普通物理學實驗課程教學之抉擇:
“驗證”　學習問題、　"學習"驗證問題

2025 物理實作平台年會

10/05/2025 台中高鐵站集思會議中心

中興大學物理系　施明智

國立中興大學
NATIONAL CHUNG HSING UNIVERSITY

Introductory physics labs: WE CAN DO BETTER

Research reveals that labs are more effective when their goal is to teach experimental practices rather than to reinforce classroom instruction.

Natasha G. Holmes and Carl E. Wieman

Physics Today 71, 1, 38 (2018); doi: 10.1063/PT.3.3816

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **13,** 010129 (2017)

Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content

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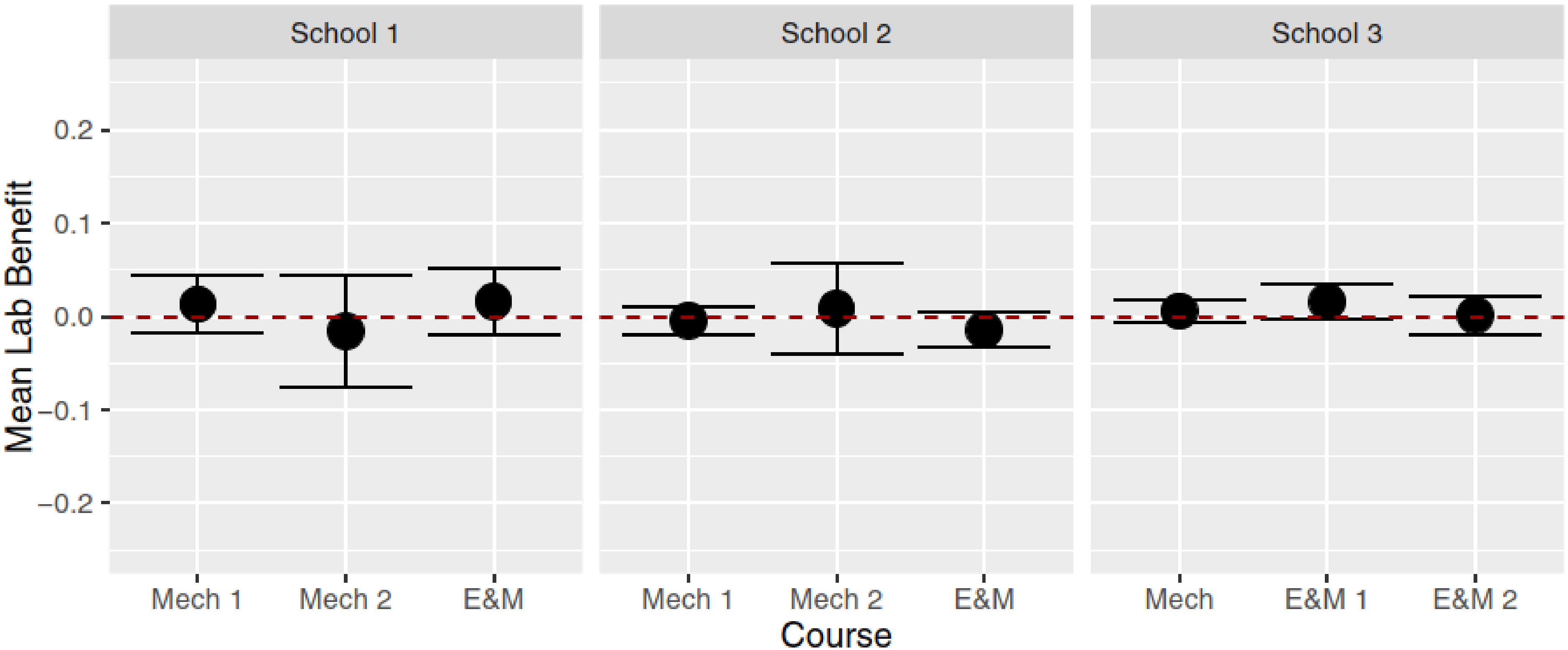
Stanford University's Study

實驗課對課程學習表現沒有實質正面的影響



N. G. Holmes, J. Olsen, J.L. Thomas and C.E. Wieman, *Phys. Rev. Phys. Educ. Res.* 13, 010129 (2017)

“ These overly structured labs have been criticized for stifling students’ use of cognitive and metacognitive skills [4,12,13], “

“ impeding students’ epistemologies regarding the nature of experimentation and scientific measurement [14–16], “

“ and being generally “uninspiring” [17]. “

N. G. Holmes, J. Olsen, J.L. Thomas and C.E. Wieman, Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content, Phys. Rev. Phys. Educ. Res. 13, 010129 (2017).

Goals range over

reinforcing content,

learning about measurement and uncertainty,

practicing communication skills,

developing teamwork skills,

more broadly, learning that physics is an experimental science.

普通物理學實驗課的定位:

引用台灣大學普通物理學實驗網頁教學目的片段文字:

https://web.phys.ntu.edu.tw/gphyslab/modules/tinyd3/index3a9f.html?id=6

近年來普通物理實驗教學模式的革變，將普物實驗課程定位為獨立而自我完備的課程，強調藉由實際儀器操作與數據分析的實驗研究方法，以探討物理規律及建構相關理論模式。實驗前準備應以相關概念或原理構思實驗步驟，繁難理論推導則為輔助。先進改革性實驗課程尤其強調探索與創新思維學習，而非僅依照課本實驗步驟從事食譜式操作。

探索式實驗教學之選擇

Nature PhySicS | VOL 17 | JUne 2021 | 662–663 | www.nature.com/naturephysics

Best practice for instructional labs

Undergraduate labs are more effective and more positive for students if they encourage investigation and decision-making, not verification of textbook concepts.

實質教學方法重點

(一)、任務取向實驗單元:

(二)、漸層遞減式的實驗指示:

(三)、加入工作坊(workshop)單元

(四)、多人編組:

(五)、規劃小組討論單元:

實例:CPU散熱器設計

任務:**設計CPU散熱器**

初步實驗指示：了解需求

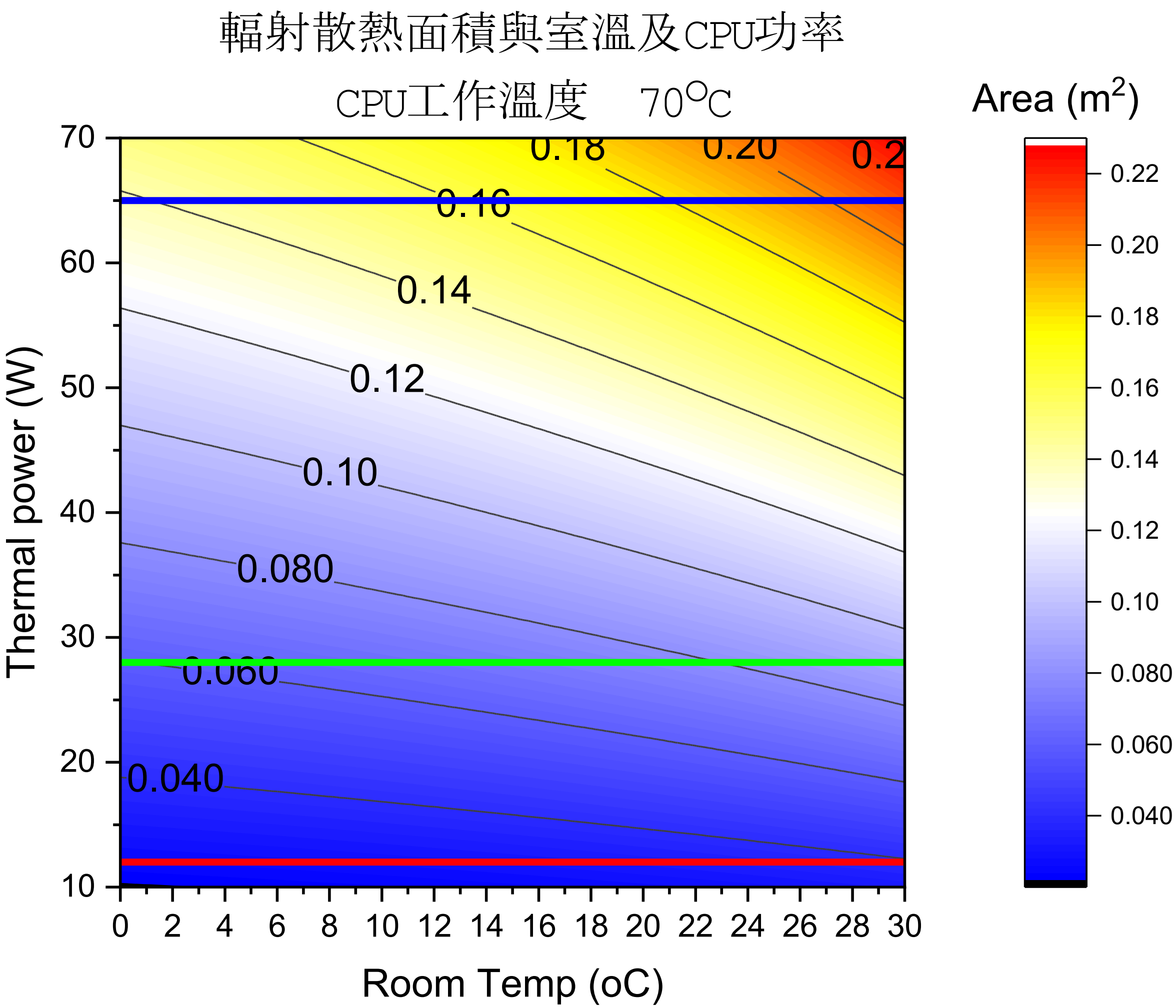
實驗指示：上網搜尋資訊

筆電: i7 11950G7 12W/28W

桌電: i7 11700F   65W

工作坊(workshop):最小散熱面積-輻射散熱

Thermal Radiation $\frac{dQ}{dt} = Ae\sigma(T^4 - T_s^4)$



散熱片:5cm x 5cm

50 cm^2

筆電: 12 W

400cm^2 8片

筆電: 28 W(超頻)

