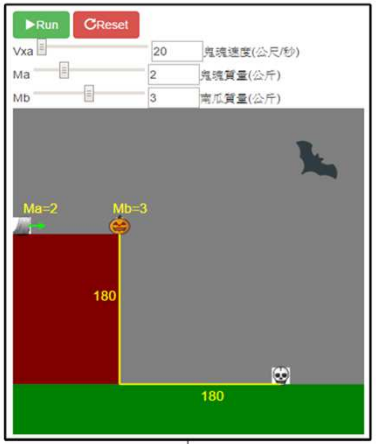
請你調控適當參數值(Vax，Ma，Mb) 使得南瓜落地時恰巧擊中骷顱頭。

可調參數:
Vxa: 鬼魂速度 (公尺/秒)
Ma: 鬼魂質量 (公斤)
Mb: 南瓜質量 (公斤)

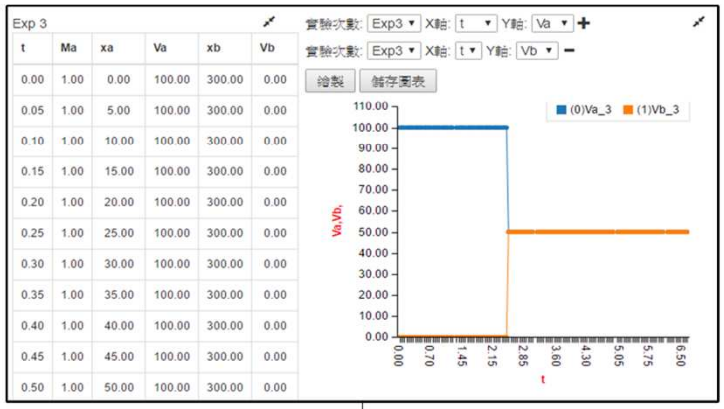


Simulation





Play/ Test Model



Model Construction

Report

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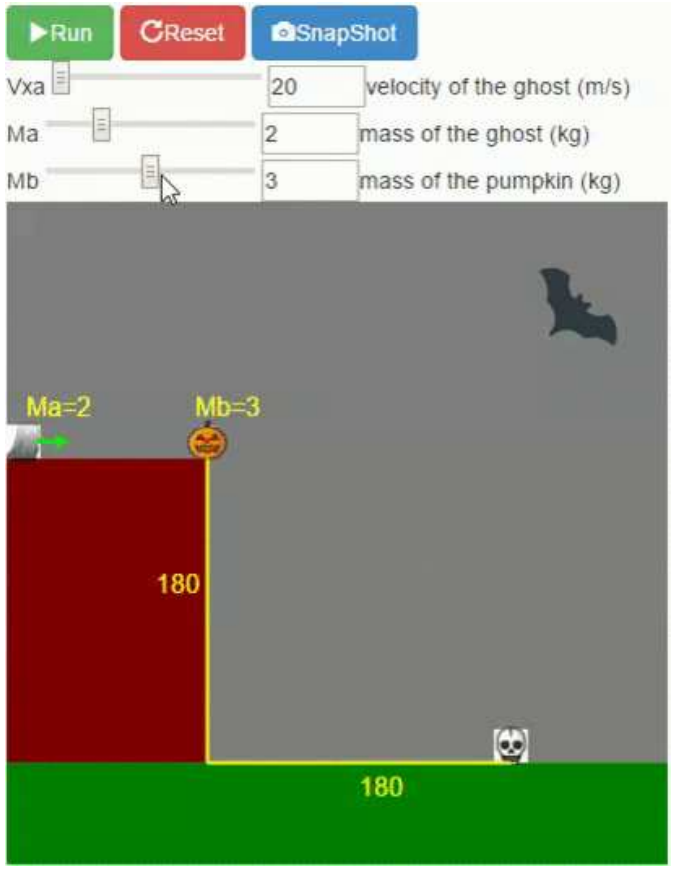
Problem-solving simulation game

- Pedagogical design
  - **Play:** student understand the goal of the game.
  - **Simulation:** students operate simplified simulation displaying how the velocities of two objects change after collision.



Problem-solving simulation game

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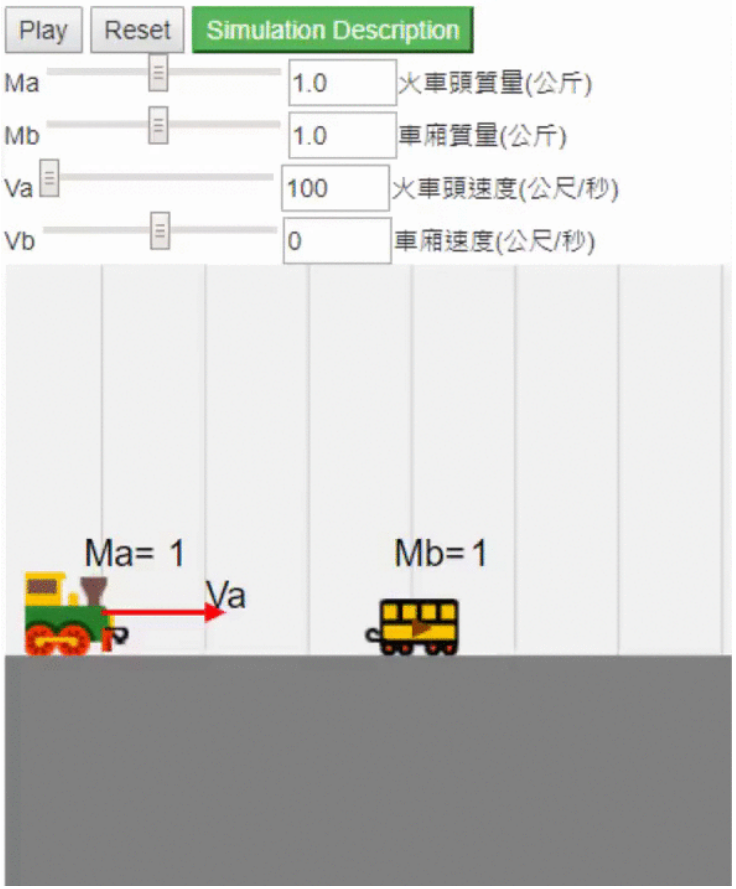


Problem-solving simulation game

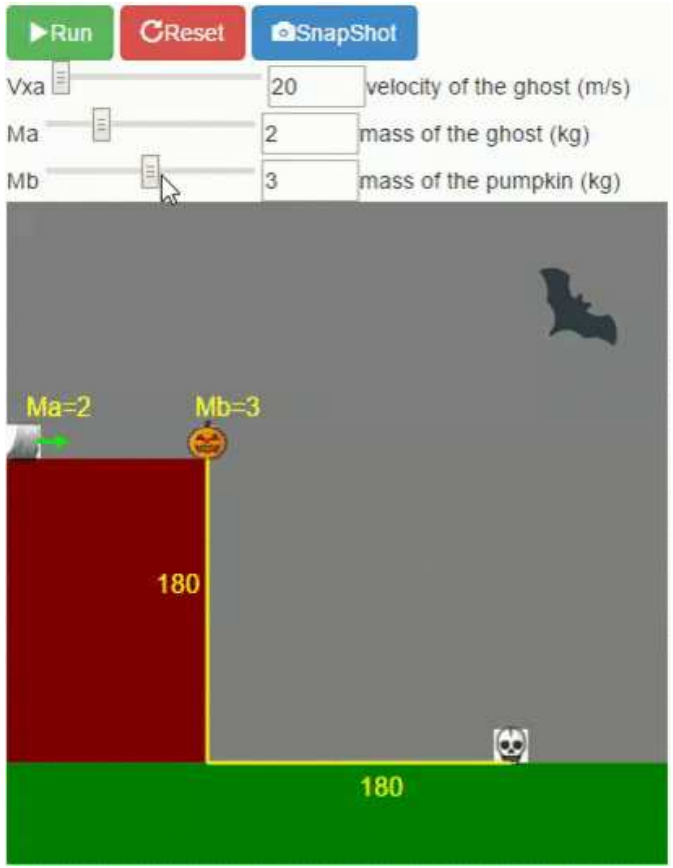
- Model construction: students obtain a quantitative model of collisions to precisely solve the problem given by the game.

