國立中山大學 教學實踐南區基地 教學實踐研究計畫撰寫工作坊 場次1通識/人文學門

教學實踐研究計畫
經驗分享

王鴻祥
工業設計系
TAIPEI TECH 國立臺北科技大學 National Taipei University of Technology

Once upon a time,
there was an

email.

王鴻祥 國立臺北科技大學工業設計系

【計畫申請公告】敬邀老師踴躍申請「大專校院教學實踐研究計畫」，詳如內文說明。 收件匣 ×

北科大-楊小慧　　1月8日 週一 下午4:46

老師 您好，

我是教務處教資中心的小慧，抱歉來信打擾，因老師有參與中心「創新與創業」或「創新思考設計」或「微型創業實戰」等創創課程，針對課程實施成效，若老師有興趣可以申請教育部推動「大專校院教學實踐研究計畫」，計畫徵件說明請參閱下文說明。

老師如有意願申請，可直接回覆給我們，教資中心將全力協助，不論是否申請通過教育部該計畫補助，若經校內審核通過，都將給予部份經費補助，補助限量，請老師們把握機會踴躍申請，謝謝老師撥冗詳閱！

資訊聯絡窗口：教資中心　楊小慧

==

一、計畫主旨與運作模式：

(一)教育部為鼓勵教師從事**教學實踐研究**(係指教師為提升教學品質，促進學生學習成效，以**教育現場或文獻資料提出問題，透過課程設計、教材教法、或引入教具、科技媒體運用等方式，採取適當的研究方法與評量檢證成效之歷程**)。

(二)未來本補助計畫所獲成果，**教師得作為個人升等審查著作**，特辦理旨揭本補助計畫。

(三)執行方式將採類似科技部補助教師專題研究計畫模式，**直接將經費補助給教師**，而非給學校統籌運用。

(四)藉由提供經費補助、同儕審閱模式、教學成果公開平台的相關支持系統下，**鼓勵擅長教學的教師能以教學成果進行升等，引導教師專長分工及分流**，以達到教育資源投入應以重視學生學習成效為導向之目的。

二、計畫期程：107年8月1日~108年7月31日

三、補助金額：每案至多**50萬元**。

四、申請方式及注意事項：

王鴻祥 國立臺北科技大學工業設計系

18 minutes later...

王鴻祥 Hung-Hsiang Wang <wanghh@mail.ntut.edu.tw> 2018年1月8日 下午5:04
寄給 北科大-楊小慧

小慧好：

感謝通知，我將提出申請，後續若有問題，尚請協助，謝謝。

from 王鴻祥

...

北科大-楊小慧 2018年1月8日 下午5:17

王老師　您好，

感謝您願意申請本計畫，附件為教學實踐研究計畫_徵件網站操作手冊(教師申請)，請查收。

若有任何問題或需要協助的地方，再請老師不吝告知。

...

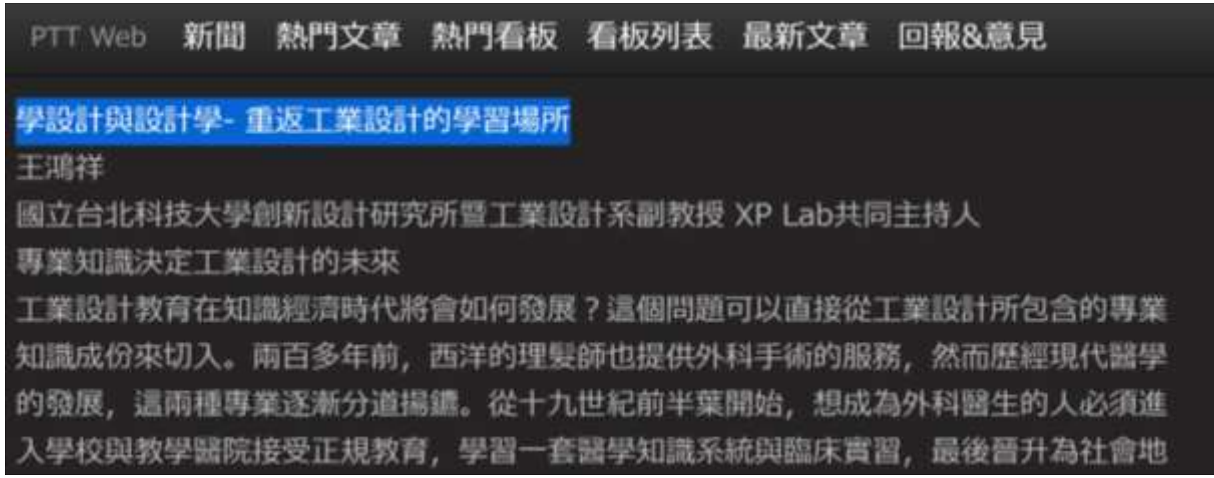
反思我19年前的「教學研究」

- 巧遇急徵計畫，無心長期耕耘？
- 只懂工業設計，是教育研究的門外漢？
- 曾獲優良教師與導師，但真的是好老師？

計畫主持人	王鴻祥	計畫名稱	工業設計專業能力指標之建立
計畫編號	91-MOE-S-027-002-X3	計畫全程執行起迄	2002.01.01 至 2002.12.31
執行機關	國立臺北科技大學工業設計系	核定日期	2002.02.07
狀態		報告	精簡報告第1年 2002/01/01-2002/12/31 精簡報告(繳交日期:2003/04/01) 出席國際學術會議心得報告(繳交日期:2003/04/01) 期末報告公開日期：2003/04/01