900cm^2 18片

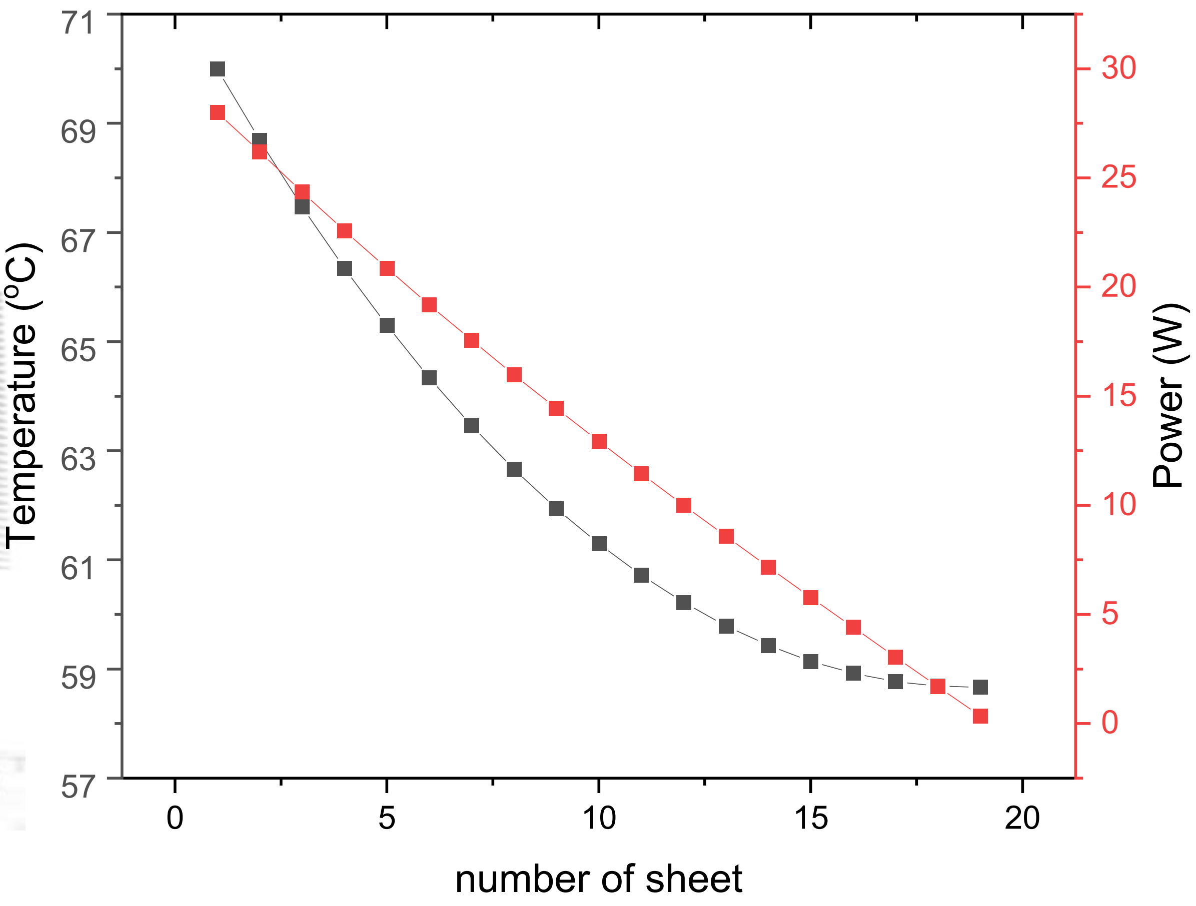
桌電: 65 W

2200cm^2 110片

工作坊(續):實況修正輻射散熱

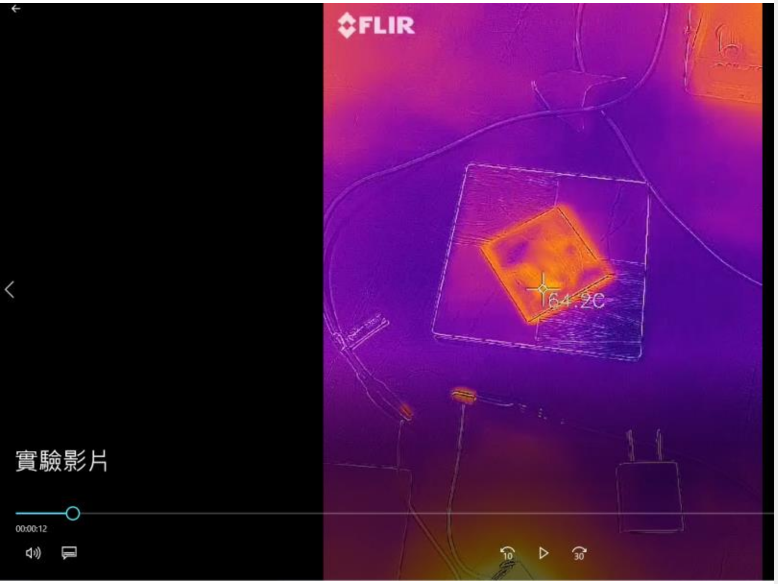
真實的世界

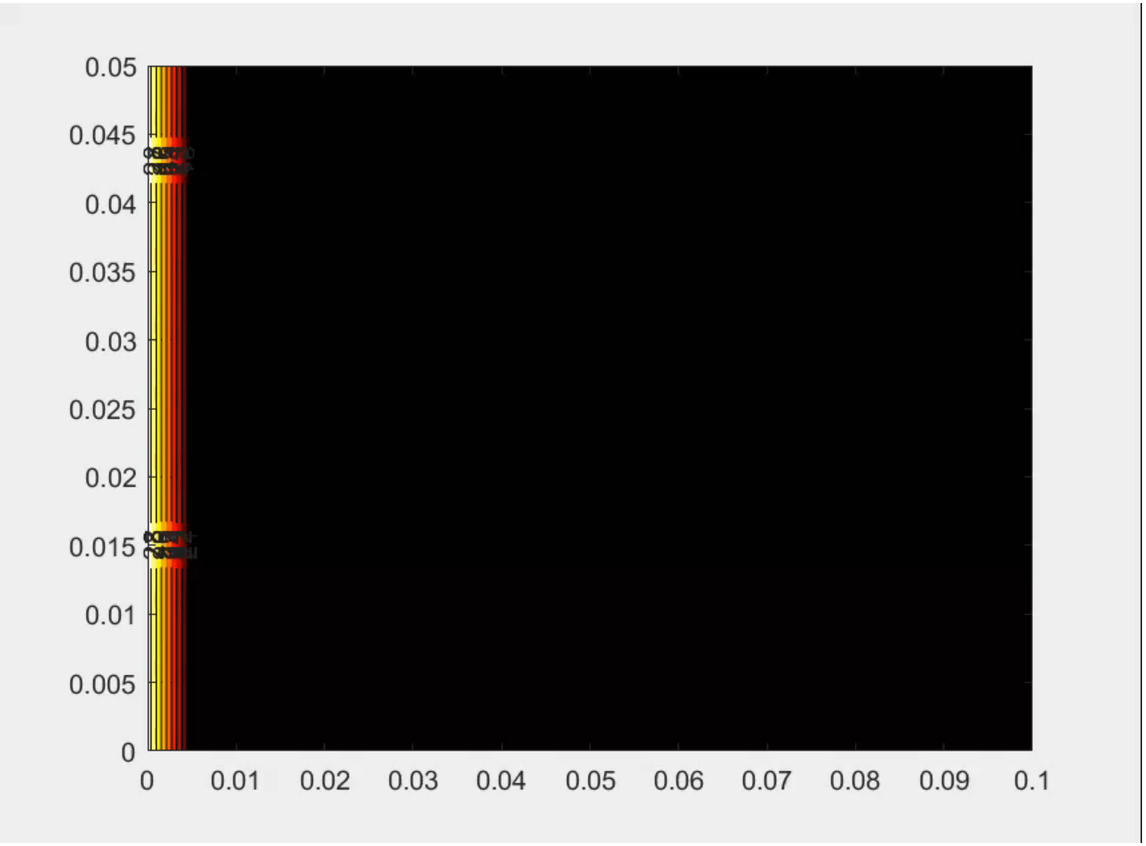
理想狀況



實驗設計與量測:最小散熱面積-輻射散熱

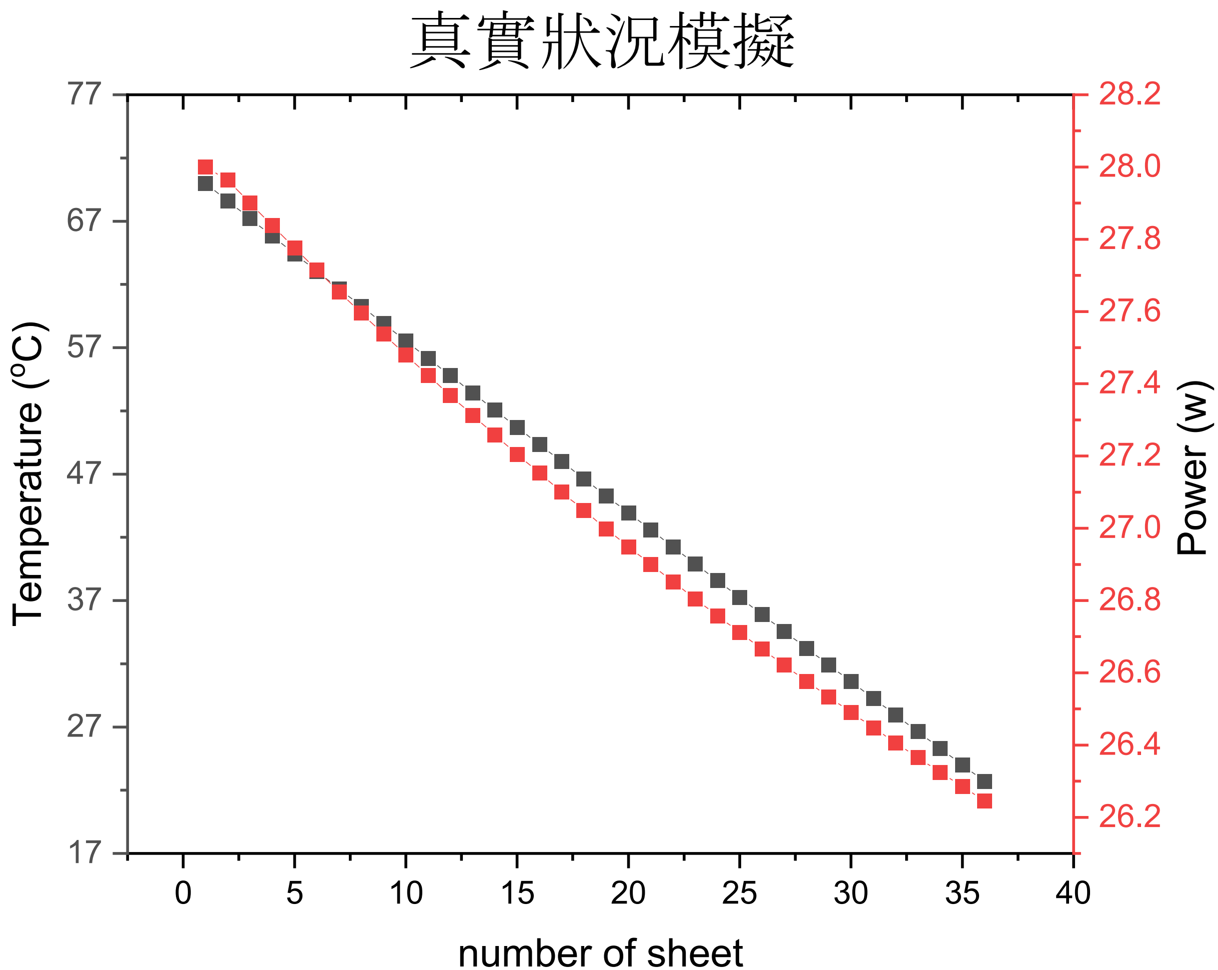
實驗設計與量測步驟:自行設計





工作坊(續):實況修正強制氣流+輻射散熱

實況? 筆電太薄!! 桌電要一百片以上!!



漸層式探索實驗教學設計案例

實驗一:波的量測—示波器操作

目標:量測兩個訊號波之振幅，相位及頻率間關係。

實驗二:RC線路之R與C之測量

目標:分辨串聯及並聯RC線路之響應，並測得R & C值。

實驗三:離子溶液之導電特性

目標:判別量測離子溶液導電特性時，等同於R、C、RC串聯或RC並聯線路?

實驗四:電極校正

目標:校正電極並量測標準離子濃度

實驗五:量測離子導電率

目標:如何決定離子導電率

需要評量工具以增進與評估學習成效

總結式(summative)與形成式(formative)評量

探索式實驗教學著重過程中的應變，運用傳統評量方式評量最終總合學習成果，僅以後者評估會有所偏差。

評量指標(Rubrics)為形成式評量是否能提升探索式實驗學習成效

學習成效評量– 評量指標(Rubrics)