紀錄	變數	數值	單位	描述
☑	t	0.00	秒	時間
☑	Ma	1.00	公斤	火車頭質量
☑	xa	0.00	公尺	火車頭位置
☑	Va	100.00	公尺/秒	火車頭速度
☑	Pa	100.00	公斤*公尺/秒	火車頭動量(Ma*Va)
☑	Mb	1.00	公斤	車廂質量
☑	xb	300.00	公尺	車廂位置
☑	Vb	0.00	公尺/秒	車廂速度
☑	Pb	0.00	公斤*公尺/秒	車廂動量(Mb*Vb)
☑	xc	150.00	公尺	系統質心位置
☑	Vc	50.00	公尺/秒	系統質心速度
☑	Pc	100.00	公斤*公尺/秒	系統質心動量

Problem-solving simulation game

- **Test model**: Students use the model they built to solve the game. To avoid trial-and-error they were only allowed to play the game three times.

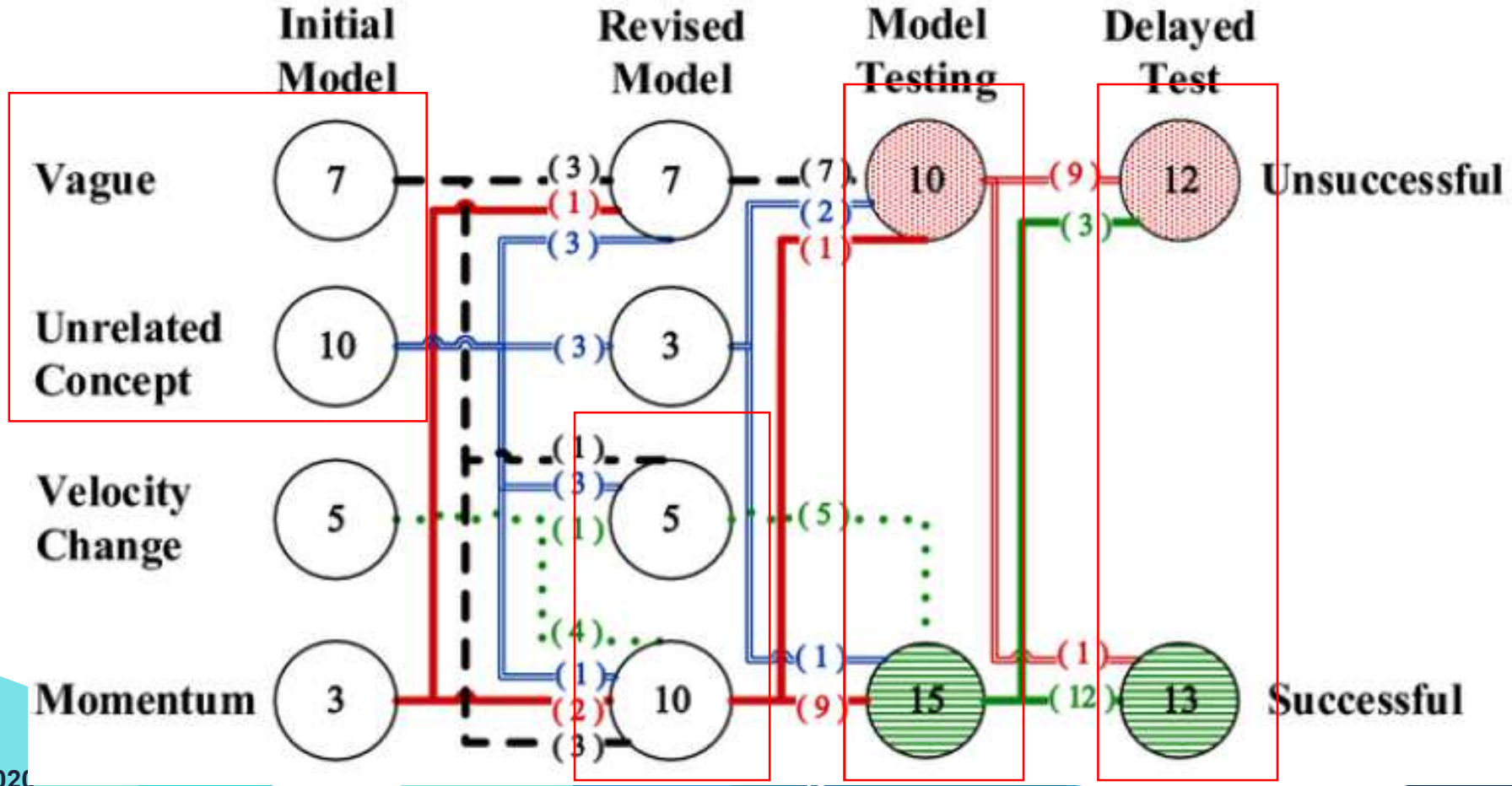
- **Writing report**: Students write a report regarding the task they achieved in that session.



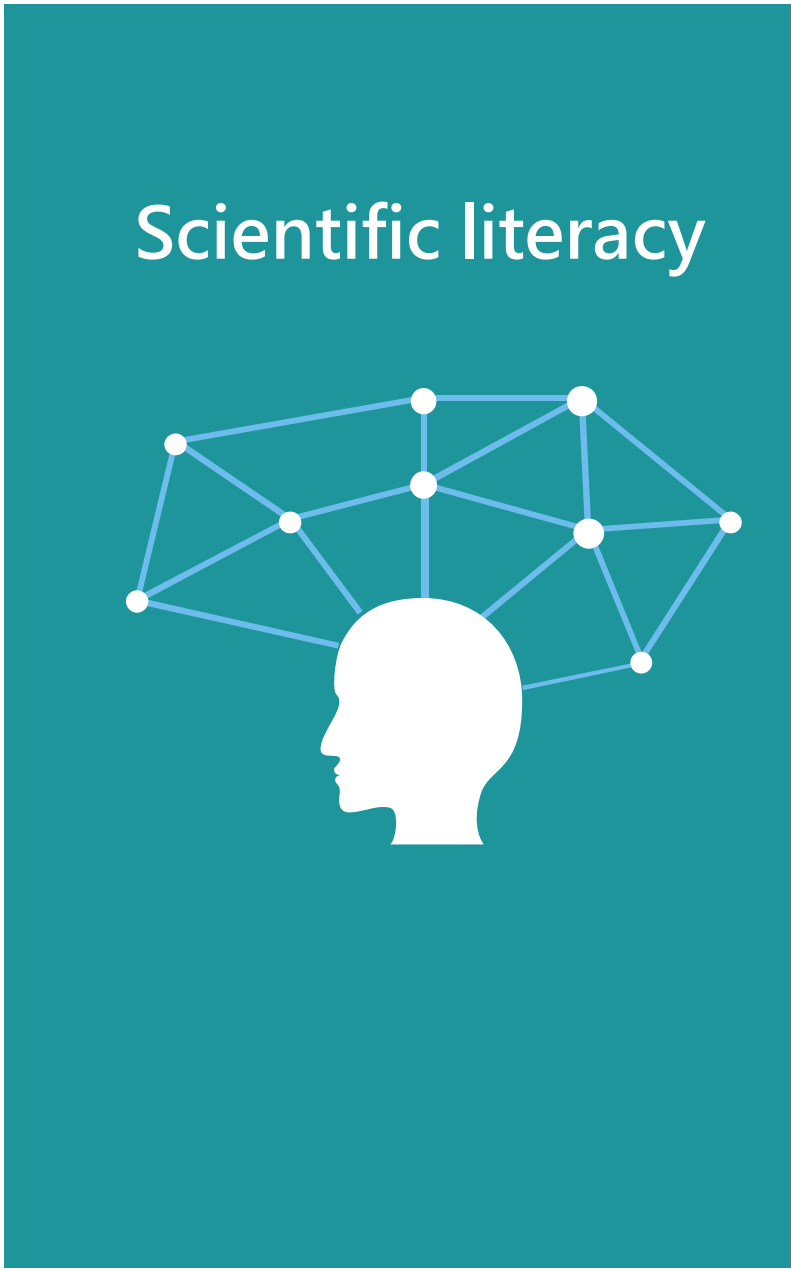
The experiment and analysis

- To understand how 25 high school students build their own model in the inquiry activity.
- The modeling-based learning activity was implemented in a 90-minute session.
  - Initial and final models

Model change



Guided inquiry activity with simulations



Scientific literacy

- Scientific literacy has been emphasized in science education standards globally (e.g., NGSS Lead States, 2013).
- The ability to “do science” (OECD, 2016).
  - **to explain phenomena scientifically**
  - **to design scientific inquiry**
  - **to interpret data scientifically**

Cookbook style laboratory instruction

The cookbook-style laboratory instruction has unfavorable effect on science learning.

(Blanchard et al.,2010; Scalise et al., 2011).

