Promoting STEM education at the upper primary and secondary levels by using self-directed learning as a strategy

利用自主學習作為高小及中學階段實踐STEM教育的策略

Organizer: The Education University of Hong Kong

常識科 (2017)

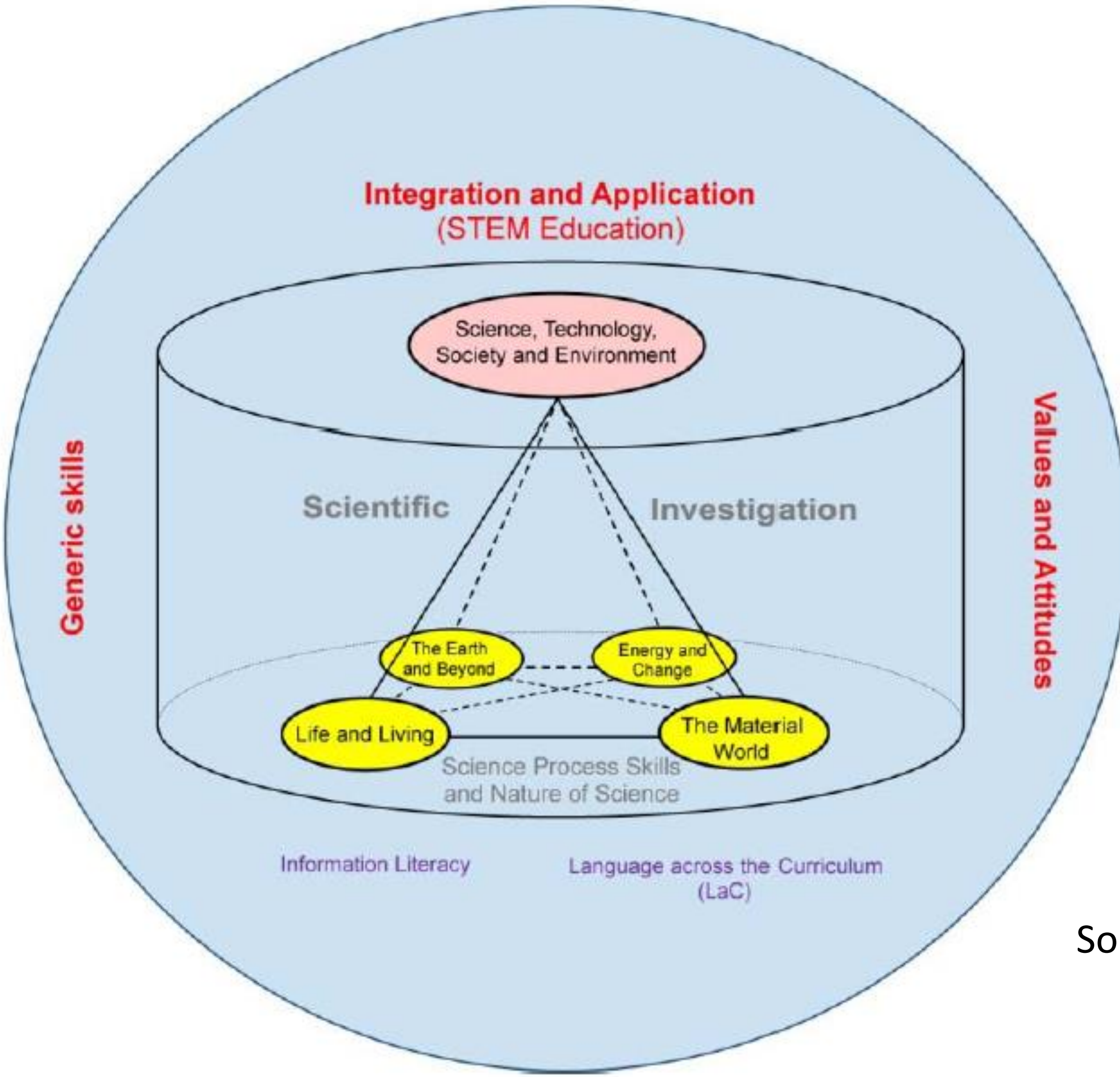
1.4 課程發展重點—聚焦・深化・持續

1.4.1 發展 STEM 教育

常識科的課程會持續優化，以加強學生綜合學習和應用知識與技能的能力。學校可以透過優化課程規劃，增強常識科課程中與科學、科技範疇相關核心學習元素的連繫，並選擇能配合學生學習能力的數學概念和技能，以增潤有關應用科學與科技來解決日常生活問題的學與教活動，為學生提供手腦並用的學習機會，幫助他們發揮創意，不斷創新。相關例子見第三章「課程規劃、管理與領導」、第四章「學與教」及第五章「評估」。

(Source: HKCDC)

Curriculum Frameworks of Science, Technology and Mathematics Education KLAs



Source: HKCDC

The Major Renewed Emphases at the Junior Secondary Level and Beyond (Source: HKCDC)

Major renewed emphases (MRE) are brought on board to better respond to the changing needs of society as reflected in the updated seven learning goals. With reference to their own contexts and stages of development on various curriculum areas, schools should plan the whole-school curriculum with due consideration of the SECG to strategically integrate the following MRE for coherent and systematic implementation in their school development plans alongside the school priorities for the next three to six years:

- strengthening **values education** (including moral and civic education and Basic Law education)
- reinforcing the learning of **Chinese history and Chinese culture**
- extending "Reading to Learn" to "**Language across the Curriculum**"
- promoting **STEM education** and **ITE**
- fostering an **entrepreneurial spirit**
- diversifying **life-wide learning** experiences (including those for Vocational and Professional Education and Training)
- stepping up **gifted education**
- enhancing the **teaching of Chinese as a second language**.

To assist schools in implementing the MRE at the whole-school, cross-curricular, KLA and subject levels, related professional development programmes will be arranged.

Today is not the end of our input, but the beginning…….

Needs analysis
(from participating schools)

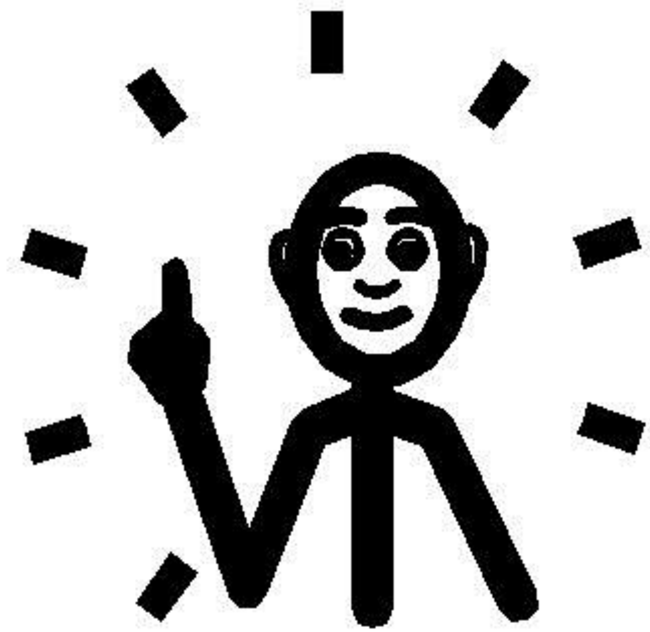
- Principles of STEM education and SDL
- School-based STEM curriculum development
- Synergizing/integrating STEM activities with subject learning (e.g., scientific inquiry)
- STEM teaching team building
- Instructional/Activity design (STEM-SDL)
- Motivating students to engage in SDL
- Developing assessment tools for STEM and SDL
- STEM for mixed ability
- Integrating technology into STEM activities
- Development e-learning platform for STEM-SDL

Pedagogical reasoning cycle (Lee Shulman, 1987)

5-stage cycle:

- Comprehension
- Transformation
- Instruction
- Evaluation
- Reflection

1. Comprehension



What is STEM ?