參考 Rutgers University Physics and Astronomy Education Research group

https://sites.google.com/site/scientificabilities/rubrics

RUBRIC C: Ability to design & conduct an experiment to *test* an idea/hypothesis/explanation or mathematical relation					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
C1	**Is able to identify the hypothesis to be tested**	No mention is made of a hypothesis.	An attempt is made to identify the hypothesis to be tested but is described in a confusing manner.	The hypothesis to be tested is described but there are minor omissions or vague details.	The hypothesis is clearly stated.
C2	**Is able to design a reliable experiment that tests the hypothesis**	The experiment does not test the hypothesis.	The experiment tests the hypothesis, but due to the nature of the design it is likely the data will lead to an incorrect judgment.	The experiment tests the hypothesis, but due to the nature of the design there is a moderate chance the data will lead to an inconclusive judgment.	The experiment tests the hypothesis and has a high likelihood of producing data that will lead to a conclusive judgment.
C4	**Is able to make a reasonable prediction based on a hypothesis**	No prediction is made. The experiment is not treated as a testing experiment.	A prediction is made but it is identical to the hypothesis, OR Prediction is made based on a source unrelated to hypothesis being tested, or is completely inconsistent with hypothesis being tested, OR Prediction is unrelated to the context of the designed experiment.	Prediction follows from hypothesis but is flawed because * relevant experimental assumptions are not considered and/or * prediction is incomplete or somewhat inconsistent with hypothesis and/or * prediction is somewhat inconsistent with the experiment.	A prediction is made that * follows from hypothesis, * is distinct from the hypothesis, * accurately describes the expected outcome of the designed experiment, * incorporates relevant assumptions if needed.
C5	**Is able to identify the assumptions made in making the prediction**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but the assumptions are irrelevant or are confused with the hypothesis.	Relevant assumptions are identified but are not significant for making the prediction.	Sufficient assumptions are correctly identified, and are significant for the prediction that is made.
C6	**Is able to determine specifically the way in which assumptions might affect the prediction**	No attempt is made to determine the effects of assumptions.	The effects of assumptions are mentioned but are described vaguely.	The effects of assumptions are determined, but no attempt is made to validate them.	The effects of the assumptions are determined and the assumptions are validated.
C7	**Is able to decide whether the prediction and the outcome agree/disagree**	No mention of whether the prediction and outcome agree/disagree.	A decision about the agreement/disagreement is made but is not consistent with the outcome of the experiment.	A reasonable decision about the agreement/disagreement is made but experimental uncertainty is not taken into account.	A reasonable decision about the agreement/disagreement is made and experimental uncertainty is taken into account.
C8	**Is able to make a reasonable judgment about the hypothesis**	No judgment is made about the hypothesis.	A judgment is made but is not consistent with the outcome of the experiment.	A judgment is made, is consistent with the outcome of the experiment, but assumptions are not taken into account.	A judgment is made, consistent with the experimental outcome, and assumptions are taken into account.

離子濃度量測實驗評量指標示範

具有設計與執行觀察性實驗能力之評量

科學能力	缺乏	不足	待改善	充裕
指出溶液導電所需探討現象	完全未提及任何現象	描述現象但未能判定相關性	現象描述模糊不完整	現象描述清晰且緣由明確
設計具體可信實驗探索現象	實驗設計與現象不相關	實驗設計未能產出有用結果	實驗設計缺部分重要線索	實驗可測得相關且關鍵數據
確認量測物理量及主被動性	量測物理量與現象無關	僅部分量測參數為相關	相關物理量但未辨自變因變	相關物理量且能辨自變因變
清楚可用電極特性及校正法	無敘述	敘述量測項目但無實質方法	具量測項目但方法模糊不全	量測項目完整方法敘述明確
清晰描述直接量測數據與數	無敘述	敘述不全或標示不明或數據	難以理解結果呈現客觀結果	明確以文字及圖表描述結果

Rubrics設計– 科學能力訓練項目

指出溶液導電所需探討現象

確認量測物理量及主被動性

清楚可用電極特性及校正法

清晰描述直接量測數據與數據合理性

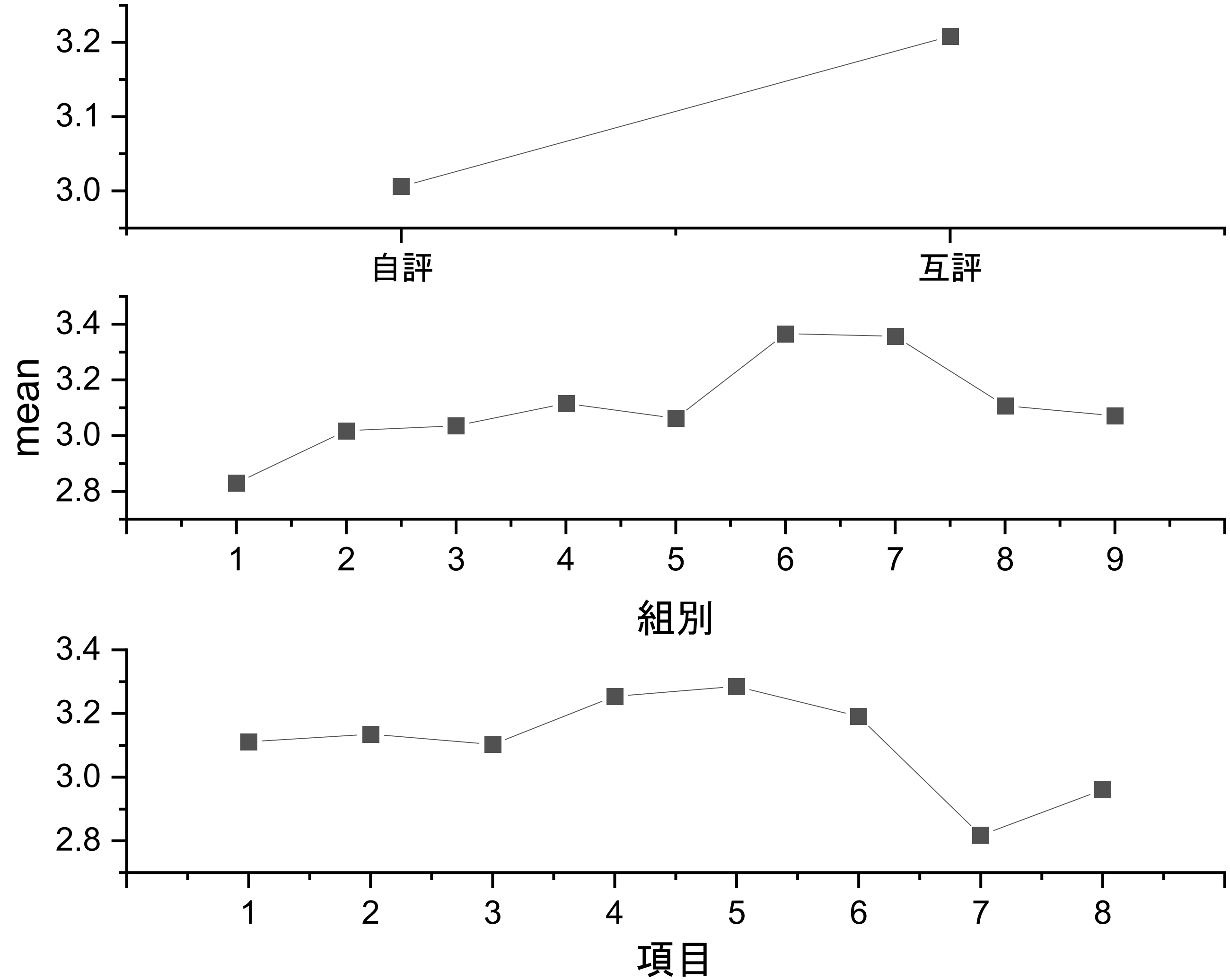
指出實驗不足因素及提出改善建議理由

指認出實驗結果趨勢與特性

能以數學或物理模型描述數據趨勢或特性

能提出機制解釋數據特性

評量指標量化分析 Three way ANAVO



自評較嚴

組別差異

能力有別

At the 0.05 level, the population means of 評別 are **significantly** different.
At the 0.05 level, the population means of 組別 are **significantly** different.
At the 0.05 level, the population means of 項目 are **significantly** different.
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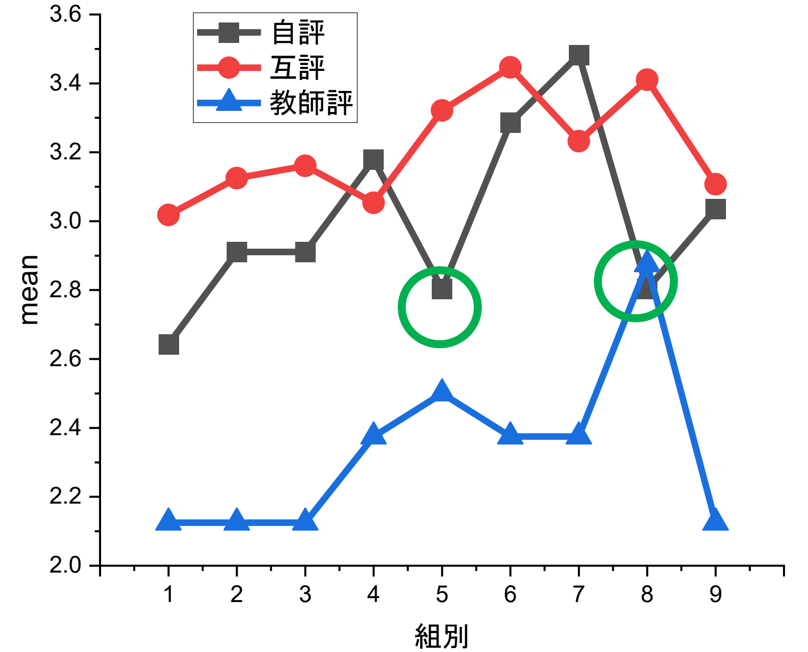
實驗評量指標分析II