計畫主持人	王鴻祥	計畫名稱	貫通式教學模式之研究- 以電腦輔助工業設計的教學革新為例
計畫編號	91-2516-S-027-002-	計畫全程執行起迄	2002.08.01 至 2003.07.31
執行機關	國立臺北科技大學工業設計系	核定日期	2002.07.05
狀態		報告	精簡報告第1年 2002/08/01-2003/07/31 精簡報告(繳交日期:2003/10/09) 期末報告公開日期：永不公開
承辦人	王台徽	承辦司處	科教國合司

王鴻祥 (2003), "學設計與設計學- 重返工業設計的學習場所," 回饋雜誌，第68期，技嘉教育基金會，12-19.



現在我最想做的一件事...

- 該開始回顧教書生涯，多做一件有意義的事
- 工業設計與教學的共通點：

  使用者為中心
  改變 (將現狀變成更好的狀態)
  實踐派的專業

  ...
- 我要重返教學研究，申請教學實踐計畫！

分享一

- 我有多大的勇氣？
- 我還承擔得起？
- 我應該正向思考？

2 days later,
there was a
workshop.

急件-【工作坊資訊】教資中心敬邀參與「大專校院教學實踐研究計畫」推動工作坊 (107年1月15日星期一中午12:00假一教學大樓教師休息室) 收件匣 × 0-後續處理 ×

北科大-楊小慧 2018年1月10日 下午5:24

老師 您好：

感謝老師們有意願申請教育部「大專校院教學實踐研究計畫」，
因計畫申請時程緊迫，煩請老師勞心趕一下計畫申請書，
為利老師們能更加順利撰寫計畫書，並提高申請通過率，
教資中心安排推動工作坊，敬邀有意申請計畫之老師出席參與，
老師亦可請研究生或研究助理共同出席，惟場地空間有，故至多2名。

工作坊資訊如下：
日期：107年1月15日星期一
時間：中午12:00 (敬備午餐)
地點：第一教學大樓教師休息室

主題(一) 計畫推動說明及補助要點
主題(二) 教育研究方法介紹 (行動研究法/實驗設計法)

想起幾件事...

- 研究生時期參加過幾場教學多媒體、計畫書撰寫工作坊
- 菜鳥老師的教學聖經：Gilbert Highet (1950) *The Art of Teaching*
- 國際研討會上常見各國實務界的設計師發表研發成果的論文

該怎麼著手？

- 對象/場域：在工業設計系歷史傳統下，我該選擇什麼對象與現場？
- 問題/需求：跨領域合作的創新很重要，我怎麼幫助學生提升這種能力？
- 取向/方法：作為"research in designerly ways"的信徒，我該採什麼研究方法？

Gilbert Highet說：

- 小範圍的教學準備工作，教師們經常做得很好
- 對於大規模的（一學年授課的全盤）計劃，很難有優良的表現

➢ 重新統整我的創新思考教學計畫

工作坊的教育專家們說：

- 行動研究，行動研究，行動研究！
- 作為Donald Schön的粉絲，我聽懂什麼是「在行動中反思」(reflection in action)