What is STEM education ?

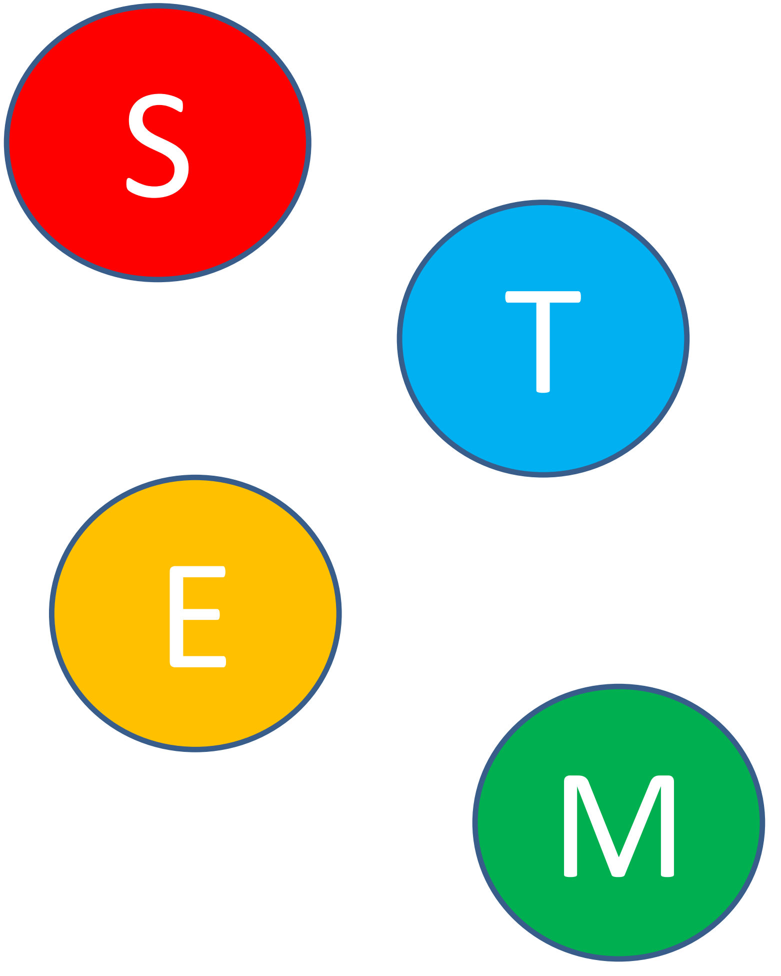
Tsui also said students do not get proper guidance in science, technology, engineering and mathematics, or STEM, and that resources are being wasted.

As an example, Tsui said that instead of students constructing a parachute that will safely deliver an egg to the ground, they only focused on how to protect the egg, rather than how to design and construct the parachute.

Source: The Standard

STEM 與現行數理科目有何不同 ？

- Science (科學)
- Technology (科技)
- Engineering (工程)
- Mathematics (數學)



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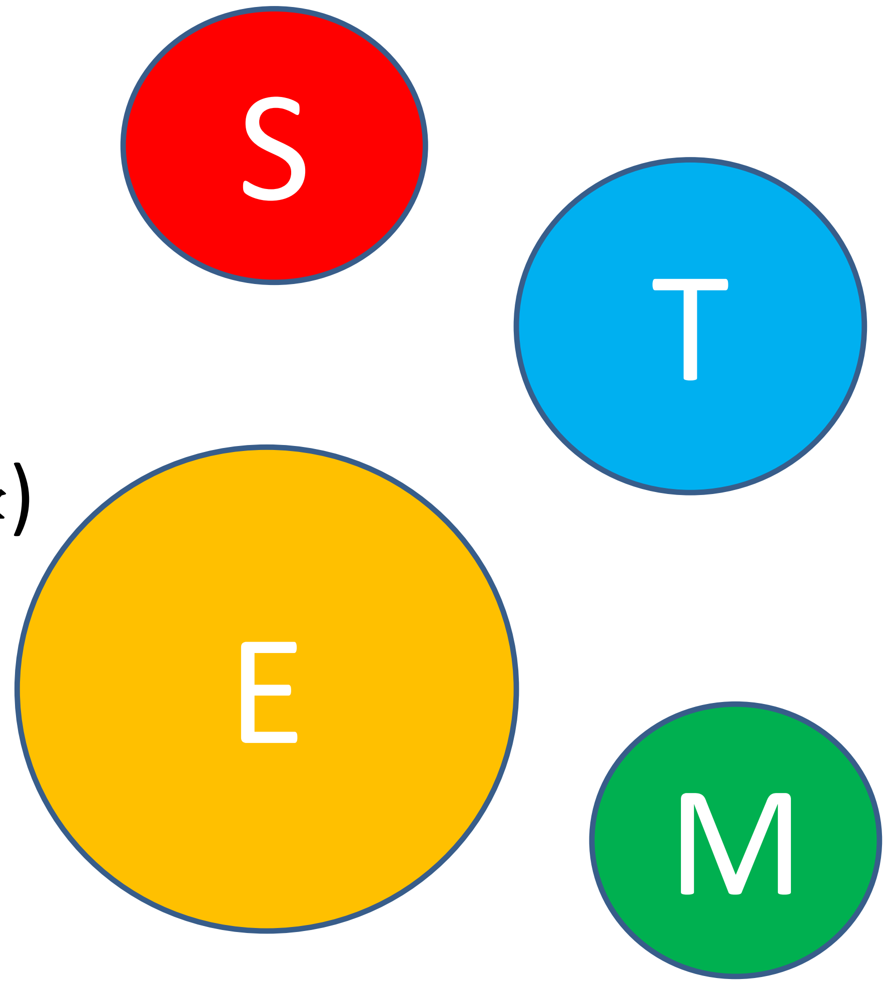

Engineering – What is it?

Comparing science and engineering

	Science	Engineering
Problem	Answering questions	Solving problems
Experiment/Test	Testing hypotheses	Testing solutions
Evidence	To judge validity of hypotheses	To judge effectiveness of solutions
Criteria	The best explanation nearest to reality	As desired by man
Conclusion/ Decision	Choosing the most valid hypothesis that fits with the evidence	Combined strengths of solutions; consider trade-offs


サーモンハラス
さば文化干し定食
790
890
とろさば塩焼き定食
さんま塩焼き定食
しまほっけ半身定食
つぼ鯛定食


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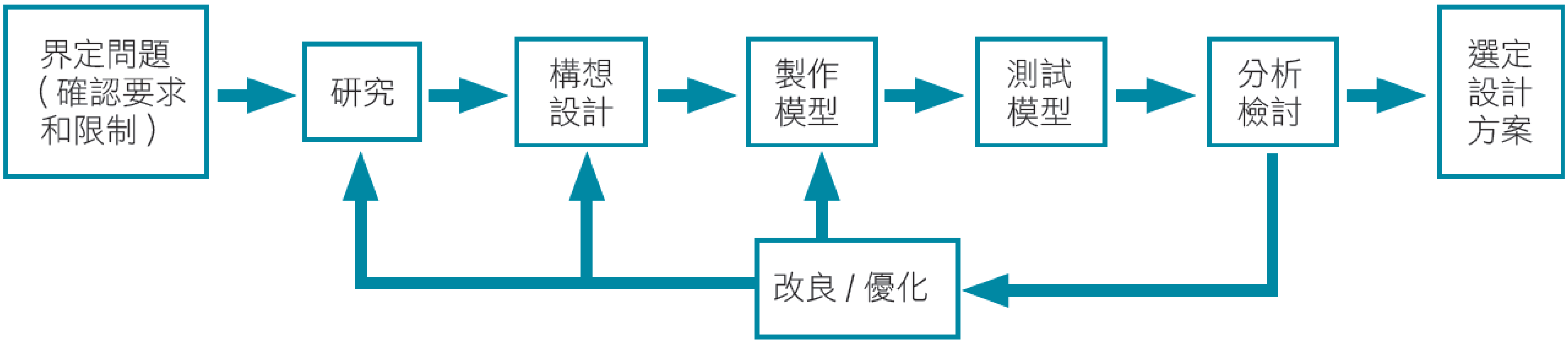
Engineering design工程設計