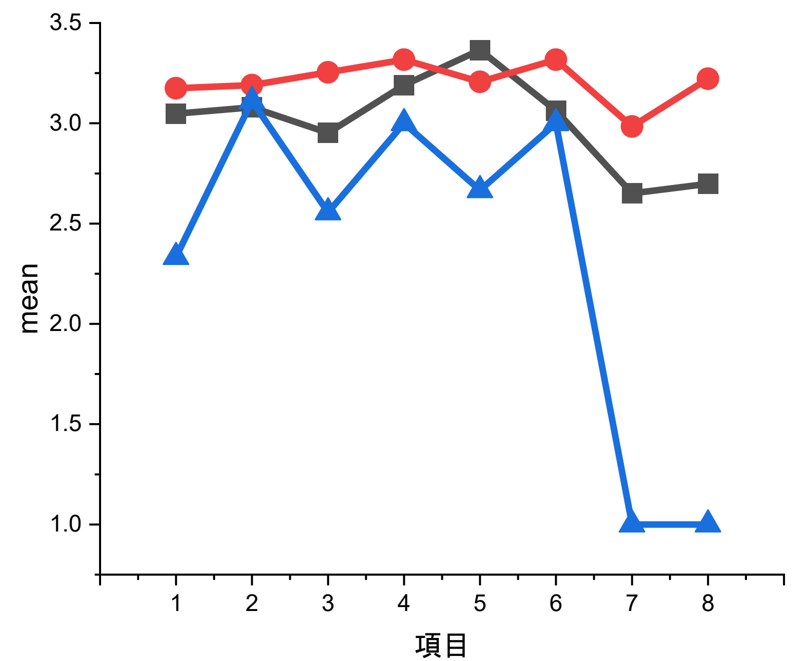
學生心態可區分為安於現狀與檢討學習兩類型

多數學生以能力所及為高標準則，缺自我改進之念

自評偏低的為用心思索踏實面對問題的學生族群

技巧性與應用性的能力較易吸收，邏輯推理能力成長較緩慢



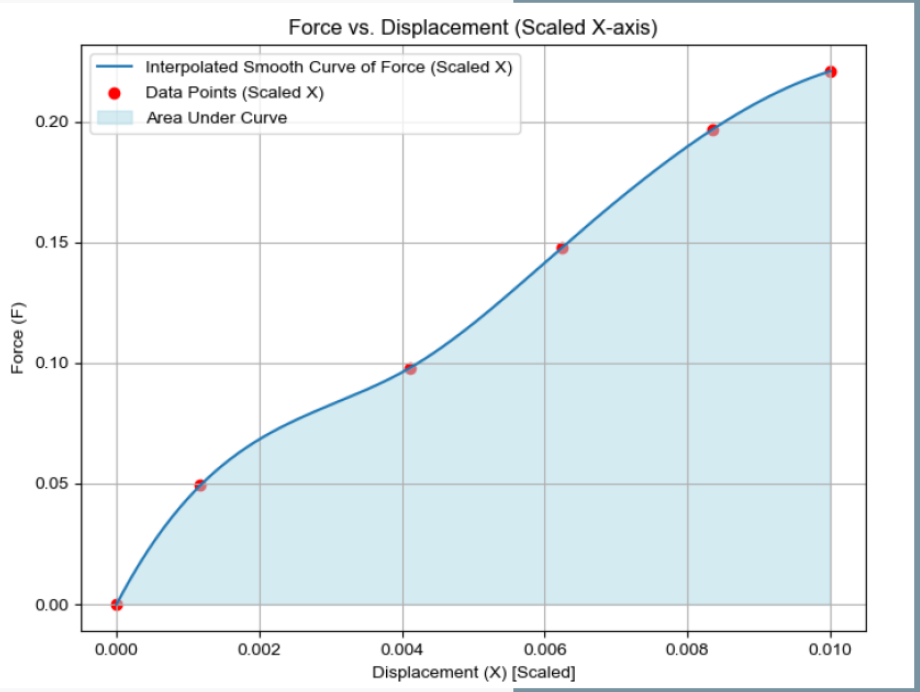


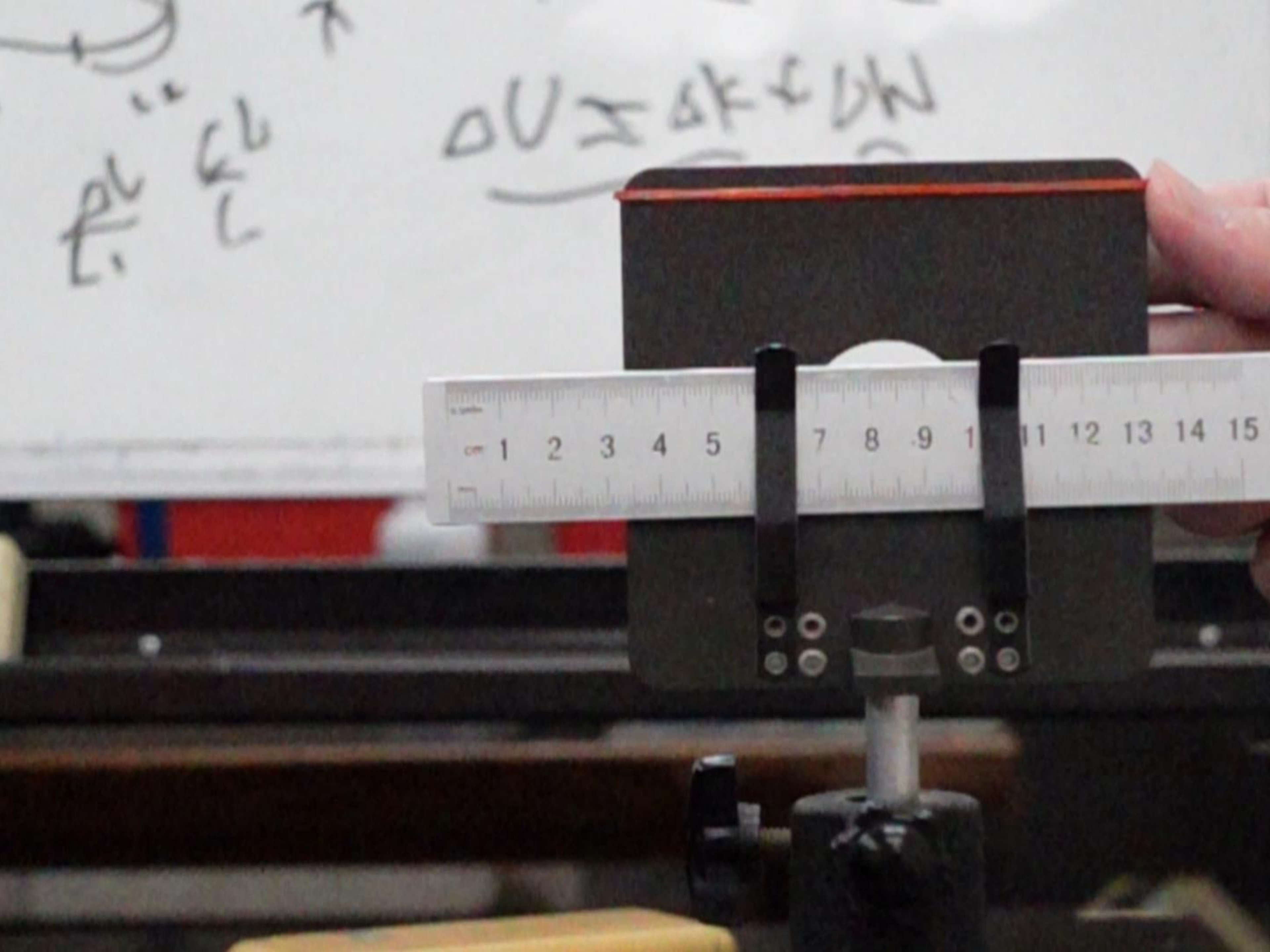
- 開放性主題探索(IYPT題目)訓練學生
- 執行分:學習階段與自主階段。
- 具體說明:以前六週老師主導探索學習為例說明做法，主題為
  - **為何橡皮筋均勻與非均勻拉伸，造成不同彈射距離**
- **第一周**首先設計自製設備，實驗確認現象真偽與差距數值大小
- **第二周**以最直接的思考，檢驗是否為起始彈性位能差異。
- 實驗結果比對:多次實驗趨勢是對的，但要求學生確認數值，多次實驗後發現差數值不符。