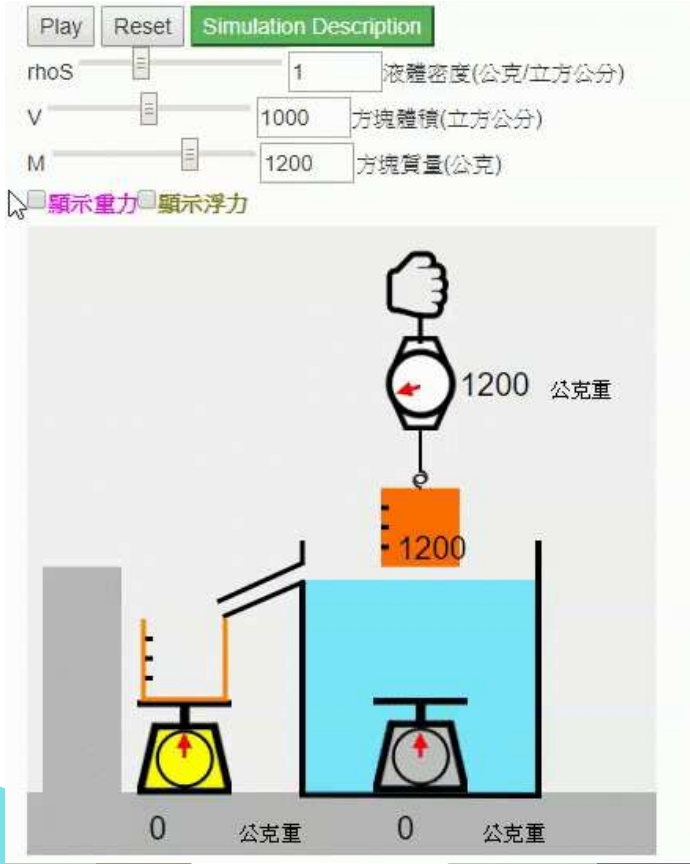
Guided inquiry with simulations

In one class period, the teacher instructed the students how to use the CoSci simulation and demonstrated how to conduct virtual experiments using the simulation.

Then the students were allowed to conduct their own inquiry with the simulation for two class periods.

The students' inquiry was guided by the system through provided inquiry questions and prompting hints and questions.

Guided inquiry with simulations



Buoyancy + Scientific literacy

Middle school students investigate why objects sink or float in the liquid and the phenomenon of buoyancy.

Understand the task

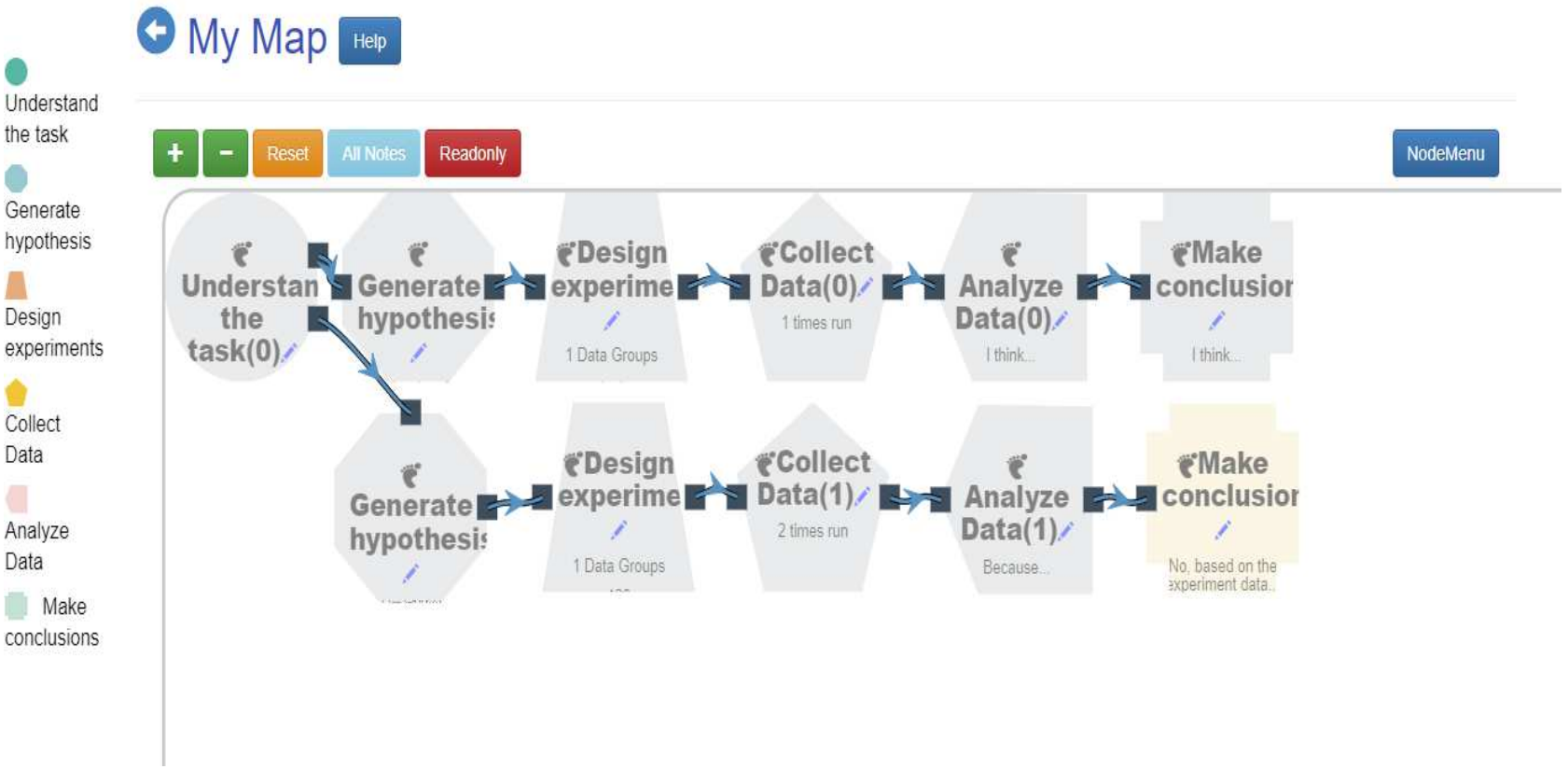
Generate hypothesis

Design experiments

Collect Data

Analyze Data

Make conclusions



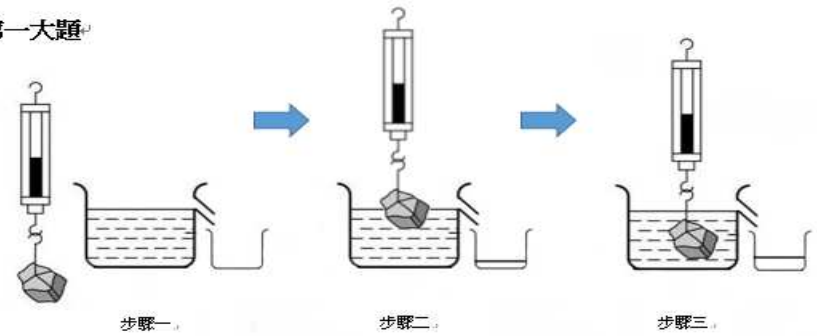
Students configured their own inquiry plan.

Guided inquiry with simulations

- A comparative study
  - One class was taught by the teacher
  - The other learned by the guided inquiry
- Both classes participated in a 100-minute learning session.
- Data set
  - School science test scores
  - Scientific literacy test scores

Scientific literacy test

第一大題



奇奇在實驗室中進行浮力相關實驗，實驗裝置如上圖。奇奇拿了體積 1200cm³、質量 1500g 的石塊掛在彈簧秤下方，秤量石頭的質量，接著將石塊慢慢放入水中，測得石塊在水中的質量以及石塊排開水的體積，如下表所示。

	石頭體積 cm³		彈簧秤讀數 gw	排開的水重 gw	在水中重量 gw	浮力 gw
	液面下	液面上				
步驟一	0	1200	1500	0	未放入水中	0
步驟二	600	600	900	600	900	600
步驟三	1200	0	300	1200	300	1200