圖一： 工程設計流程圖

STEM 與數理科目有何不同 ？

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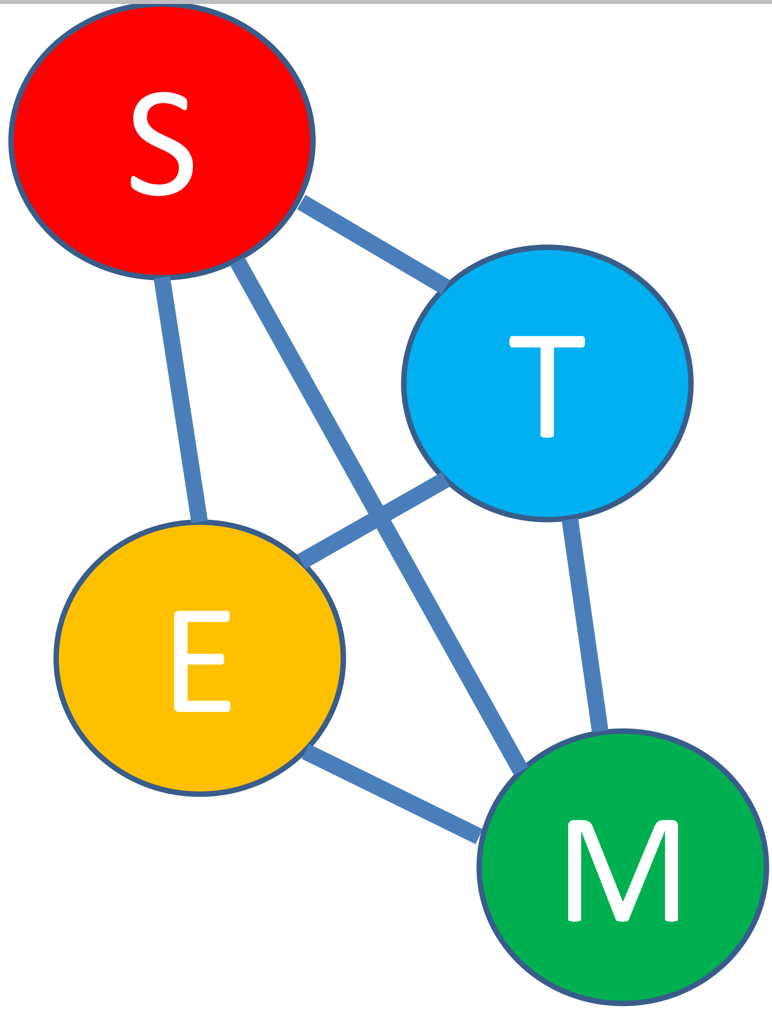

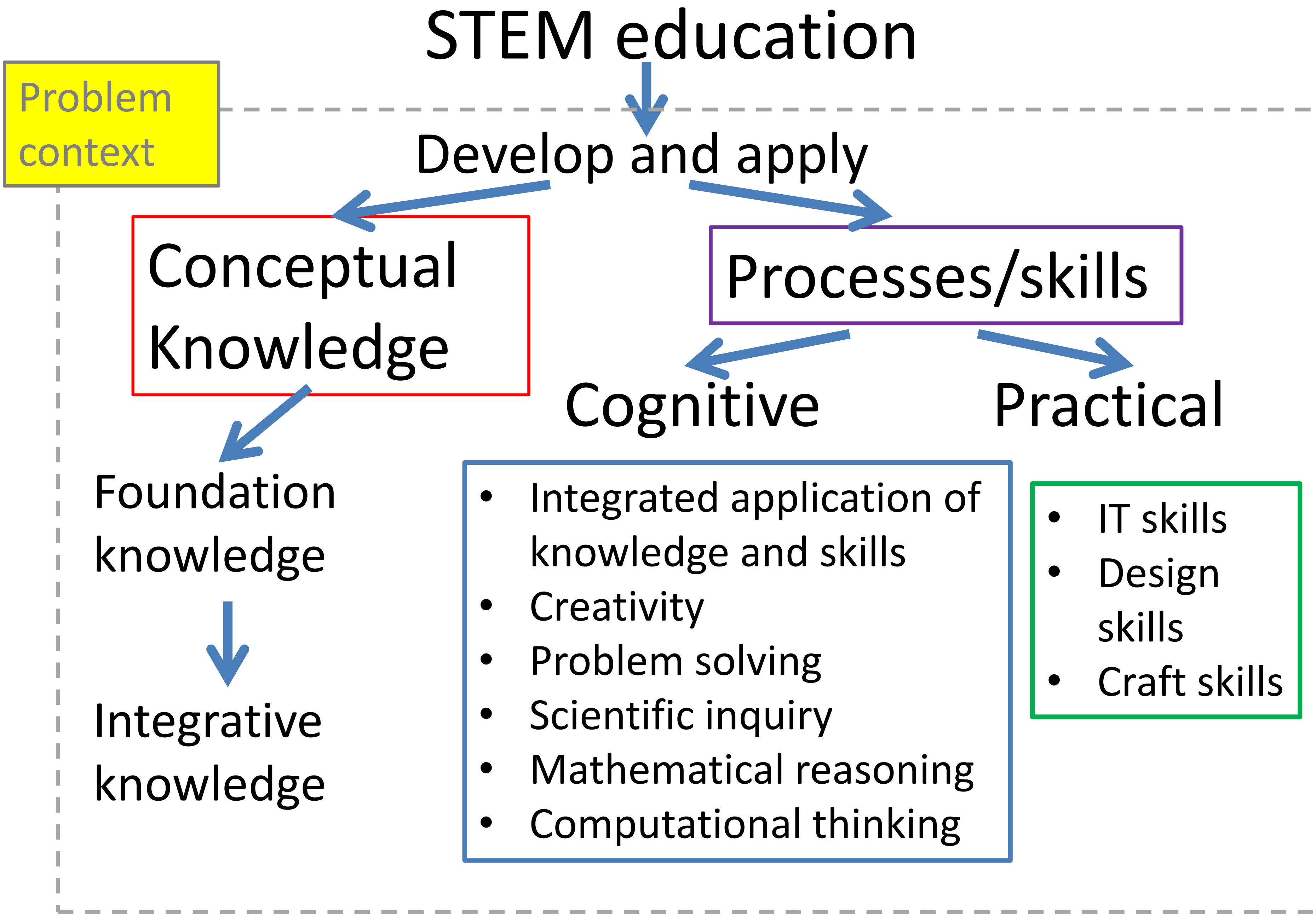

STEM education
Problem context
Develop and apply
Conceptual Knowledge
Processes/skills
Cognitive
Practical
Foundation knowledge
Integrative knowledge
• Integrated application of knowledge and skills
• Creativity
• Problem solving
• Scientific inquiry
• Mathematical reasoning
• Computational thinking
• IT skills
• Design skills
• Craft skills


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SHY HERO STOPS RUNAWAY CRASH COACH
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ALLING UNI TANDARDS BLASTED
EX-HKU HEAD FIRES SHOTS AT EDUCATION BUREAU
Former HKU vice chancellor Tsui Lap-chee. XINHUA, SING TAO

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Measuring average fall rate of the parachute (M)