➢ 用科學的、系統化的方法解決現場問題

教育專家們的小叮嚀

- 若為「發表」故，「實證」不可拋！
- 我喜歡思辨科學哲學，但我應該務實一點？

➢ 聽專家的話，留意主流觀點

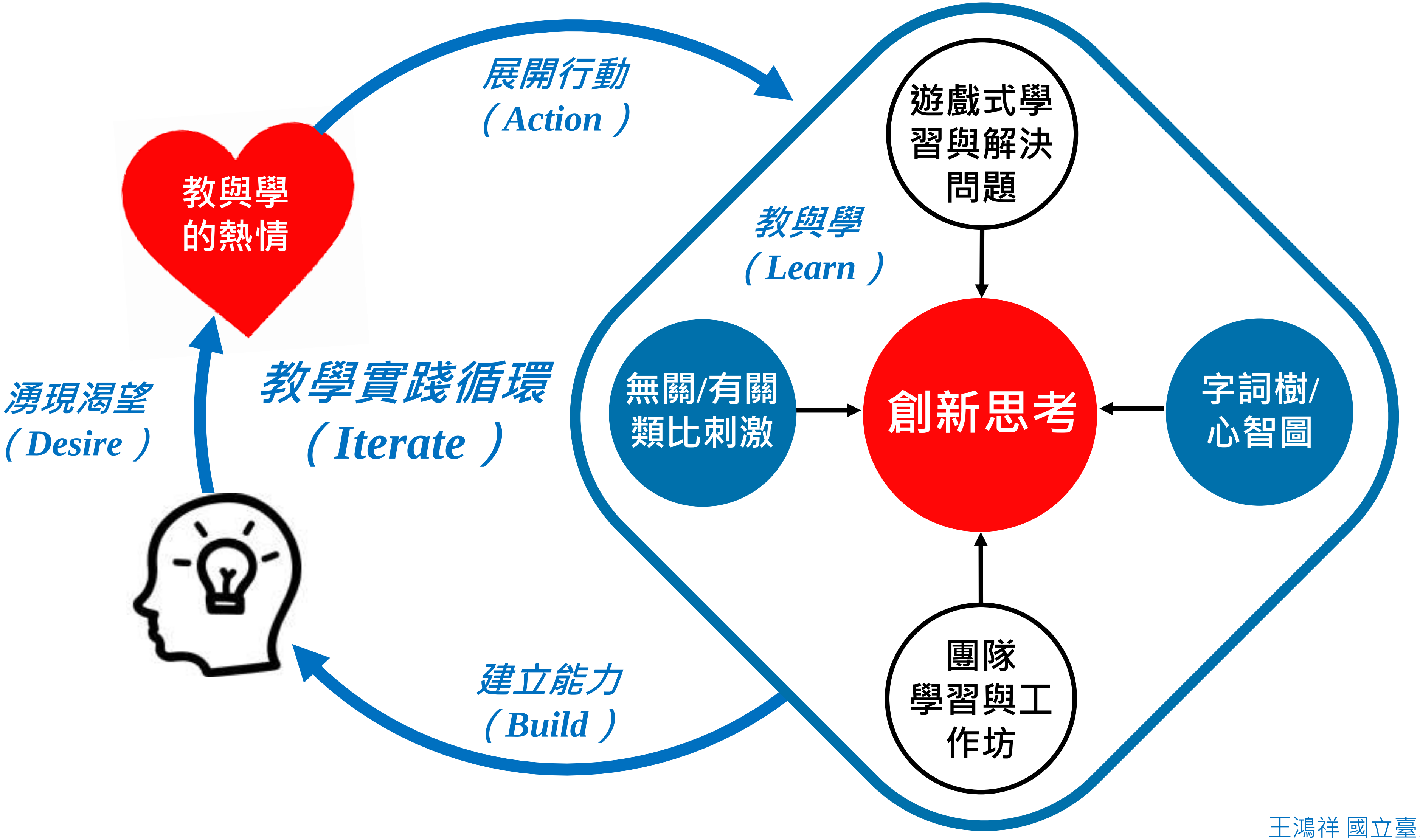
分享二

- 向教育專家學習使用「教育學語言」！
- 廣泛探索複雜的現象 vs 聚焦可能的變項關係？
- 解決特定的實際問題 vs 發展普遍的抽象理論？

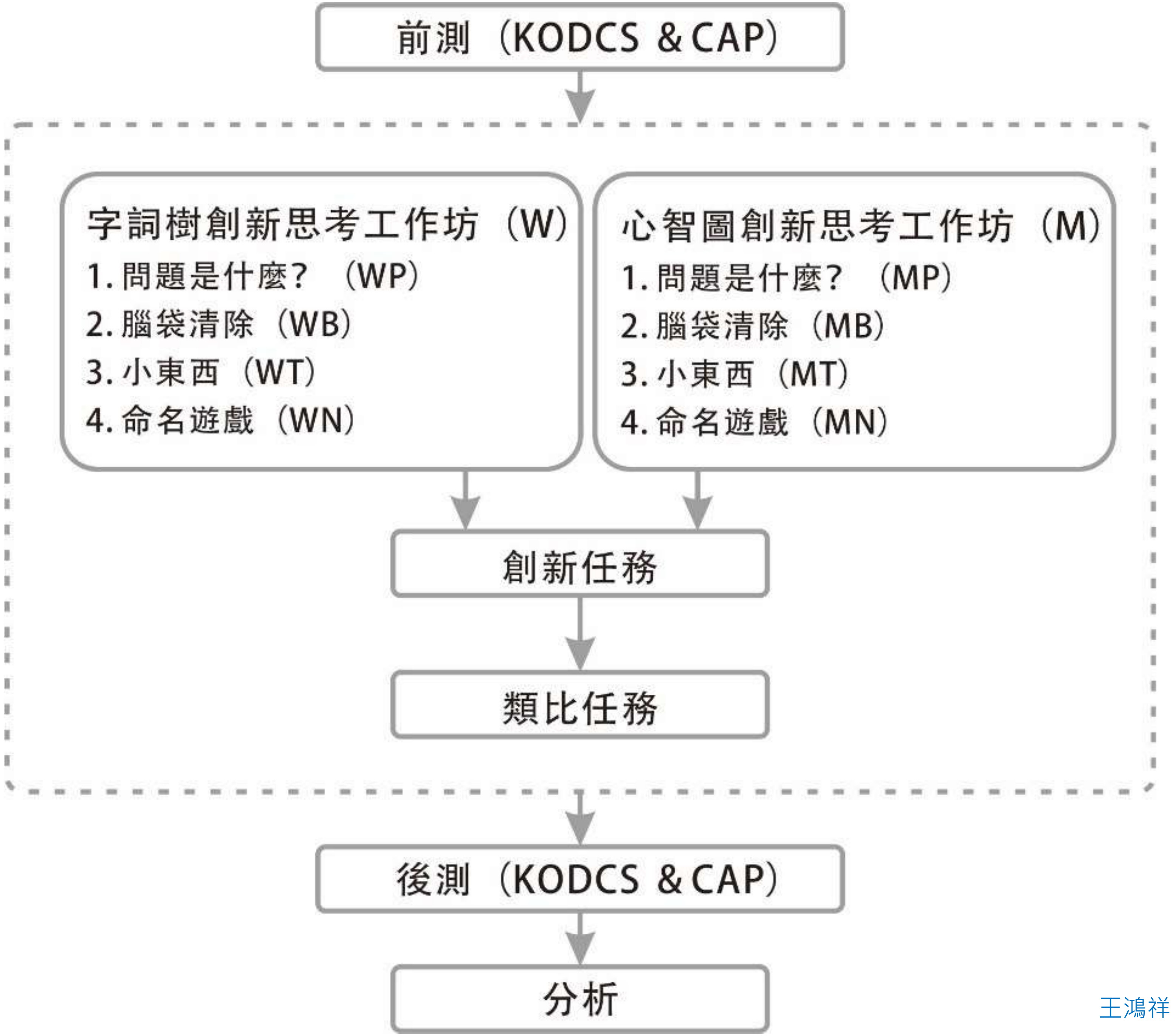
迅速著手

- 場域：通識科目創新創業學程兩個大班制「創新思考」，來自六個學院的大一學生
- 問題：有學者主張：Word Tree可有效提高工程學生的創造力，且給定與目標無關的類比刺激物較能激發創造力
- 取向：處理行動研究問題的實驗方法

計畫名稱：提升創新思考學習成效的教學實踐研究



王鴻祥 國立臺北科技大學工業設計系



王鴻祥 國立臺北科技大學工業設計系

工作坊主題

	1. 問題是什麼？	2. 腦袋清除	3. 小東西	4. 命名遊戲
	有關的刺激物		無關的刺激物	
字詞樹 （W組）	第一學期 A班	第一學期 A班	第一學期 A班	第一學期 A班
心智圖 （M組）	第二學期 B班	第二學期 B班	第二學期 B班	第二學期 B班

王鴻祥 國立臺北科技大學工業設計系

1 week later...

Fwd: [教育部教學實踐研究計畫] 提醒申請資料之完整確認

收件匣 ×

北科大-楊小慧 1月22日 週一 下午2:32

老師 您好：

轉寄教育部來信通知提醒有關計畫上傳資料應包含如下：(請留意第4點研究倫理審查文件)

1.共同主持人同意書(如果有共同主持人) 檔名需為：共同主持人同意書-共同主持人姓名-學校簡稱