1-1 請觀察步驟一到三的數據，你發現浮力的大小與哪些數值相同？為何如此？

1-2 請觀察步驟一到三的數據，解釋石塊在水中的重量如何變化？為何如此？

OECD Scientific literacy framework

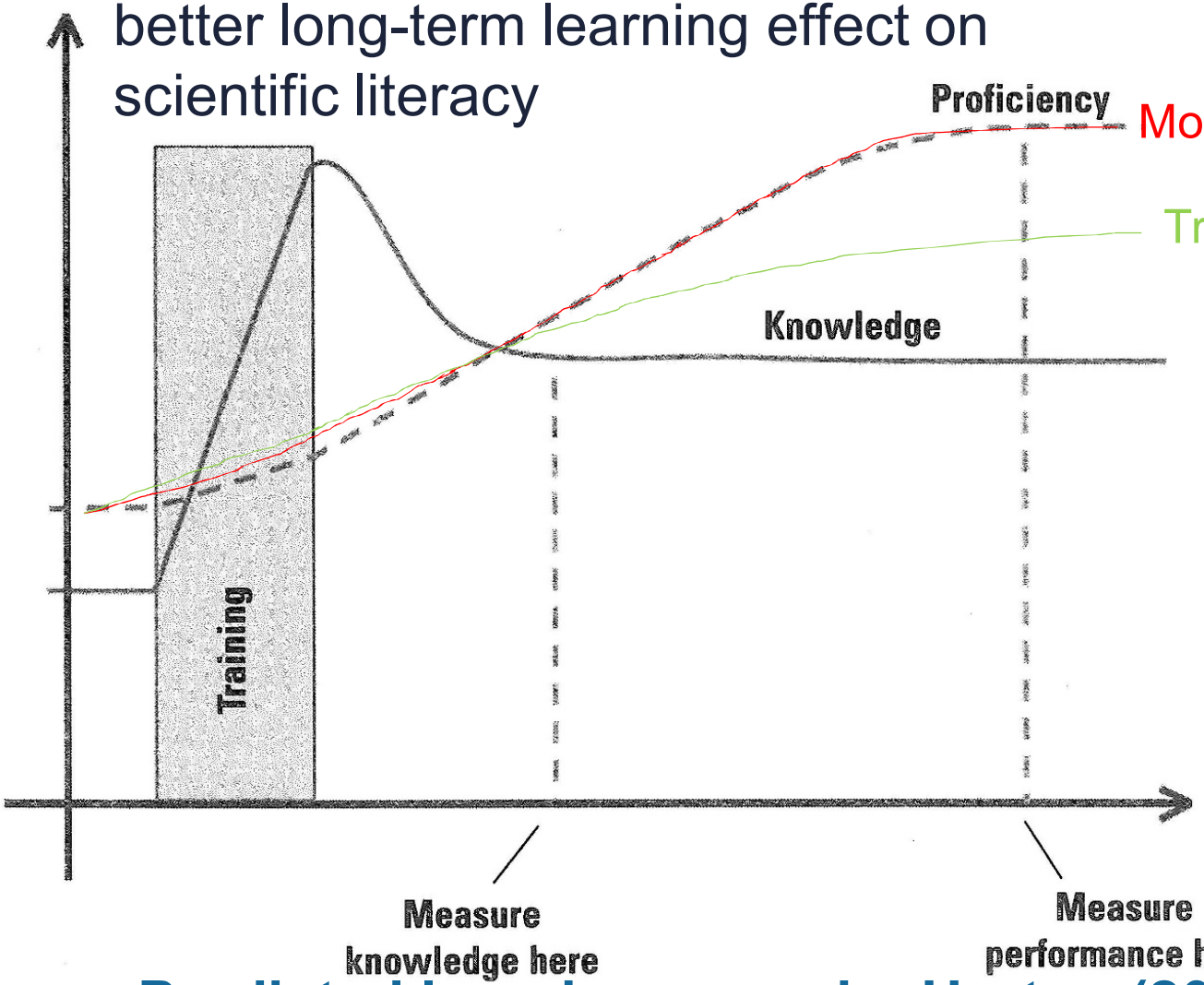
- Explaining phenomena scientifically(SC-A)
- Design of scientific inquiry (SC-B)
- Interpretation of the data (SC-C)

Scientific literacy test

Table 5. Means and standard deviations of the posttest, delayed-test, and post achievement scores

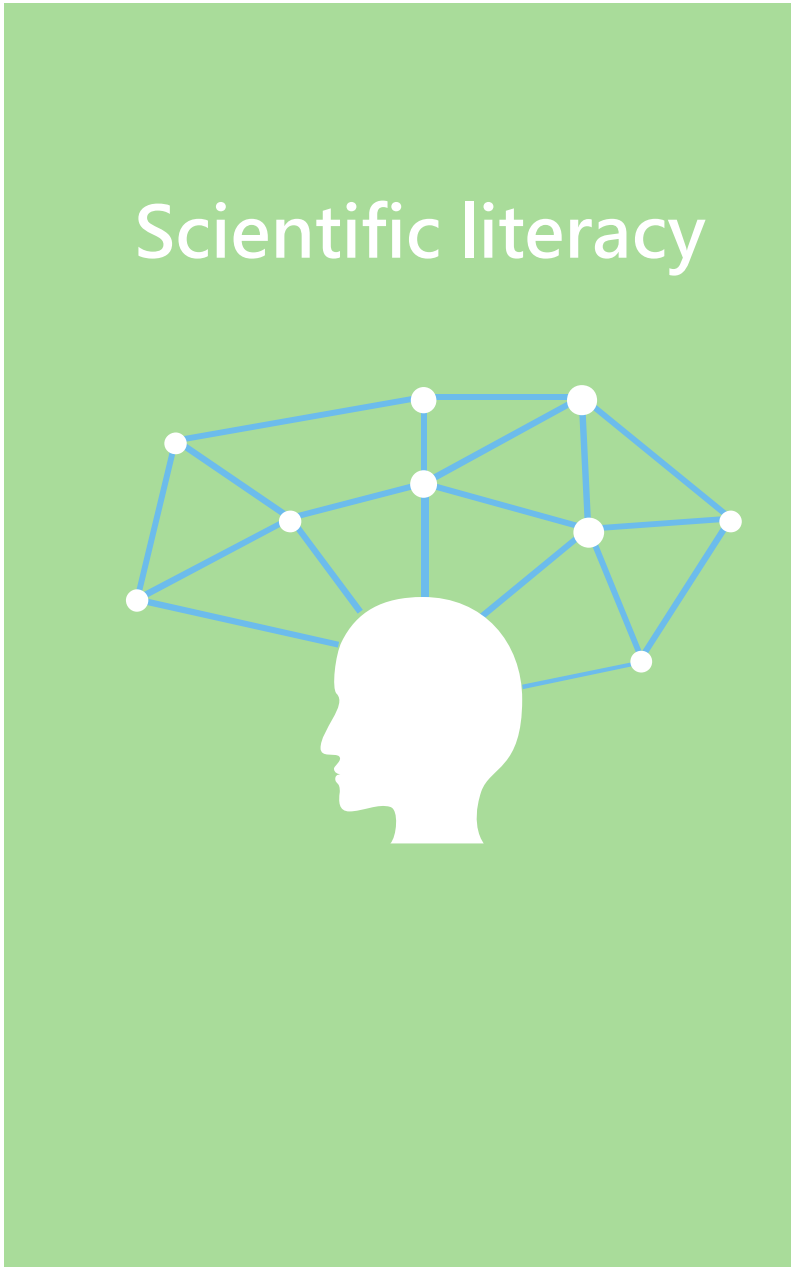
	Scientific Literacy Posttest		Scientific Literacy Delayed-test		Post School Science Achievement Score	
	M	S.D.	M	S.D.	M	S.D.
The treatment group	14.92	6.23	19.08	6.53	64.20	15.01
The control group	13.73	5.94	14.44	6.58	63.44	15.75
Independent sample *t* tests	t=0.689, p=.494		t=2.522, p=.015		t=0.177, p=.860	

better long-term learning effect on scientific literacy



Predicted learning curve by Horton (2001)

Critique on the inquiry with simulations



Critique on the inquiry with simulations

- The practice of critiquing helps students develop integrated understanding of science concepts (Chang & Chang, 2013; Chang & Linn, 2013).
- Critiquing helped students improve their scientific explanations (Matuk et al., 2019).

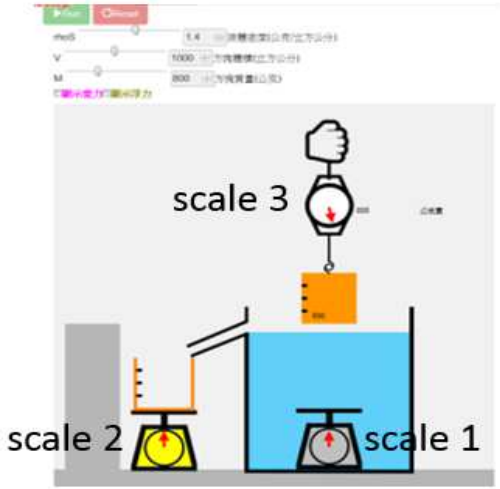
The Student Critique Design

Student complete the critique worksheets.

The teacher led the whole class discussions of the critiques.