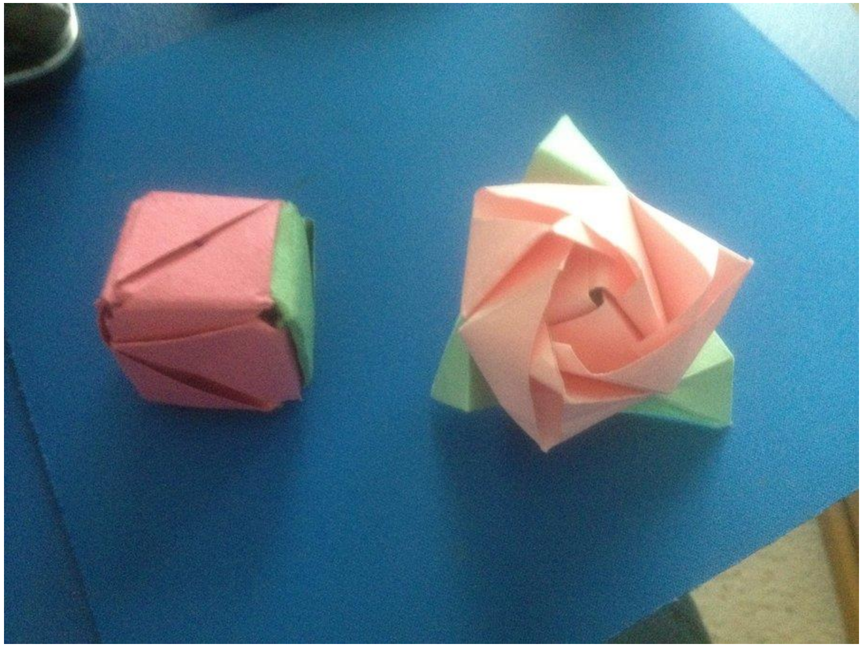
Calculating momentum and impact as it touches ground (S)

Inquiry into factors affecting fall rate of parachute (e.g., shape, size, and curvature)(S)

Constructing a parachute that can maximize the fall rate without damaging the egg (S,M,T)

(Source: The Standard)

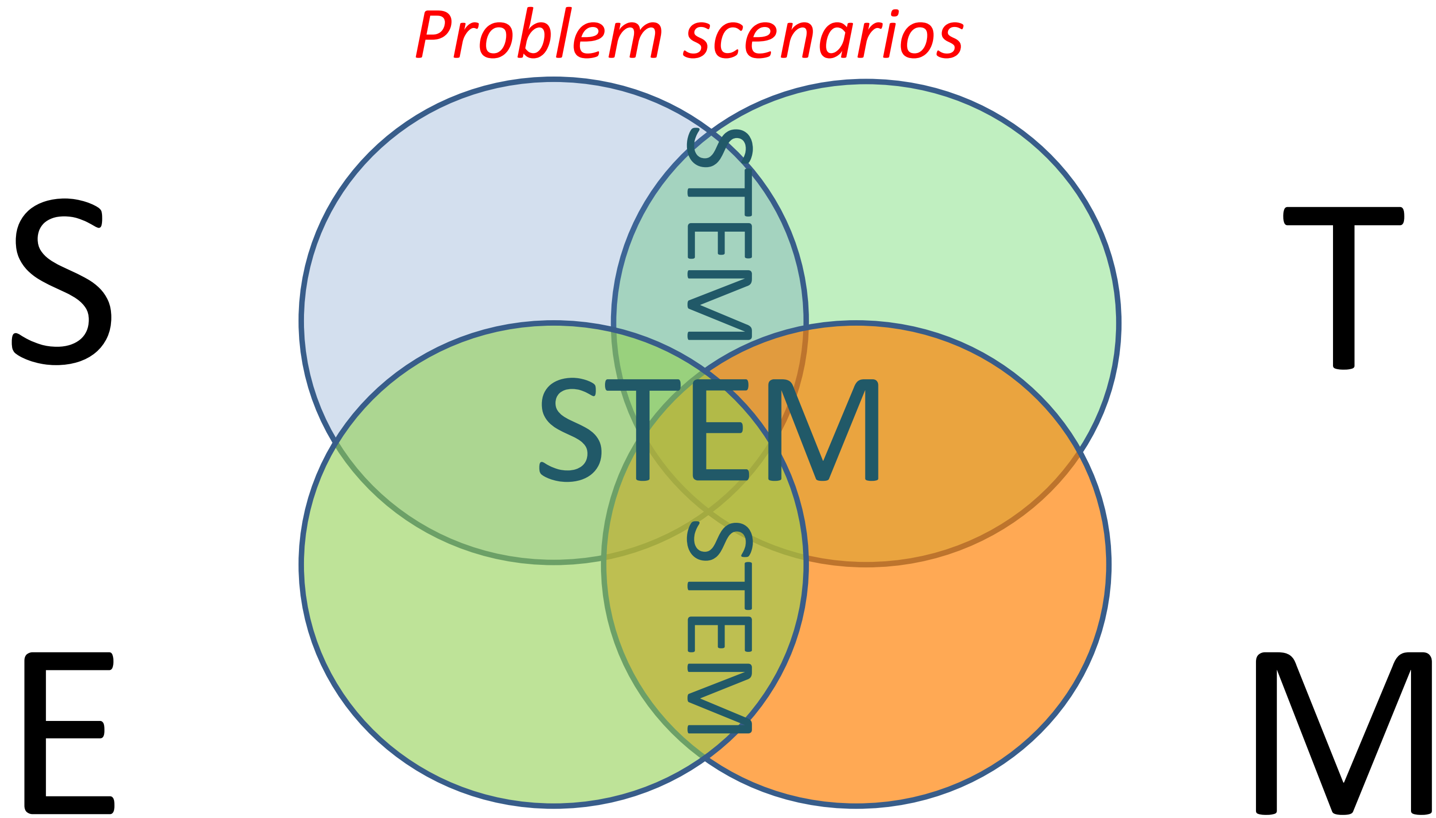
2. Transformation



Keys to transformation

1. **Integrated learning**
2. **Learning through application/problem solving (Application-led learning)**
3. **Development of 21st Century skills**

From ‘Foundation knowledge’ to ‘knowledge integration’



US New Generation Curriculum

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. ▪ Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. (MS-ETS1-1) **Developing and Using Models** Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. ▪ Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4) **Analyzing and Interpreting Data** Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. ▪ Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3) **Engaging in Argument from Evidence** Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world. ▪ Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2)	**ETS1.A: Defining and Delimiting Engineering Problems** ▪ The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1) **ETS1.B: Developing Possible Solutions** ▪ A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) ▪ There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) ▪ Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) ▪ Models of all kinds are important for testing solutions. (MS-ETS1-4) **ETS1.C: Optimizing the Design Solution** ▪ Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3) ▪ The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4)	**Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ETS1-1) ▪ The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. (MS-ETS1-1)

Source: NGSS (Aspire, 2013)