2.計畫內容書 計畫內容 PDF 檔名： plan-申請人姓名-學校簡稱-計畫中文名稱前 3 個字

3.經費聲明書 檔名需為：fund-申請人姓名-學校簡稱-計畫中 文名稱前 3 個字

4.研究倫理審查相關文件 檔名：re-申請人姓名-學校簡稱-計畫中文名稱前 3 個字

->勾選 需送交「人體研究倫理審查委員會」查核者，請依據自身狀況以下擇一文件上傳:

(1)「研究倫理審查委員會核准函」

(2)「送審證明」併同 「研究倫理審查聲明書」一併上傳

->勾選「本研究非屬人體研究」者，需將「研究倫理審查聲明書」併同「告知同意規畫或告知同意說明書」，兩者簽名後掃瞄為PDF檔一併上傳

「告知同意規畫或告知同意說明書」可參考專案辦公室整理他校之範本，老師們依需求可自行修訂

https://tpr.moe.edu.tw/newsDetail/4b1141f260b5ded50160beb3e24305a4

5.(若以研究原住民為目的之計畫)需檢附以下之一文件: 檔名：ire-申請人姓名-學校簡 稱-計畫中文名稱前 3 個 字

一切交給上帝

分享三

- 改善某個班級的某個重要的教學問題
- 掌握某個熱門教育議題、現有理論與成果
- 建立可檢驗改善成效的研究方法
- 果斷、迅速、正向

6 months later...

很不錯的生日禮物！

【重要】教育部107年度「大專校院教學實踐研究計畫」審查結果公告

收件匣 ×

北科大-楊小慧　7月25日 週三 下午5:42

王鴻祥 老師 您好：

依教育部107年7月24日臺教技(五)字第1070108318C號函（如附件），您申請之 **提升創新思考學習成效的教學實踐研究** ，核定結果為 **通過** ，獲補助經費為