Inquiry with the simulation

	rhoS	M	V	rhoA	Vu	Vs	scale1	scale2	scale3	Buoyant F
Exp1	1.00	600.00	1000.00	0.60	600.00	600.00	0.00	600.00	0.00	600
Exp2	1.00	800.00	1000.00	0.80	800.00	800.00	0.00	800.00	0.00	800
Exp3	1.00	1000.00	1000.00	1.00	1000.00	1000.00	0.00	1000.00	0.00	1000
Exp4	1.00	1200.00	1000.00	1.20	1000.00	1000.00	0.00	1000.00	200.00	1000
Exp5	1.40	1400.00	1400.00	1.00	1000.00	1000.00	0.00	1400.00	0.00	1400



According to the results above, Hsian-Hsian claims that "*I hypothesized that the buoyant force equal to the weight of the fluid displaced by the object. The experiment results support my hypothesis. So, I will not change my hypothesis. This is because the weight of the fluid displaced by the object is equal to the volume of the object under the fluid. The volume of the object under the fluid is equal to the buoyant force received by the object. So the weight of the fluid displaced by the object is equal to the volume of the object under the fluid.*" Is this claim reasonable, if not, how do you revise the claim?

Student Critique Worksheets

Understand the task

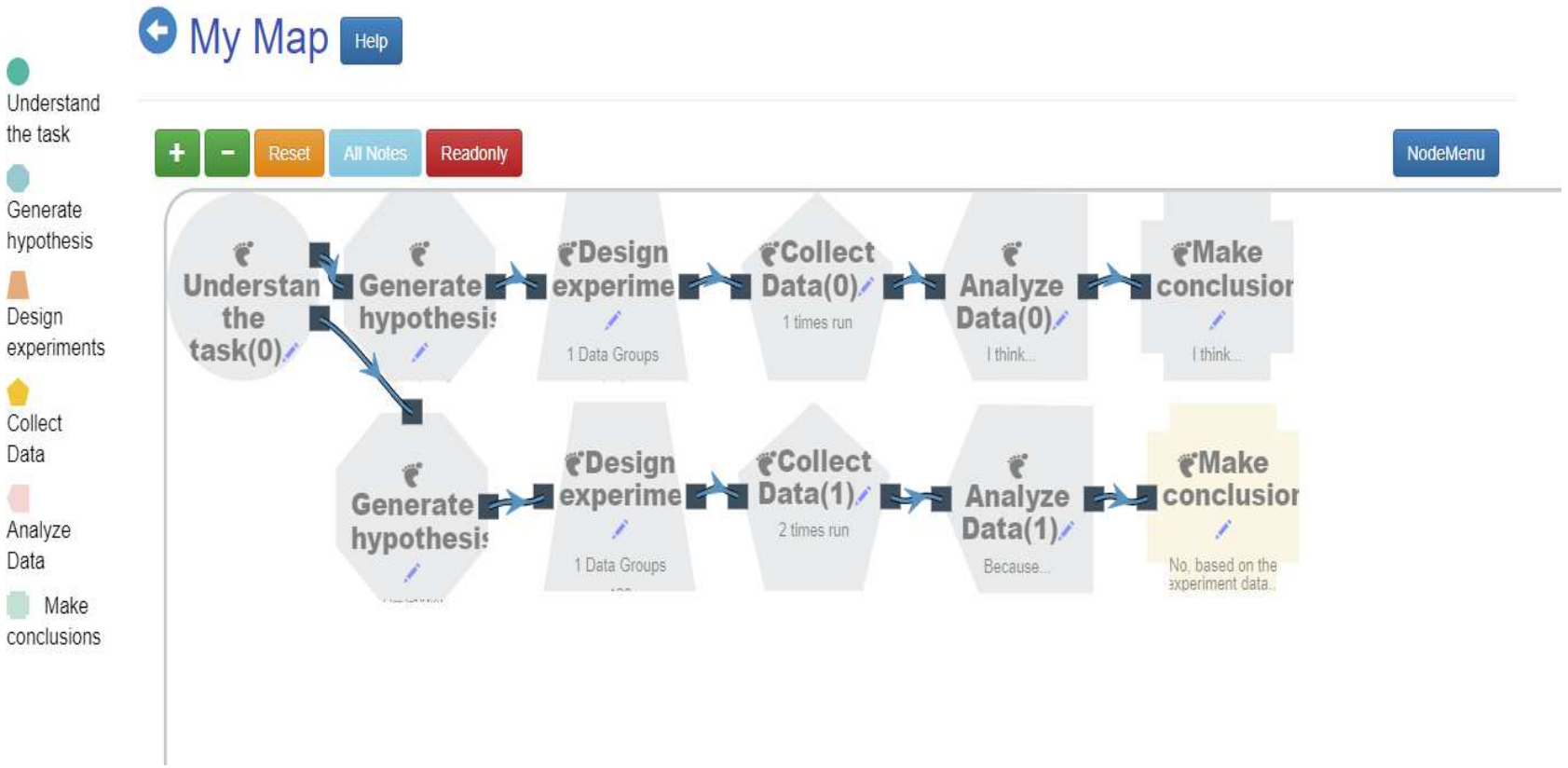
Generate hypothesis

Design experiments

Collect Data

Analyze Data

Make conclusions



Students took part in the inquiry with the simulation and inquiry map.

The experiment and analysis

- A comparative study
  - Traditional group
  - Teacher demonstration group
  - Student critique group
- All classes participated in a 100-minute learning session.
- Data set
  - Scientific literacy test scores

Conventional No-Simulation Teaching

The traditional lecture treatment also involved three class periods but teaching through textbook-based lectures with no simulation.

It involved teacher lectures about the concepts, and student practice on assessment items relating to sinking and floating.

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The Teacher Demonstration Design

In one class period, the teacher instructed the students how to use the CoSci simulation and demonstrated how to conduct virtual experiments using the simulation.

Then the students were allowed to conduct their own inquiry with the simulation for two class periods.

The students' inquiry was guided by the system through provided inquiry questions and prompting hints and questions.

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The Student Critique Design

The students worked on worksheets prepared by the science teachers that asked the students to critique fictitious experiments with the CoSci sinking and floating simulation.

The teacher also led whole class discussions to engage the students in discussing their critiques.

Then the students were allowed to conduct their own inquiry with the simulation for two class periods. The students' inquiry was guided by the system through provided inquiry questions and prompting hints and questions.