控制應變相同時楊氏係數不變
故可得應力繼而求得其彈力對位移量之比計算
曲線下積分即為總位能

$$Y = \frac{\sigma}{\varepsilon}$$

均勻拉伸:總位能 0.0198J
非均勻拉伸:總位能 0.0308J

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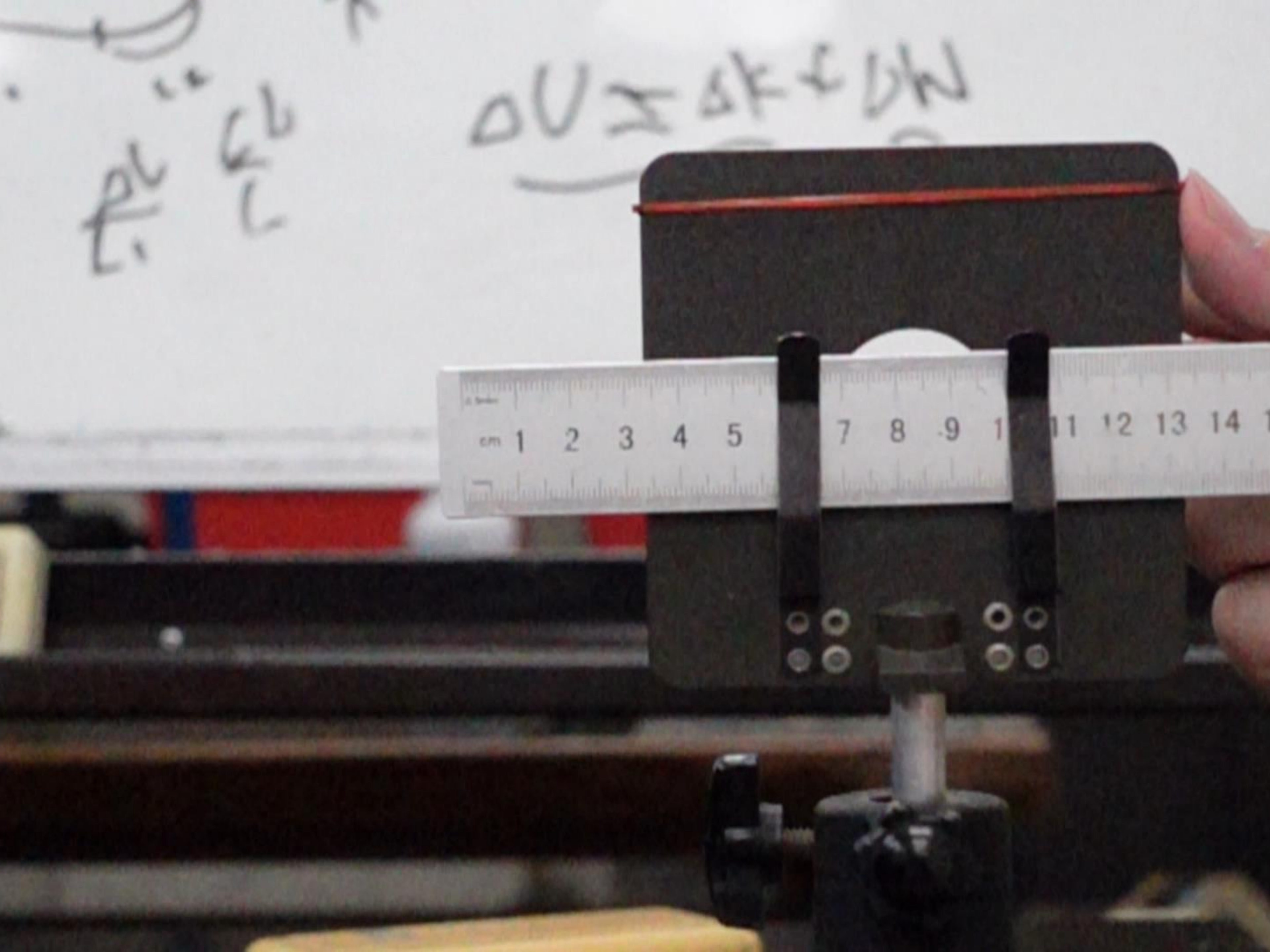

cm 1 2 3 4 5 7 8 9 11 12 13 14

Data & analysis: Conversion Efficiency

Linear Kinetic Energy

均勻拉伸		非均勻拉伸	
移動動能/總位能	21.31±1.06%	移動動能/總位能	21.25±1.08%
轉動動能/總位能	0.97±0.036%	轉動動能/總位能	2.16±0.091%