依教育部來函，敬請老師配合下列事項：

1. 確認是否同意接受本計畫補助，請申請人於107年7月24日~8月25日期間，務必至系統(網址：https://tpr.moe.edu.tw/login)點選同意，始能進行後續相關補助程序。
2. 獲教育部之申請案則不再受理校內補助案申請，是故，若老師於7/18前有送校內申請者，將自動排除，則不另行通知。
3. 教育部請學校於8月31日前發函至教育部請款，故請老師配合於107年8月16日~8月22日期間於計畫系統進行經費修正(教育部原訂是8/25前，惟配合後續作業，方請老師能再盡早完成，謝謝！)。**本計畫得編列人事費上限為計畫核定總金額之60%(計畫主持人費及兼任助理費)，另可依計畫執行必要性及需求性編列設備費。**
4. 獲補助計畫主持人應於計畫執行期間，配合教育部及指定之專案辦公室規劃參與諮詢或座談等教學社群運作事宜。
5. 校長於107年3月20日本校106學年度第2學期第1次共識會議中提及，為鼓勵教師申請教學實踐研究計畫，若本校教師無執行其他計畫，且申請教育部教學實踐研究計畫獲得通過者，將由學校補足其每月主持人費至1萬元。

以上未盡詳細說明，尚請老師依據教育部補助技專校院教學實踐研究計畫作業要點辦理，經費核銷請依據教育部補助及委辦計畫經費編列基準表核實報支。
若有任何問題請隨時提出，謝謝！

王鴻祥 國立臺北科技大學工業設計系

5. 校長於107年3月20日本校106學年度第2學期第1次共識會議中提及，為鼓勵教師申請教學實踐研究計畫學實踐研究計畫獲得通過者，將由學校補足其每月主持人費至1萬元。

計畫審查結果

學門：人文藝術及設計

計畫名稱：提升創新思考學習成效的教學實踐研究

計畫主持人：王鴻祥

計畫審查結果： 通過

(必填)請確認是否執行此計畫

◉ 同意執行計畫 (送出日期：2018-07-25) ○ 放棄執行計畫

審查意見

獻。
本教學實踐研究對象是修習創新思考的兩班學生，於本教學實踐的前測和後測皆包括三種創造力相關量表：威廉斯創造力測驗、考夫曼領域量表及創意成就問卷，而依每一場工作坊的學習目的、內容與預期成果亦擬訂出一種檢核表，用以讓教師與助教共同評估學生在四場工作坊的創新思考表現，最後亦提供學生意見調查表，用以讓學生對於每一場工作坊的教師教學與教材表達意見，如此可調查學生在整體課程學習成效的創造力提升之成果。惟須確認修習創新思考的兩班學生的相關程度與學習經驗是無差異的，否則比較的起始點就不會相同。

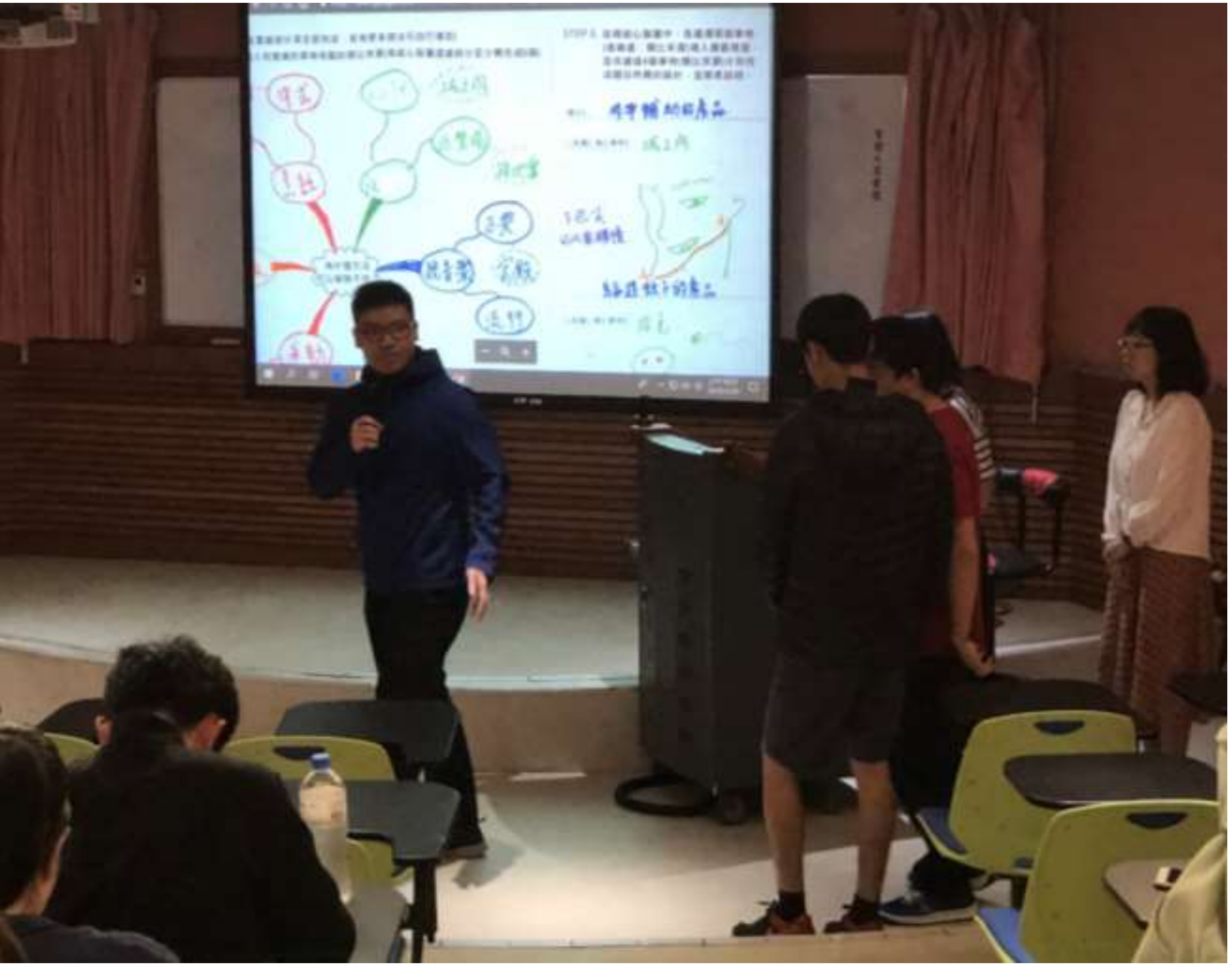
One more thing.