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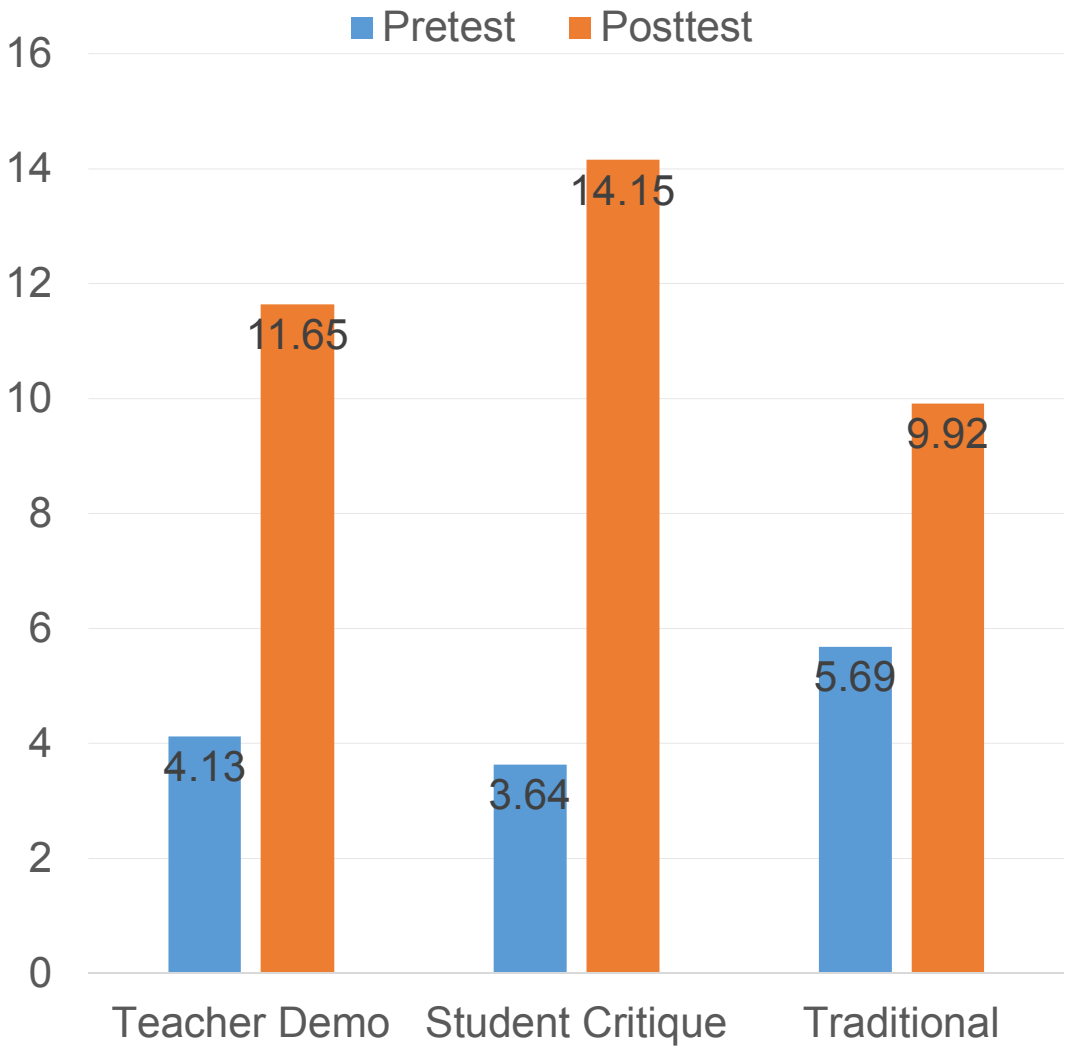
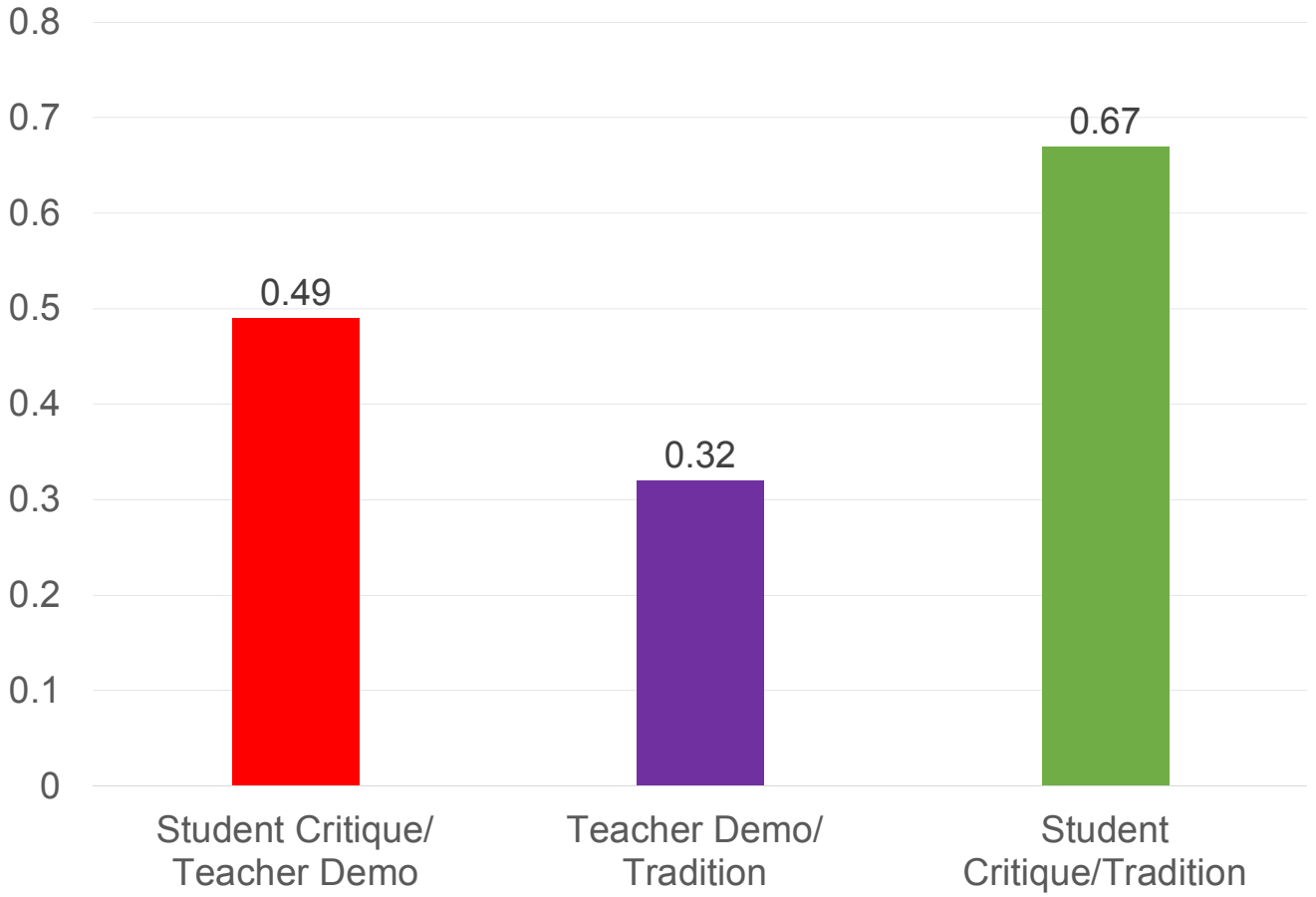


Results

- The ANCOVA result indicates that there is a significant treatment effect (F=7.908, p=0.001).
- Paired comparisons with a modified Bonferroni correction reveal significant differences between the Student Critique treatment and the traditional teaching treatment, but no significant difference between any two of the others.

The critique approach showed medium effect size over the traditional approach.

Cohen's d



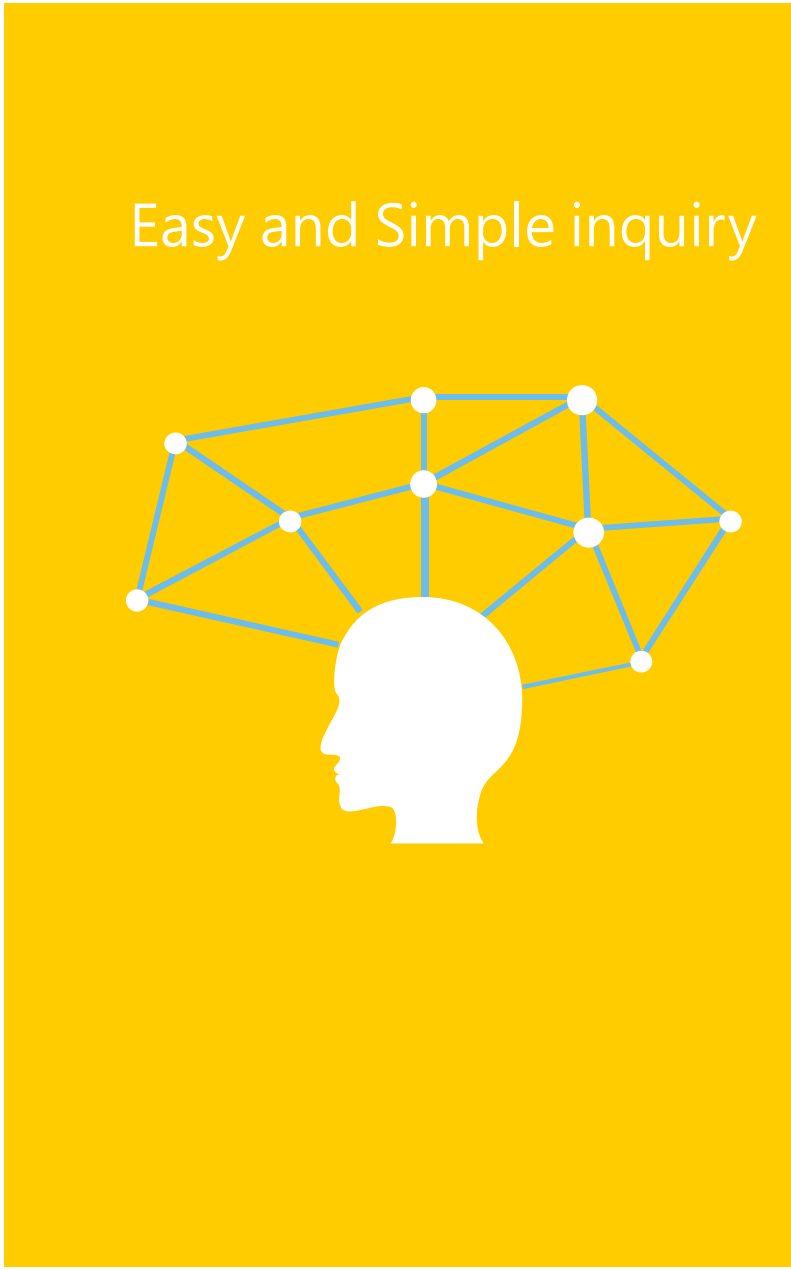
Reflections

- The three designs improved science learning effect.
- However, the three designs assume the high readiness of technology use in schools
  - Modeling-based learning with games
  - Guided inquiry with simulations
  - Critique on the inquiry with simulations