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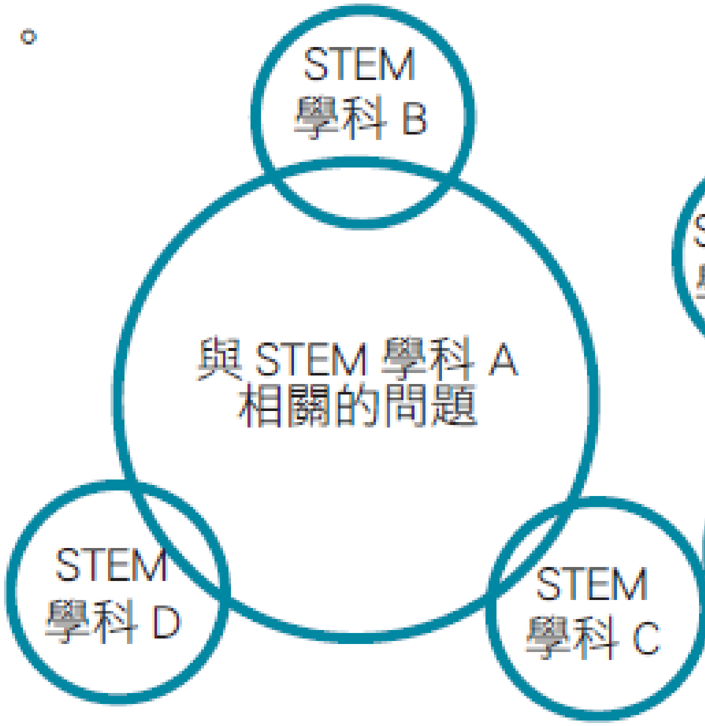
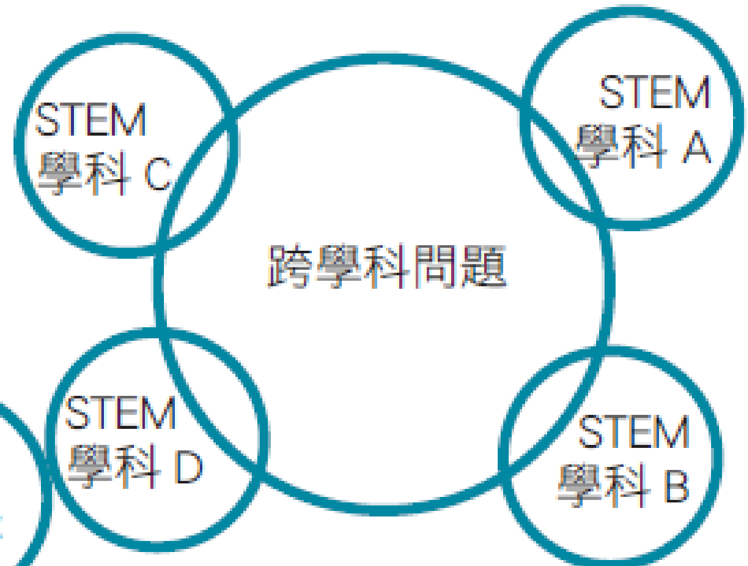
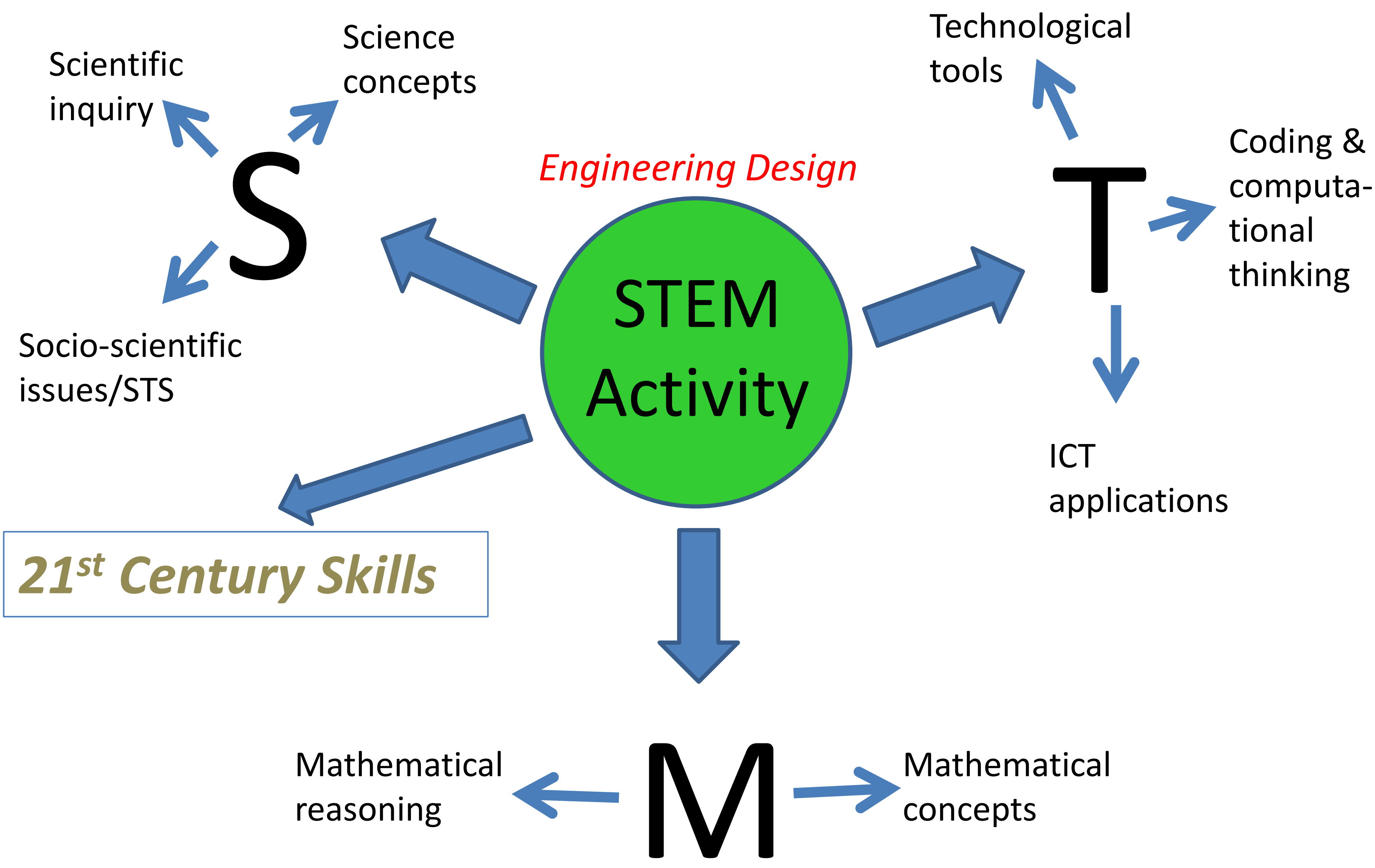


學科問題為本模式
(Disciplinary problem-based approach)



跨科問題為本模式
(Interdisciplinary problem-based approach)

Subject integration in a STEM activity



How to transform STEM principles into a classroom activity?

A Typology of STEM Activities

(**STEM 活動類型**)

表一：活動橫跨的不同學科內容

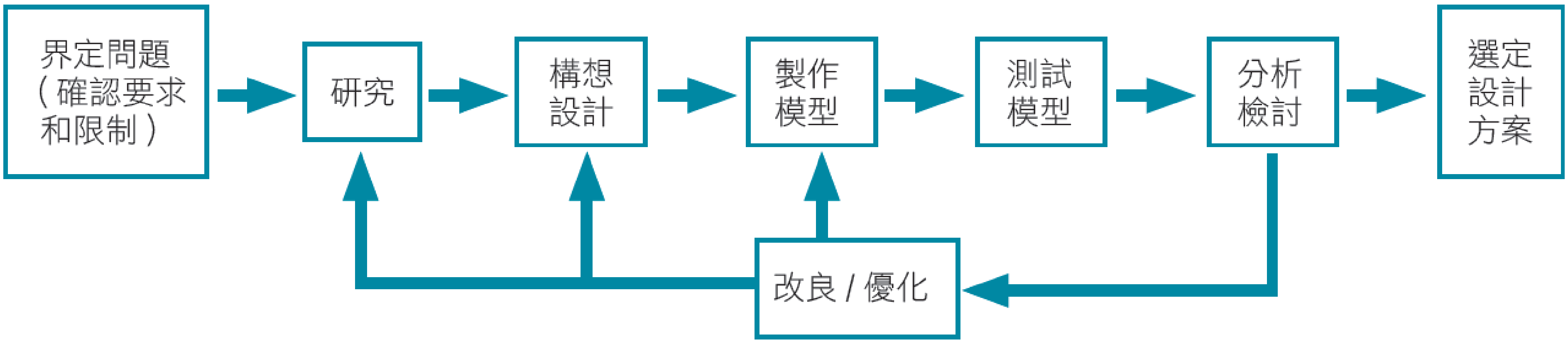
學科	學科知識及技能
科學	· 電的磁效應 · 電磁鐵的製作及應用 · 電路及電子元件 · 科學探究技能（辨別變因，公平測試，控制變因，分析結果等）
數學	· 數據分析及統計 · 數學思維
電腦	· 從網上搜集資料 · 編程 · 運算式思維 · 程式語言如 Scratch 或 c 語言，及簡易編程軟件 · 微控制器硬件 Arduino
設計與科技	· 構想機械操作的意念 · 繪畫設計圖 · 表達設計意念 · 模型製作