- 這是我唯一有承辦窗口不斷主動提醒、鼓勵、催促申請的計畫
- 學校加碼 $$$ ，好禮獎不完、教育訓練、協助申請、提供貼心after service…
- 我給 ★★★★★

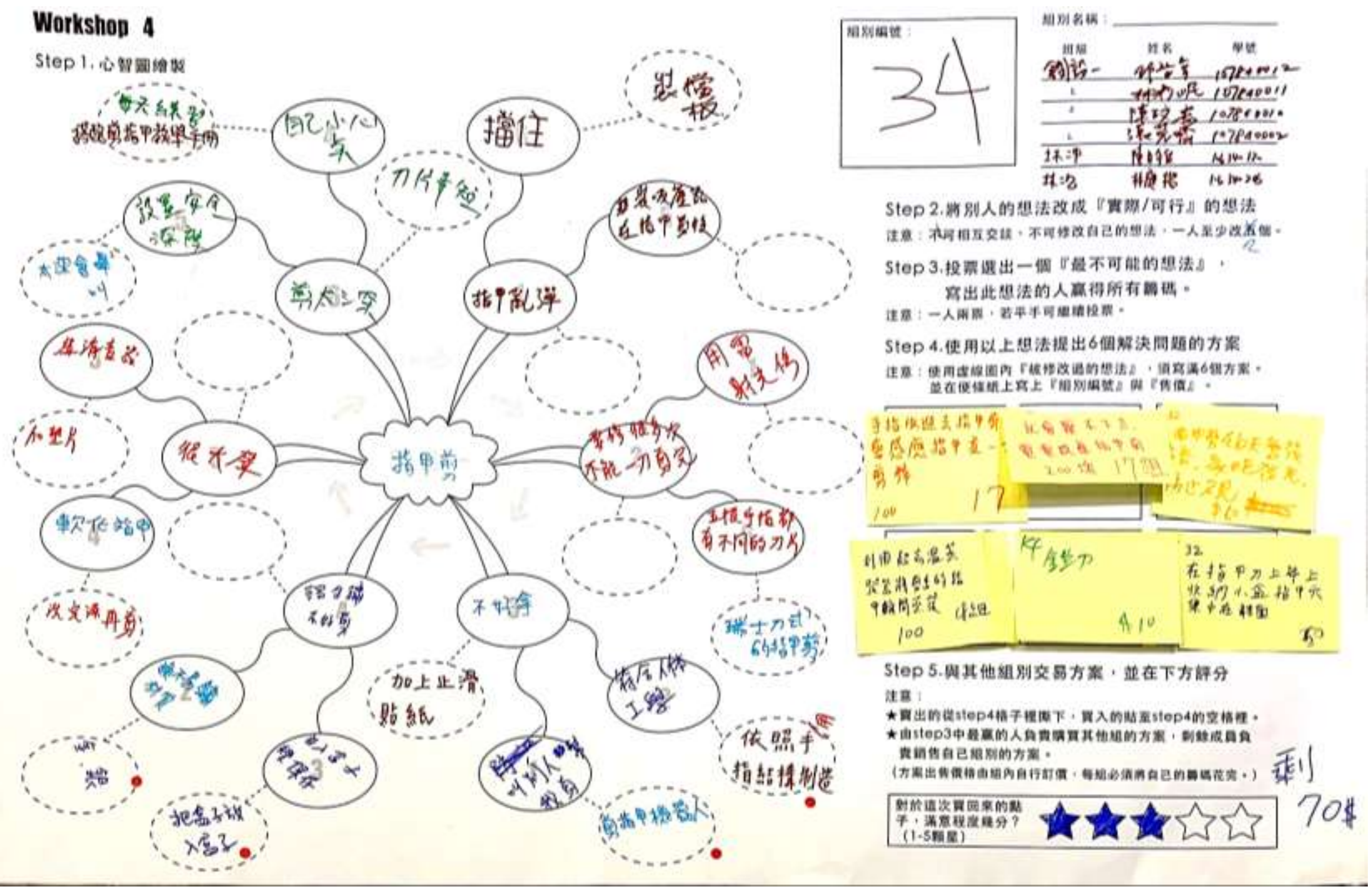
王鴻祥 國立臺北科技大學工業設計系

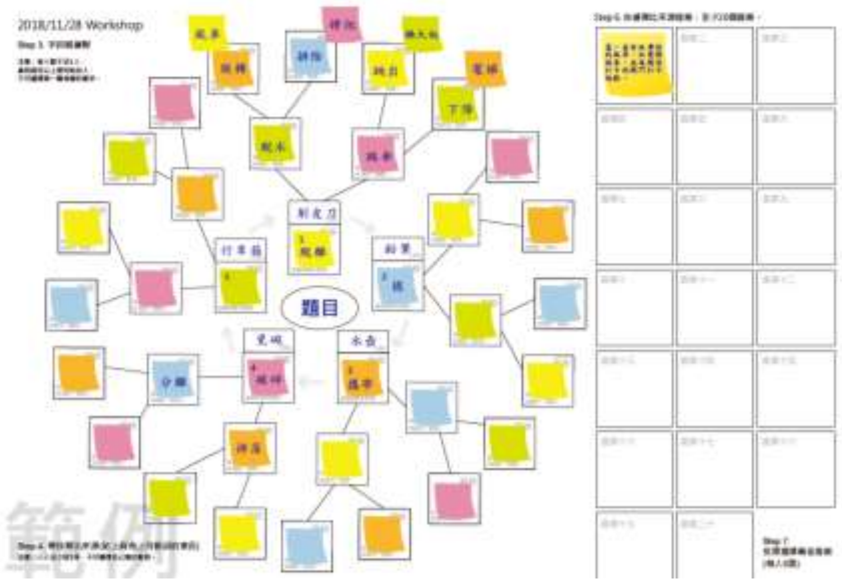
分享四

- 成果的推廣
- 學術的發表



王鴻祥 國立臺北科技大學工業設計系





王鴻祥 國立臺北科技大學工業設計系

王鴻祥 國立臺北科技大學工業設計系

王鴻祥 國立臺北科技大學工業設計系

■ 王鴻祥

字詞樹——提升創造力的方法

在團隊合作中，
綜合運用單詞樹與腦力接龍有助於提出有用的創意構想，
經過一段時間的練習更可提高個人的創造力。

［ 字詞樹是傳統的「上下文關鍵字」方法的圖形化版本，可以快速查詢和探索文本。 ］

有什麼方法可提升創意

在設計科系實作課堂裡，常常可看見老師指導學生用「心智圖」（mind map，又稱心智地圖、概念地圖）搭配腦力激盪（brainstorming）尋找創意靈感。英國心理學家東尼．博贊（Tony Buzan）1974 年出版的《心智魔法師／大腦使用手冊》（*Use Your Head*）提出心智圖這種發散式思考的輔助工具，後來廣泛用來幫助設計師發展大量的構想。

心智圖的特色是從一個主題出發，然後畫出有關聯的對象，其形式自由，結構靈活，可以毫無約束地繪製出想法，以及想法之間的連結，最後呈現出一幅把許多概念連接在一起的語意網路或認知體系的圖像。然而，常用好用卻未必代表沒有其他更適用的工具，現在讓我們來認識一種稱為「字詞樹」（word tree，又稱單詞樹、文字樹）的方法。