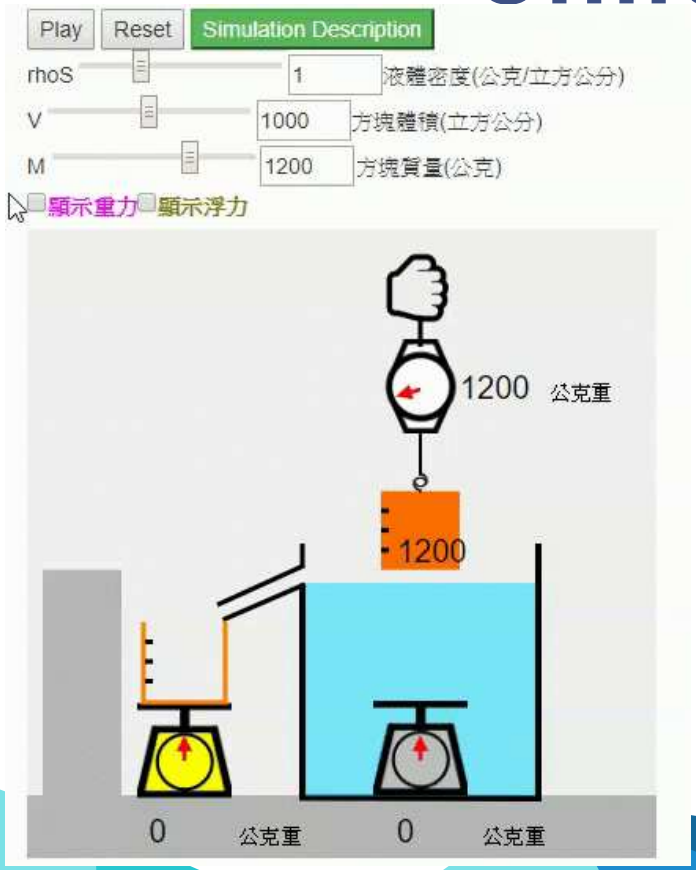
One student
One computer

Easy and Simple

Light-weight inquiry in classrooms



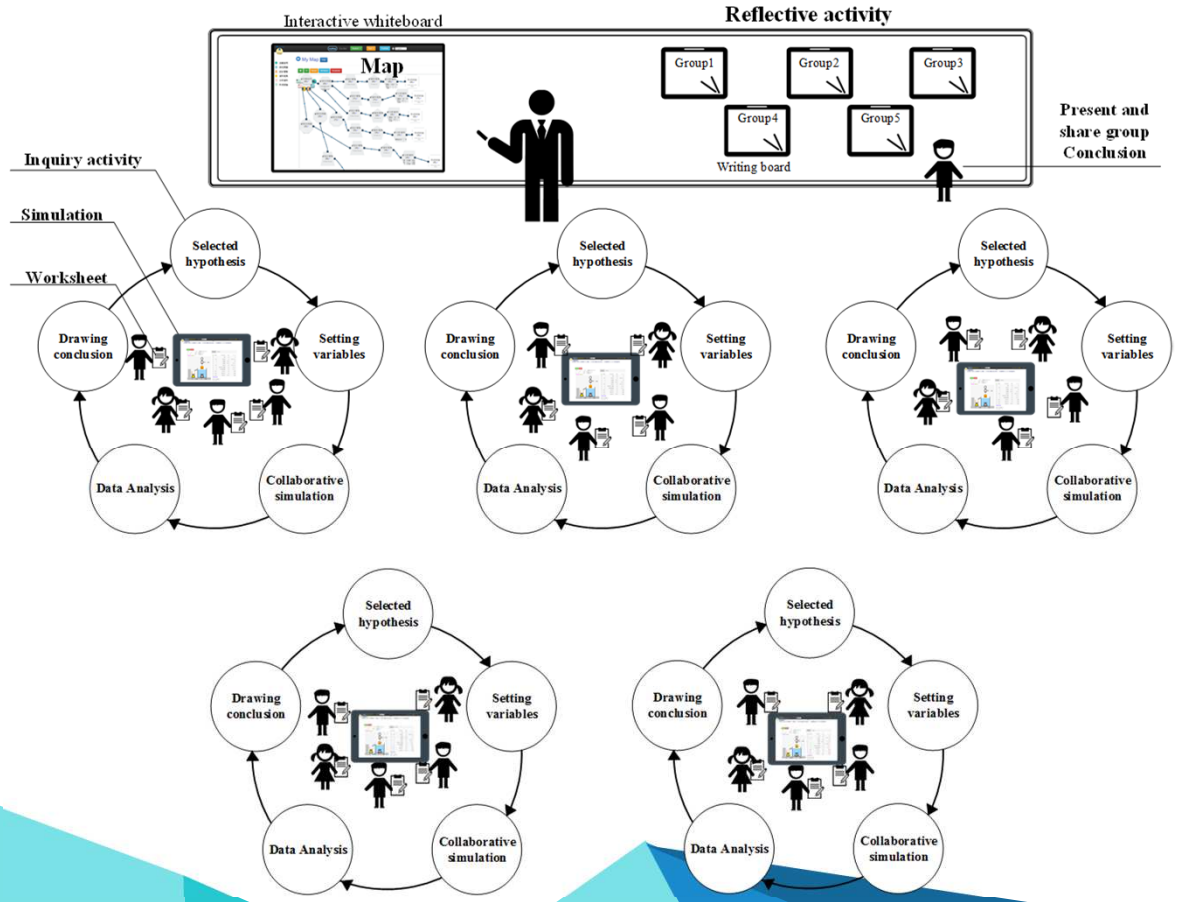
Light-weight inquiry with computer simulations



Buoyancy + Scientific literacy

Middle school students investigate why objects sink or float in the liquid and the phenomenon of buoyancy.

Classroom orchestration



- Minimalism principle: only 5 iPads and a projector were used
- Teacher-led collaboration: teacher guided students through worksheets
- Students went through the inquiry steps to build the science knowledge of buoyancy.
- They shared their group conclusion on the white board.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The experiment and analysis

- A comparative study
  - 24 in the Light-weight inquiry group
  - 25 in traditional teaching approach
- Both groups learned Buoyancy in 4 45-minute sessions
- Data collection
  - Pre- and post-test for the scientific literacy
  - Pre- and post-test for the science knowledge

Science knowledge

Table 1. The repeated measure analysis (ANOVA) of the science knowledge

Group	N	Pre-test		Post-test		*F*	*P*
		M	SD	M	SD		
Traditional	24	3.79	1.64	6.21	2.34	2.58	.115
Light-weight	25	3.36	1.44	5.44	1.66		

The two groups did not show significant difference in their science knowledge.

Scientific Literacy

Scientific Literacy	Group	N	Adjusted Mean	Std. err.	*F*	*P*
Overall	Trad.	24	1.47	.14	2.38	.13
	Ligh-W.	25	1.85	.14		
SC-A	Trad.	24	.63	.07	1.29	.26
	Ligh-W.	25	.55	.07		
SC-B	Trad.	24	.45	.06	.10	.76
	Ligh-W.	25	.44	.05		
SC-C	Trad.	24	.64	.05	7.34**	<.01
	Ligh-W.	25	.74	.05		

* $p<.05$; ** $p<.01$

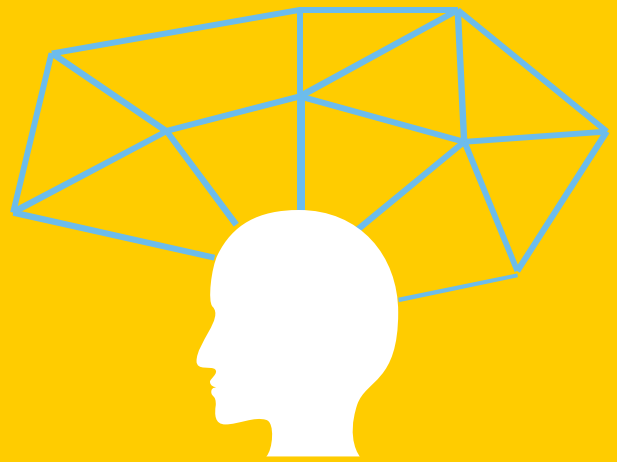
Explaining phenomena scientifically (SC-A)
Design of scientific enquiry (SC-B)
Interpretation of the data (SC-C)

The light-weight inquiry approach is helpful for improving students' ability in interpreting data.