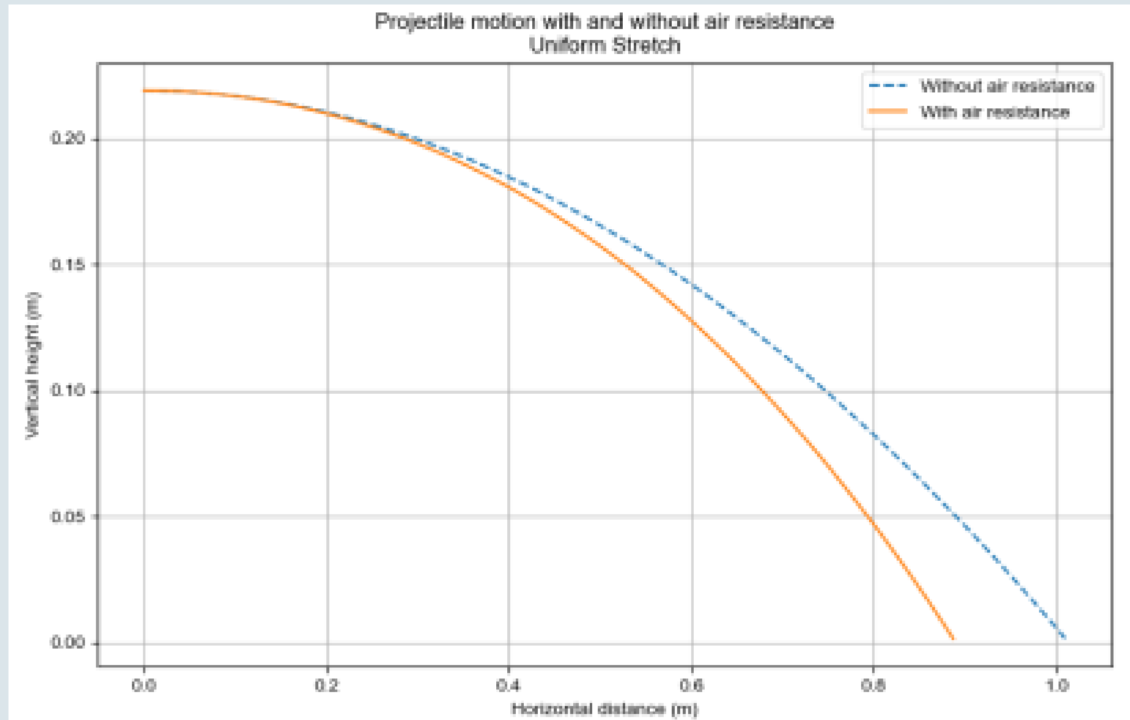
21.25/21.31=0.0997，幾乎等同。

說明拉伸方式不同並不會改變線性動能轉換效率，其轉換效率固定約為21%。

Data & Analysis: Air Resistance

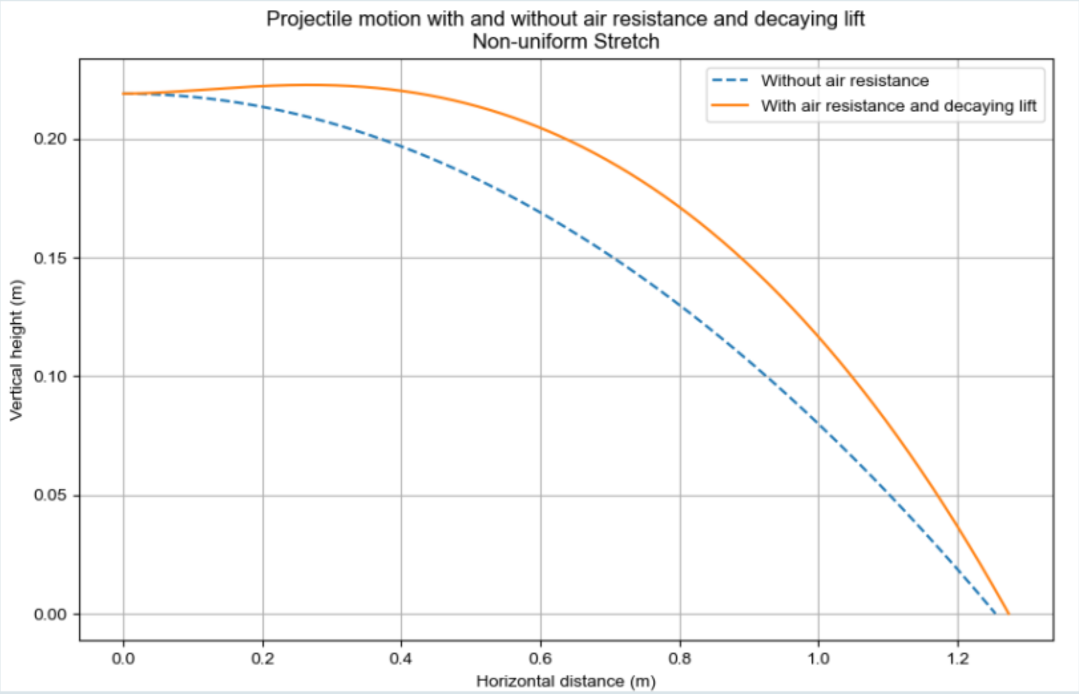
以初速度加上空阻之影響，發現空阻對時間尺度影響不大，只增加6%。
造成落地時間與真實值不匹配也使最終距離有誤，推測有其他效應顯著影響其飛行時間。

```
無空氣阻力的位移: 1.01 米
有空氣阻力的位移: 0.89 米
無空氣阻力的落地时间: 0.211 秒
有空氣阻力的落地时间: 0.224 秒
```



Program Simulation: Bernoulli's Principle

給一隨時間衰減之升力校正其飛行時間

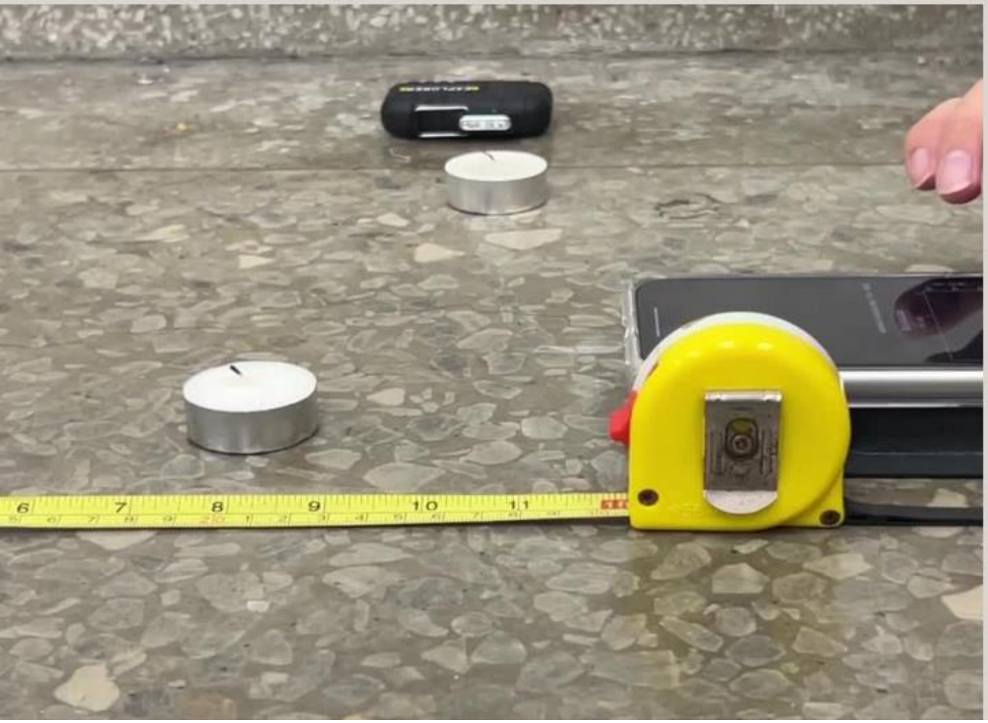



```
有空氣阻力和升力的最终落地时间: 0.281 秒
有空氣阻力和升力的最终位移: 1.274 米
無空氣阻力的最终落地时间: 0.211 秒
無空氣阻力的最终位移: 1.255 米
```

最終距離在測量距離及其誤差內
表升力之考量是有意義且吻合實驗結果

Topic : Sound v.s. Fire

原理:阻隔燃燒三要素(可燃、助燃物、足夠溫度)其一即可。



假設一:阻隔氧氣(助燃物)

利用聲音為縱波的特性，使氧氣被剝奪
震幅與音量有關，真空時間與頻率有關

假設二: 聲波帶走熱量(溫度)

聲音具有某種特性會使其可以將熱量
帶走，使燃燒的化學反應活化能不足

假設三: 共振(移走可燃物)