新的創意思考輔助工具

字詞樹是谷歌（Google）數據視覺化團隊的馬丁．沃騰貝格（Martin Wattenberg）和弗南達．維加斯（Fernanda Viégas）於 2007 年發表的一項新技術，能把文字檔案視覺化並從中進行資訊檢索。字詞樹是傳統的「上下文關鍵字」方法的圖形化版本，可以快速查詢和探索文本（文本指以語言撰寫的文件，例如一個句子、一段文字或一篇文章）。

與心智圖一樣，字詞樹本身也是樹狀結構，它的基本單位稱為「節點」，節點之間的連結稱為「分支」，節點與分支形成樹狀，而結構的開端稱為「根」。但是字詞樹的繪製比心智圖更為特定，心智圖的節點可以是任何圖文符號，分支可以是任何連結關係，但字詞樹的節點則專指文本中的單詞，分支則代表兩個單詞之間的語法、語意或語用（pragmatics：我們在現實情境中如何使用語言）上的關係。

在網站 https://www.jasondavies.com/wordtree/ 字詞樹工具輸入一個有關創造力的文本（如圖右上方），系統會自動繪製這株字詞樹，可以從中迅速了解這個文本的樹狀結構，其中字體最大的「創造力」（creativity）最重要，「是」（is）和「能力」（ability to）次之。

例如我們可以在美國軟體工程師傑森．戴維斯（Jason Davies）的網站（https://www.jasondavies.com/wordtree/）找到字詞樹工具，輸入一段文章（texts，又稱文本）之後，系統就會自動繪製一株字詞樹。我們可以從這株字詞樹迅速了解這個文本的樹狀結構，而且從字體的大小也可以知道這個文本的關鍵字重要性順序。