Dream-based research vs. Practice–driven innovation research

- Dream-based research
  - telling teachers a dream
  - rather than practically helping them transform teaching/learning

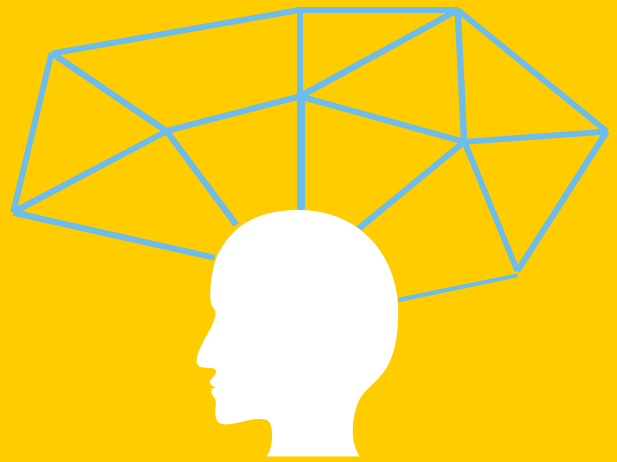
Practice-driven innovation research



Dream-based research vs. Practice–driven innovation research

- Practice-driven innovation research
  - Create innovations practically transforming teaching/learning in the context
  - Working with schools and teachers
  - Address teachers' orchestration requirements
  - Demonstrate practical impacts

Practice-driven innovation research

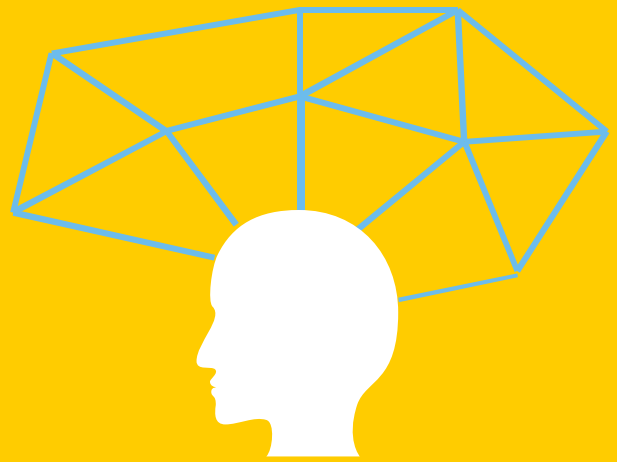


Dream-based research vs. Practice–driven innovation research

- CoSci platform
  - 100+ simulations
  - Learning activity design

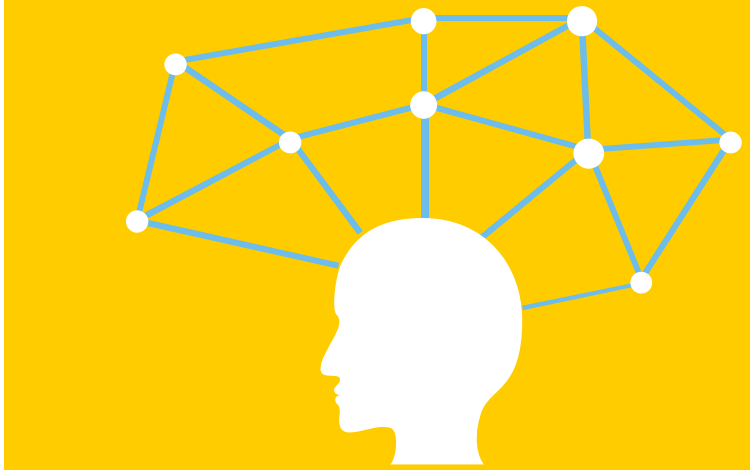
- Being collaborating with 8 schools in Taiwan to bring these simulations to schools

Practice-driven innovation research



Dream-based research vs. Practice–driven innovation research

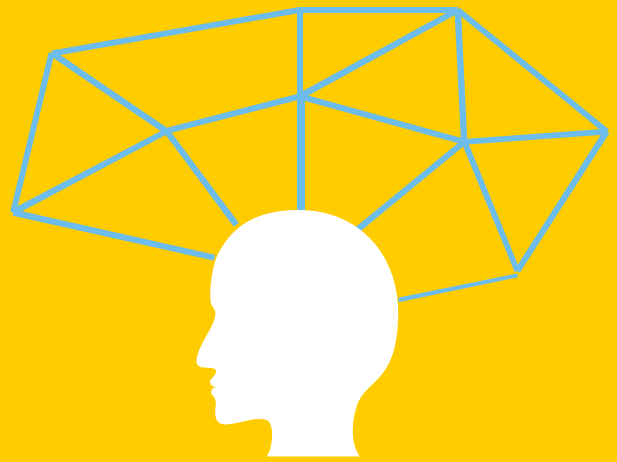
- The four simple and feasible pedagogical designs were tested in schools
  - Guiding students in model-based learning
  - Developing scientific literacy



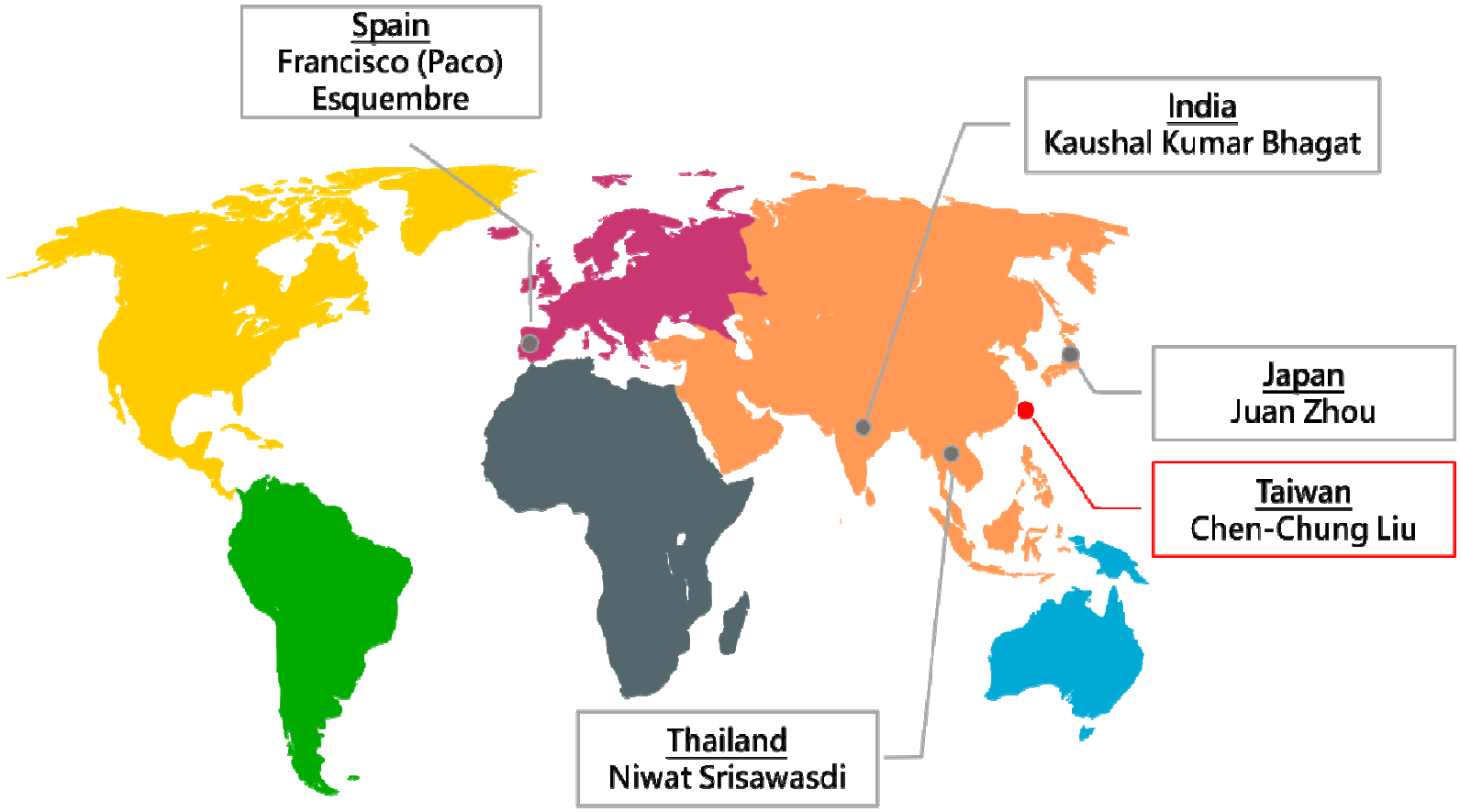
We hope:

The tool, content, and pedagogical method we create can practically improve the teaching and learning in schools.

Practice-driven innovation research



Collaboration Network



THANKS

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References

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