3. Instruction

Instruction

- Set learning outcomes
- Design activities/instructions
  - Engineering design cycle, problem-based learning, project-based learning
- Manage group work
- Facilitate self-directed learning (e.g., through e-platform)

Engineering design工程設計



圖一： 工程設計流程圖

(資料來源：李揚津等，2017)

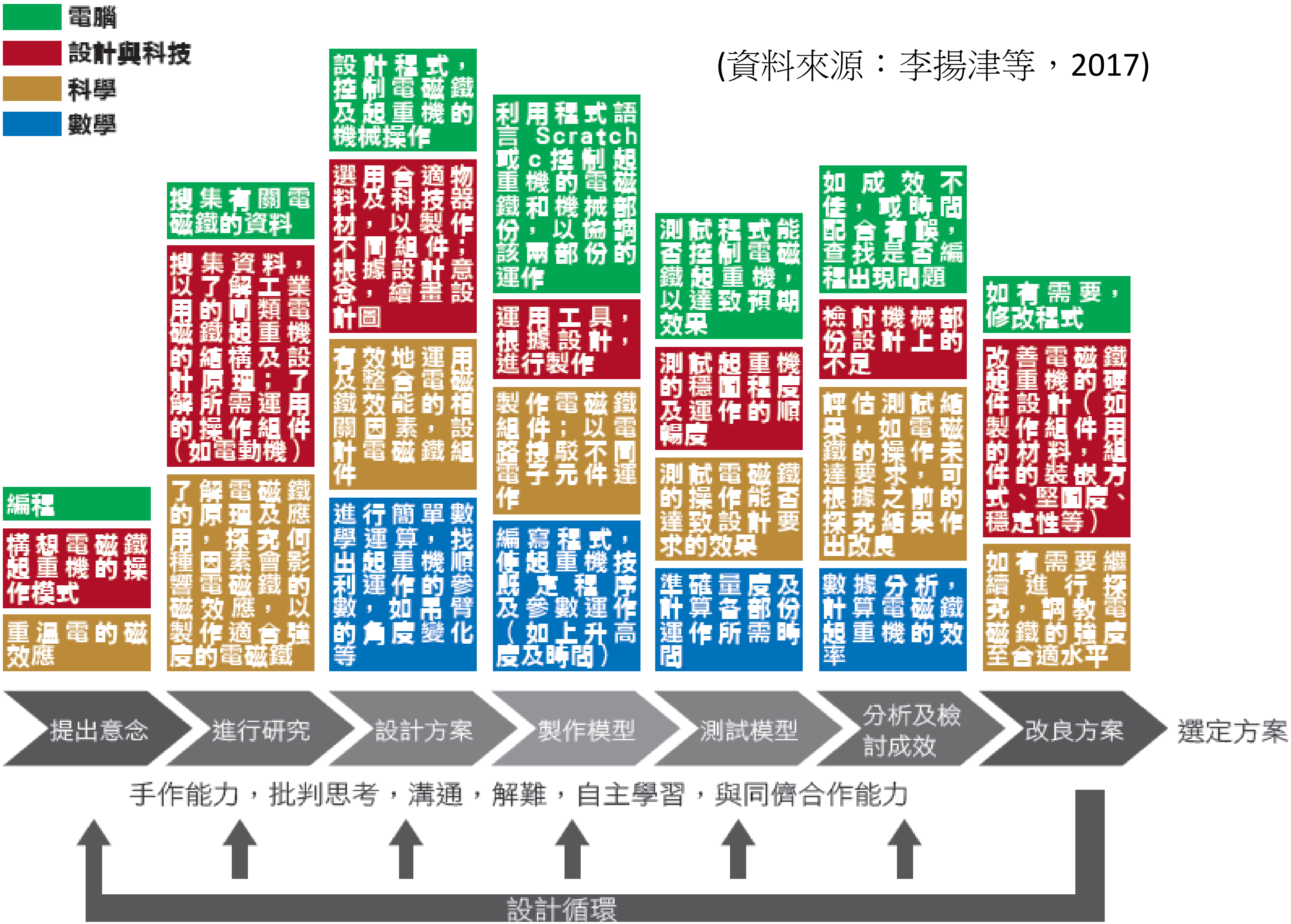
Activity Design Template

學科知識 / 工程設計	構想意念	進行研究	制定設計	製作模型	測試模型	分析及檢討	改良設計
視覺藝術			xxxx				xxxx
設計與工藝				xxxx			xxxx
資訊科技		xxxx	xxxx		xxxx		
數 學				xxxx	xxxx	xxxx	xxxx
科 學	xxxx	xxxx	xxxx		xxxx	xxxx	xxxx