聲音使蠟燭受迫震盪，導致反映物與
熱供給產生相位差，等同移走可燃物

Hypothesis 1 ---- 阻隔氧氣

- 實驗結果與假設不符

- 音量不變，頻率下降：火焰擾動漸小，無法撲滅
  音量改變，頻率固定：火焰擾動明顯，滅火容易

音量不變，300Hz頻率下降或上升，火焰擾動漸小，無法撲滅

Hypothesis 2 ---- 聲波帶走熱量

- 聲波帶走的熱 > 燃燒釋放的熱
  → 反應吸收的能量 < 反應所需活化能
  → 無法燃燒，火焰熄滅

- 外接熱像儀觀測 (計算熱流失率)
  → 無法看出將要熄滅的瞬間，是否有大量熱流失

- 假說無法判斷是否成立

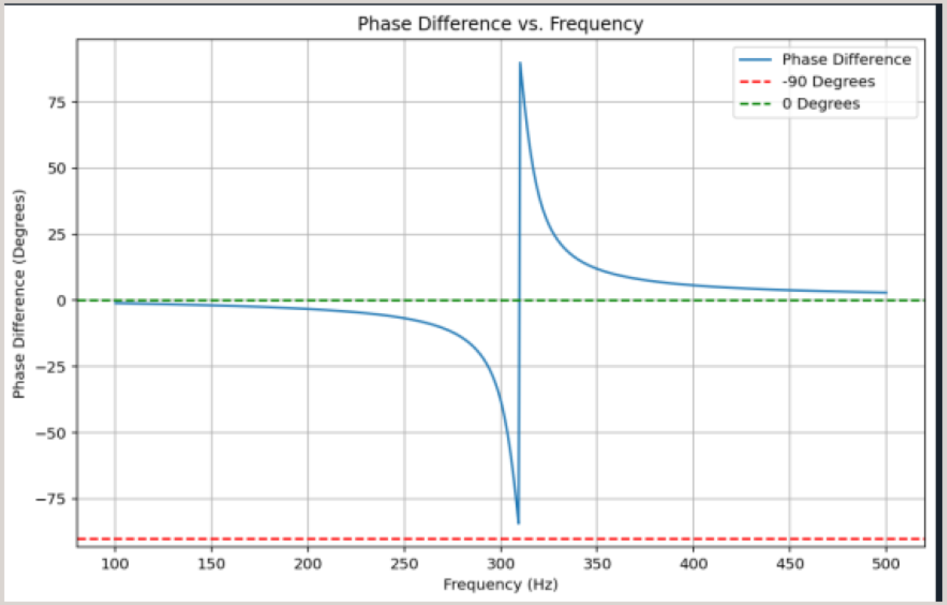
Hypothesis 3 ---- 共振

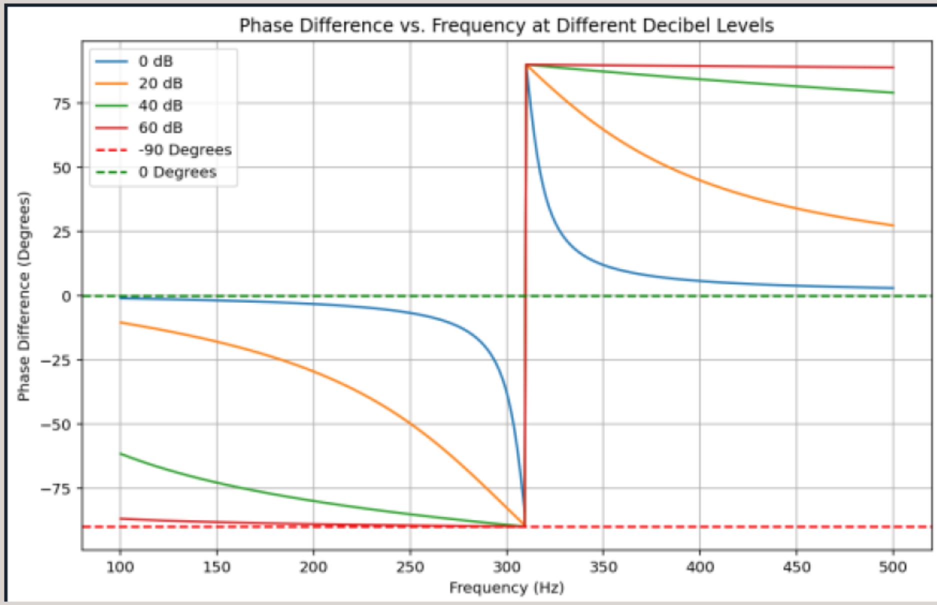
- 藉由音響傳遞出來的單頻音會導致燭芯產生某種程度的共振
- 單頻音所產生的共振導致燭芯震動的方向和氣液態蠟油的提供方向產生一個相位差
  → 燃燒中的蠟燭無法再接收到由下往上噴出的燃料

Hypothesis 3 ---- 共振

- 雷射位移傳感器
- 紅外熱成像儀
- 高幀率攝影機
- tracker & matlab
- 高速攝影機無法精確觀測蠟燭燭芯震動

學生電腦模擬探討阻尼項對共振區間相位差的影像範圍





結論: 可能改變了甚麼

以下論述皆為基於學生回答敘述性問卷之回答內容主動敘述(修課人數58人，回收有效問卷52份

學生學習方式認知，接受非菜單式的探索學習模式

40/52份問卷回答提及認同專題導向式教學，其中33人主張應改為自主探索式教學，7人則希望部分授課內容能加入探索學習單元。

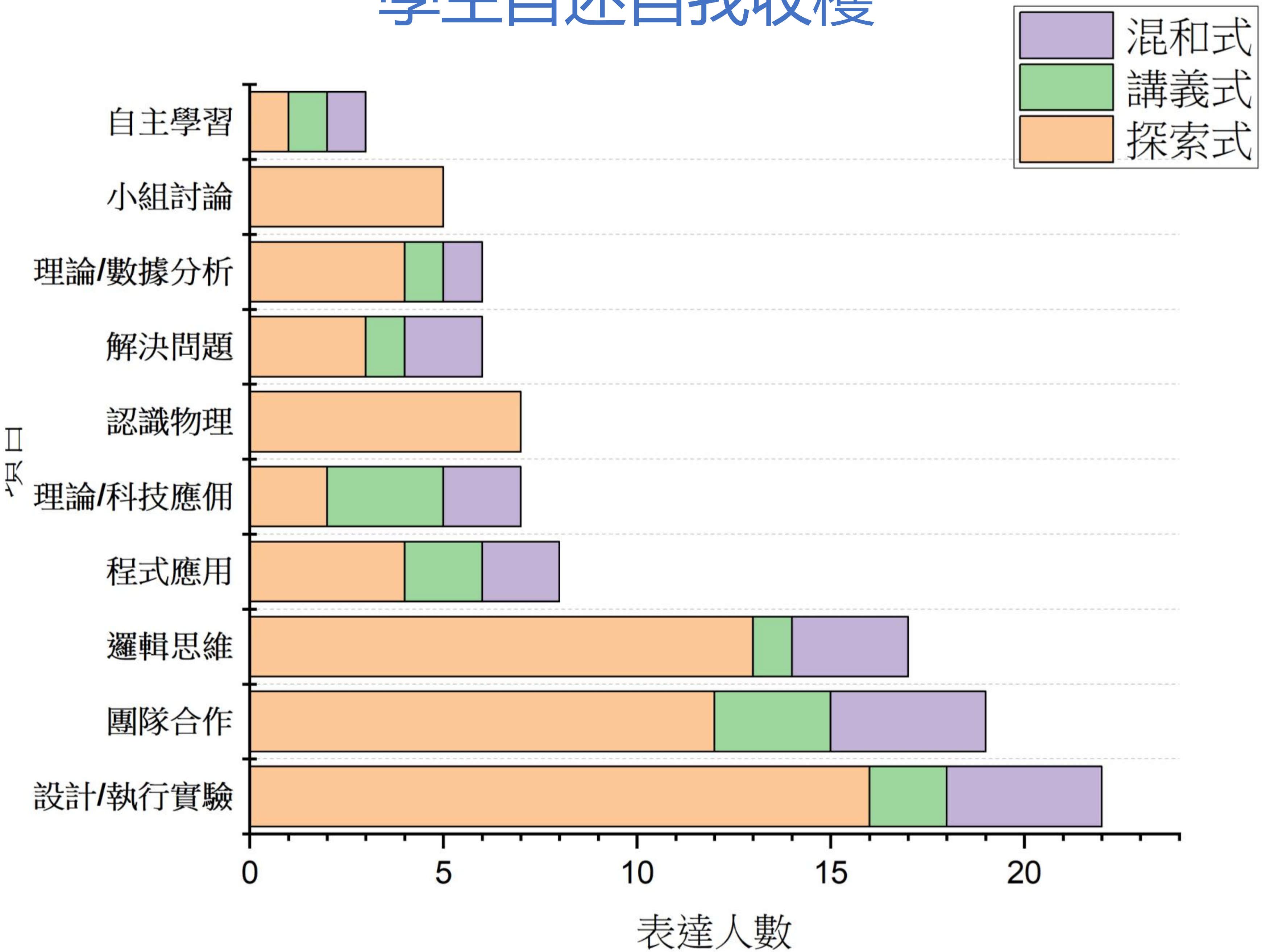
了解與體會和老師互動討論之重要性，及其對學習成效之助益

24/52學生提出保留此教學時段，認為這施他們收穫最多的學習時段。

促使部分學生體會自主學習的重要性，及於學習過程能獲得之益處

19/52學生強調探索過程賦予自己主動學習的動力，成效大於被動學習

學生自述自我收穫



混和式
講義式
探索式
自主學習
小組討論
理論/數據分析
解決問題
認識物理
理論/科技應用
程式應用
邏輯思維
團隊合作
設計/執行實驗
0
5
10
15
20
表達人數

感謝聆聽

Data & analysis: Linear Kinetic Energy

Uniformly Stretched

均勻拉伸

距離 1.07±0.023m

時間 0.281±0.0076s

初速度 4.81±0.13m/s

做一簡單假設：
移動動能之轉換效率固定

$$\frac{U_{均}}{U_{非均}} = \frac{K_{T均}}{K_{T非均}}$$

國外研究

問題出在哪?

關鍵是實驗手冊

現行實驗課程皆備有完整指示的實驗手冊，諷刺的是這些完善的引導資訊，造就了學生可以甚麼都不知道， 也可以完成實驗。

學生還需要做甚麼?

N. G. Holmes, J. Olsen, J.L. Thomas and C.E. Wieman, *Phys. Rev. Phys. Educ. Res.* 13, 010129 (2017)