跨學科技能　創造力　溝通　邏輯及批判思考　系統思維

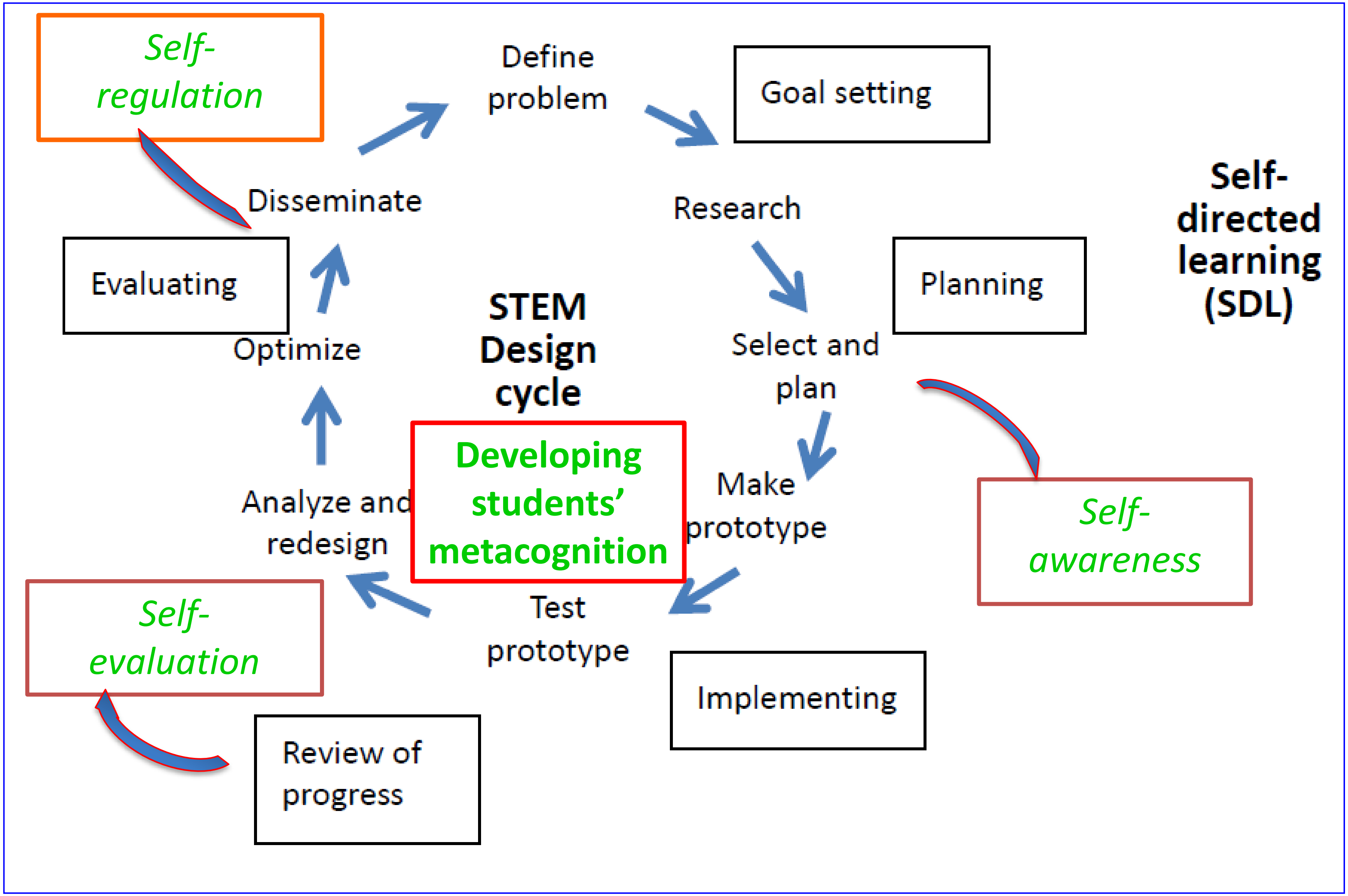
團隊合作　自我管理　解難

xxxx　代表相關知識或技能



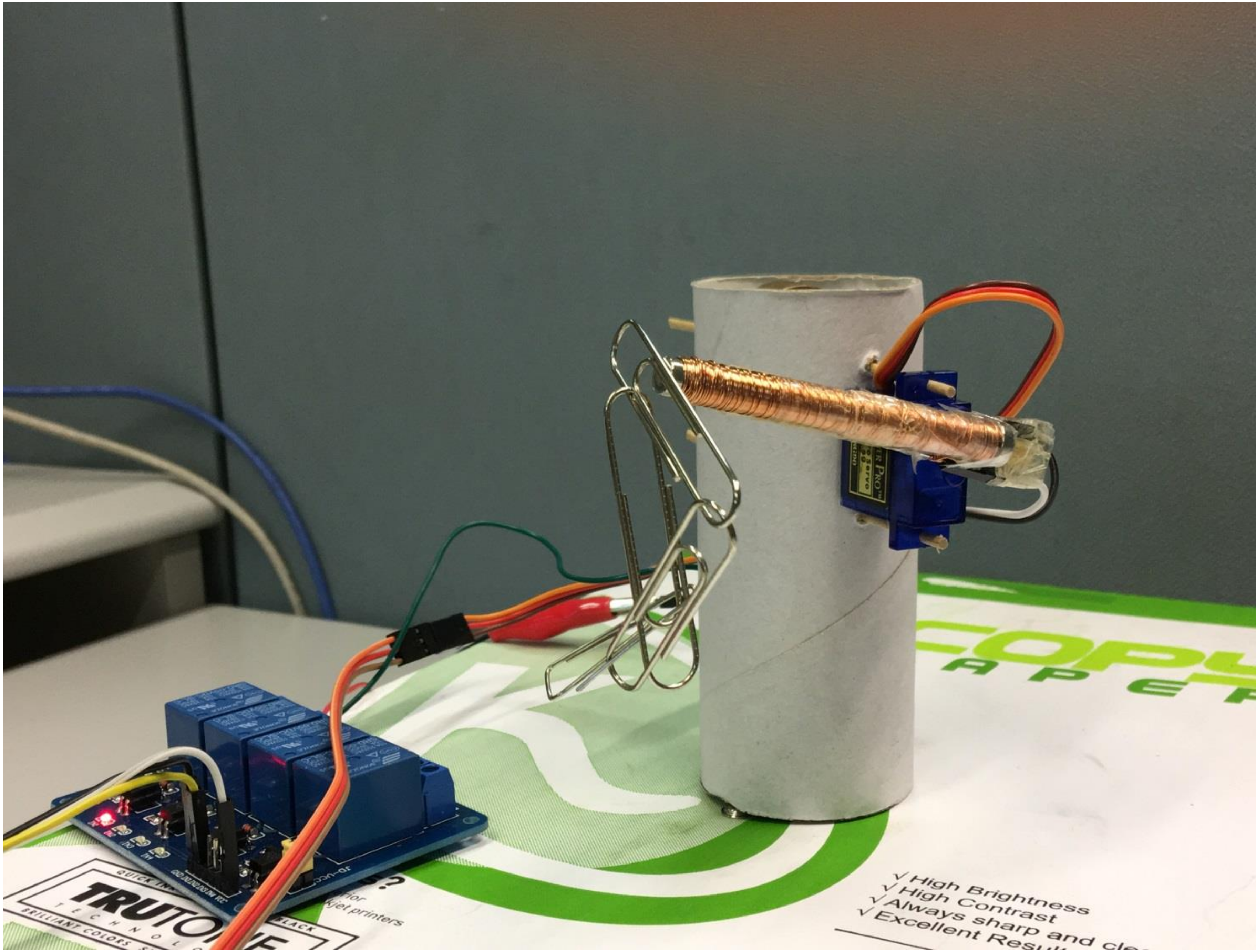
圖一：學科內容與設計過程的配合

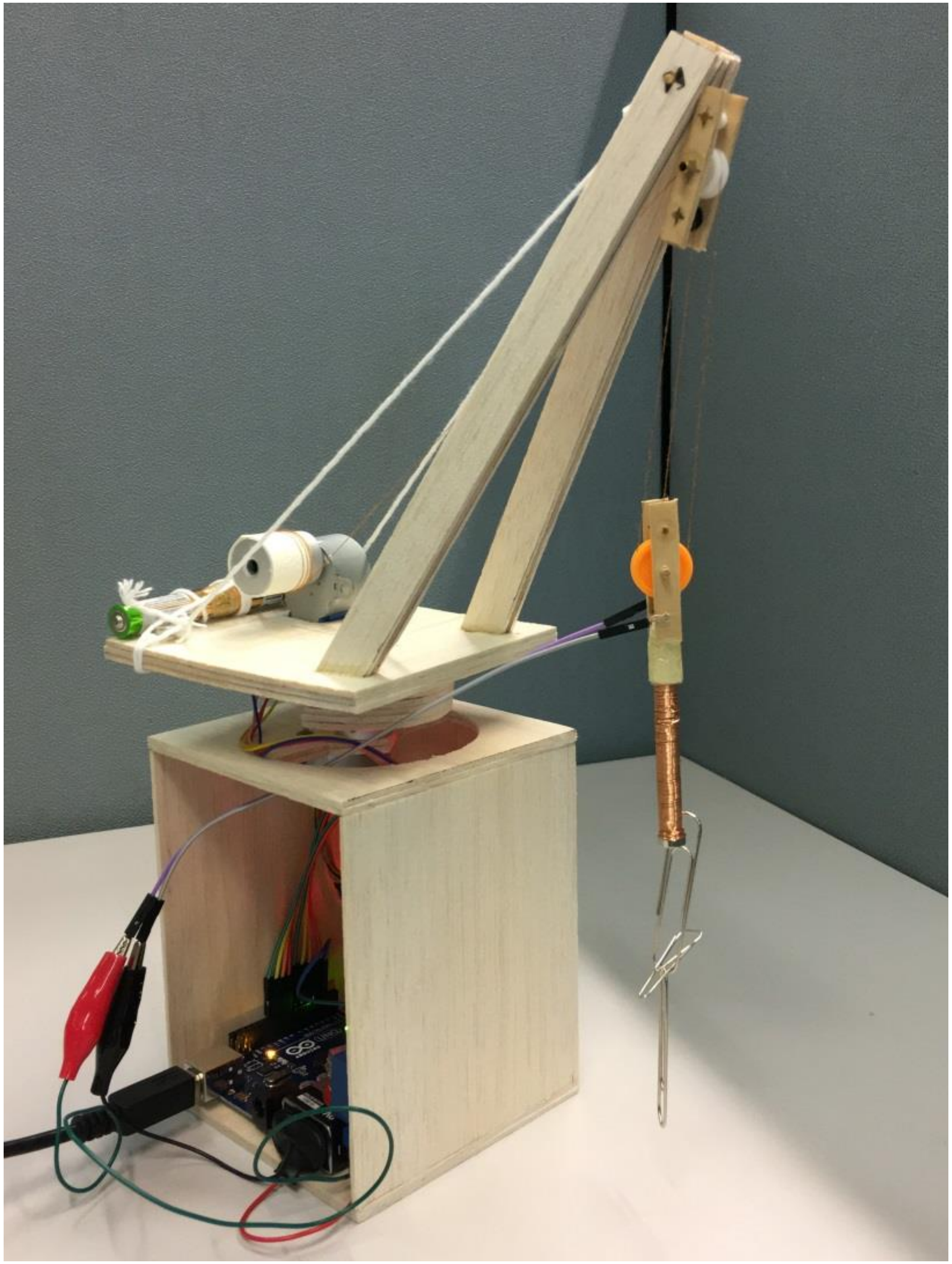
STEM education through/for Self-directed Learning



圖二：建議教學流程　(資料來源：李揚津等，2017)

Example of STEM activity design (I) - Electromagnet


√ High Brightness
√ High Contrast



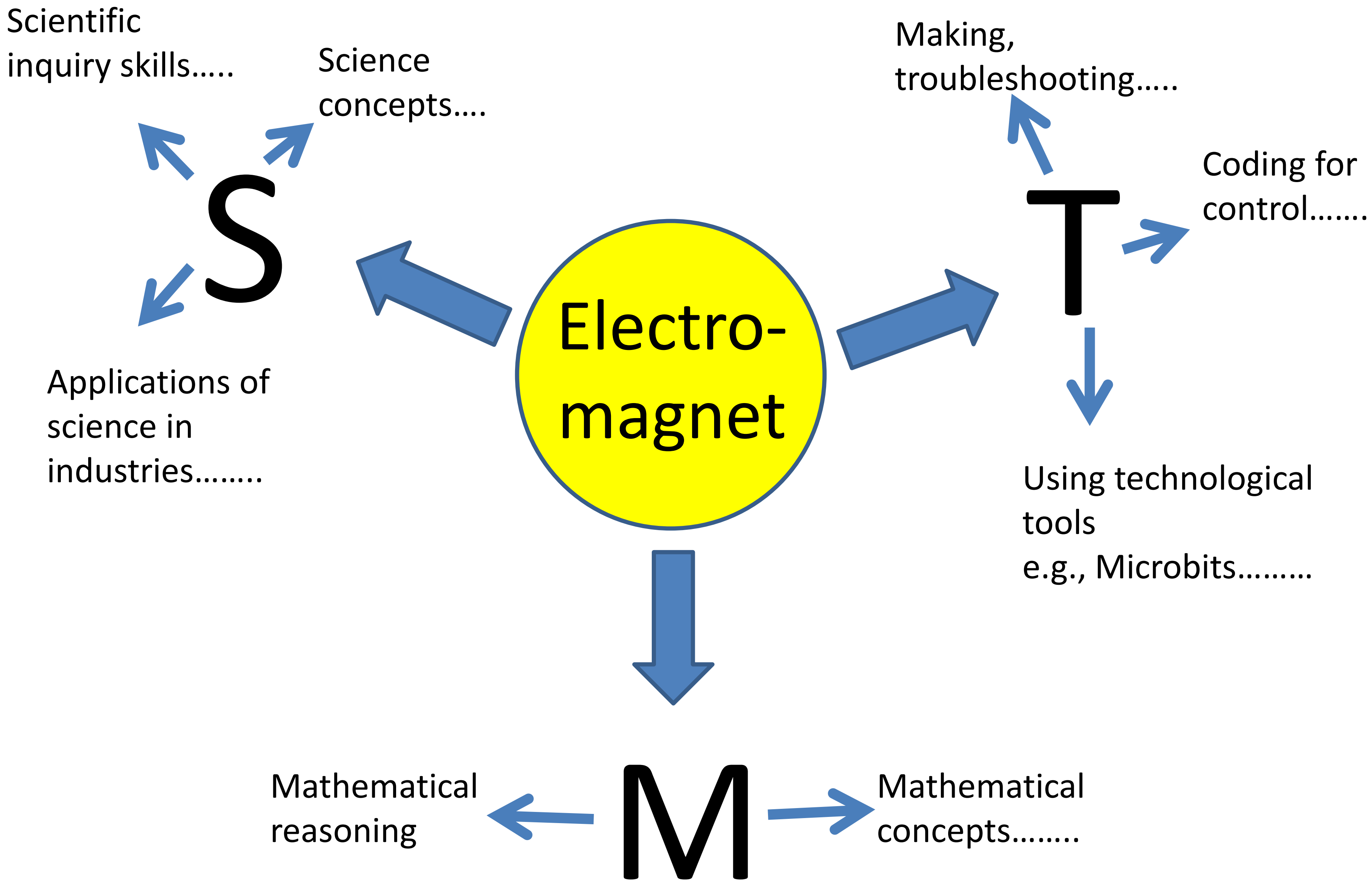
Example of STEM activity design (II) - Parachute

4. Evaluation

Evaluation methods

- Mind map
- Concept map
- Drawing of design
- Inquiry report of the testing process
- Final product
- Student self-evaluation
- Student reflective journal
- Student learning portfolio/e-portfolio

Mind Map


Scientific
inquiry skills…..
Science
concepts….
S
Applications of
science in
industries……..
Electro-
magnet
Making,
troubleshooting…..
Coding for
control…….
T
Using technological
tools
e.g., Microbits………
Mathematical
reasoning
M
Mathematical
concepts……..

Assessment rubric

(資料來源：李揚津等，2017)

評估項目	評估標準	
了解問題的挑戰	• 不理解電磁鐵起重機的原理及功用，只模仿別人或現有的設計	• 掌握問題的要求及電磁鐵起重機的功用，並清楚設計上的限制
研究	• 繞過研究階段而直接製作電磁鐵起重機	• 進行全面的研究，包括研究工業用的起重機的設計，以及對電磁效變因進行有系統探究及公平測試
構想意念	• 只能提出表面化的意念	• 從多方面考慮電磁鐵起重機在設計上的要求，能詳細考慮各組件在操作上的協調
表達意念	• 只表達了電磁鐵起重機的基本意念，忽略了細節部分（如組件的協調、操作上可能出現的問題），可行性不大	• 能具體地表達設計意念，設計的細節部分亦經過深思熟慮，以增加製成品可行性
製作方法	• 不懂運用編程，以控制機械或電磁鐵部份的操作	• 有效進行編程，亦能根據科學探究所得到的結果製作電磁鐵組件
解難	• 未能識別、分析或解決製作上遇到的難題	• 能聚焦於製作上所遇到的難題，提出解決方法
進行測試	• 未能按設計要求進行測試	• 能對設計的每一項要求作嚴謹的測試
反覆修訂	• 未能有系統地根據回餽改良設計，或只完成單一輪設計	• 根據測試的數據及他人的回饋，加入新理念，改良原來的設計
對活動過程進行反思	• 單憑直覺進行設計，缺乏自我監察力，對過程及製成品缺乏反思	• 由始至終都能不斷反思及監察設計策略的成效，如自律地按時間表完成工序、運用客觀數據作檢討及改良
製作質量	• 未能滿足設計要求，各組件的運作未能互相配合及協調，結構欠穩	• 能滿足設計要求，運作暢順，可靠性高，結構穩定，能重複多次使用
	初學水平 1 2	3 4 5 專業水平

圖十三：有關工程設計及製作方面的評估項目及評分標準

5. Reflection