字詞樹原本是為了把非結構化的文本檔案視覺化成樹狀結構，能更快速、更容易掌握文本的主題含意。這個特性正好可用來幫助進行類比式設計，找尋更多更有用的類比來源以解決問題。一個簡單的類比式設計例子是「安心圈」，當設計一個在公共場所提醒聽覺障礙者與視覺障礙者迴避地面溼滑區域的產品時，構想出「投射出某個空間以警示人員迴避」的原理（例如應用紅外線感知器偵測人員靠近，用雷射光投射出警示區域界線，以揚聲器發出警示聲音等），於是把這個原理當作一項類比目標。

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這時類比來源就是可達成這些功能的類似案例（例如其他類別的產品或生物），設計師在發展產品構想階段的主要任務，就是尋找類似且可套用的類比來源。經過廣泛搜尋與篩選參考類似原理的案例之後，「安心圈」的設計師參考了工地用的「吊車警示裝置」雷射投影出空間的原理，把不同類別的產品案例當作類比來源，套用到類似的產品功能需求。

臺北科技大學工業設計系盧謙馨的 2015 金點新秀設計獎作品「安心圈」，結合了紅外線人體位移偵測感應器、雷射光發射器與擴音器，可投影出紅色警戒圍圈線告知行人危險的地板濕滑區域範圍，並在行人靠近時發出警告聲響，以提高過路人的安全保障。其類比來源是「吊車警示裝置」，套用其投射警示空間的設計原理。

在創新工程設計的教學應用

谷歌團隊推出字詞樹技術的次一年，美國學者茱莉．林斯、克里斯汀．伍德和亞瑟．馬克曼（Julie Linsey、Kristin Wood 和 Arthur Markman）便發表一篇論文，報導如何運用字詞樹與「腦力接龍」（brainwriting，由第一棒把自己的想法傳給下一棒繼續發展出新的想法，如此循環接力）發展出一套可增進學生類比式設計能力的工作坊。

參與這項實驗的 92 位機械系大四學生的工程設計表現顯示，用字詞樹與腦力接龍進行思考的實驗組學生，比起純粹用腦力激盪法的對照組學生，能產出更多出人意表且有用的類比思考與解答，也更能運用不同的策略，在多元的領域中廣泛地搜尋適當的類比來源。當然，實驗組的工作坊表現比對照組好，並不代表他們的創造力也比對照組進步的更多。

這項應用新技術提升學生創造力的實驗很有趣，值得在創新思考教學裡嘗試。雖然原本的類比式設計工作坊的任務設定為「設計一種第三世界國家使用的花生剝殼裝置」，參與者沒有機械領域知識是沒有辦法進行的，但是照說字詞樹應該可以推廣到其他領域，甚至是跨領域。

臺北科技大學土木工程系施易成、工業設計系簡百慧同學的德國 2012 red dot award design concept 作品「吊車警示裝置」，利用雷射光線在地面投射一個可隨吊裝作業移動而改變範圍的危險警示區，警告地面作業員勿進入這個區域，其設計原理是投射出某個空間以警示人員迴避。

因此，參考亞瑟．梵岡地（Arthur VanGundy）於 2005 年出版的《101 個創造力與問題解決的教學活動》（*101 Activities for Teaching Creativity and Problem Solving*），選擇一些不需要仰賴特定領域知識，也可以操作的日常生活用品或活動之類的設計題目，規劃了四場各為期三周的類比式設計工作坊。

例如第三場工作坊是「小東西」（Tickler Things），學生以 4 至 6 位為一組，第一階段的 30 分鐘創新任務暫時不公布設計題目，先發給每組 5 件與題目不相關的小東西（例如火柴盒汽車、黃色小鴨），然後要求他們以這些小東西為討論的起點探索關鍵問題，從中歸納出關鍵的動詞。接著才公布題目（例如指甲剪改善、迎新活動），要求每組把關鍵動詞當作字詞樹的根，並使用腦力接龍的方式繪製出完整的字詞樹。

第二階段是 45 分鐘的類比任務，每組必須從完成的字詞樹中找出類比來源，並使用類比來源完成 20 個與題目相符的創意提案。這些過程都記錄在大幅海報紙上。可用來分析樹狀結構的節點與分支、有效的類比數量，以及設計成果的創新程度。這些工作坊的材料與過程都設計成學習單，方便學生快速學習。

【字詞樹原本是為了把非結構化的文本檔案視覺化成樹狀結構，以更快速、更容易掌握文本的主題含意。】

類比式設計工作坊把來自不同學院的學生以 4～6 位組成一組，每一組依照學習單提示的步驟，在演講廳裡找尋適當的角落進行分組工作坊。

類比式設計工作坊的分組成員彼此通力合作，用字詞樹—腦力接龍法或心智圖—腦力激盪法共同完成每一場的創新任務。

字詞樹—腦力接龍工作坊的分組成果例子。「指甲剪改善」是字詞樹的根，分支出動詞「磨平」等 5 個節點，然後繼續尋找與「磨平」等有關的動詞，最後尋找具有類似動詞特徵的東西當作類比來源。

【字詞樹的特性可用來幫助進行類比式設計，找尋更多更有用的類比來源以解決問題。】

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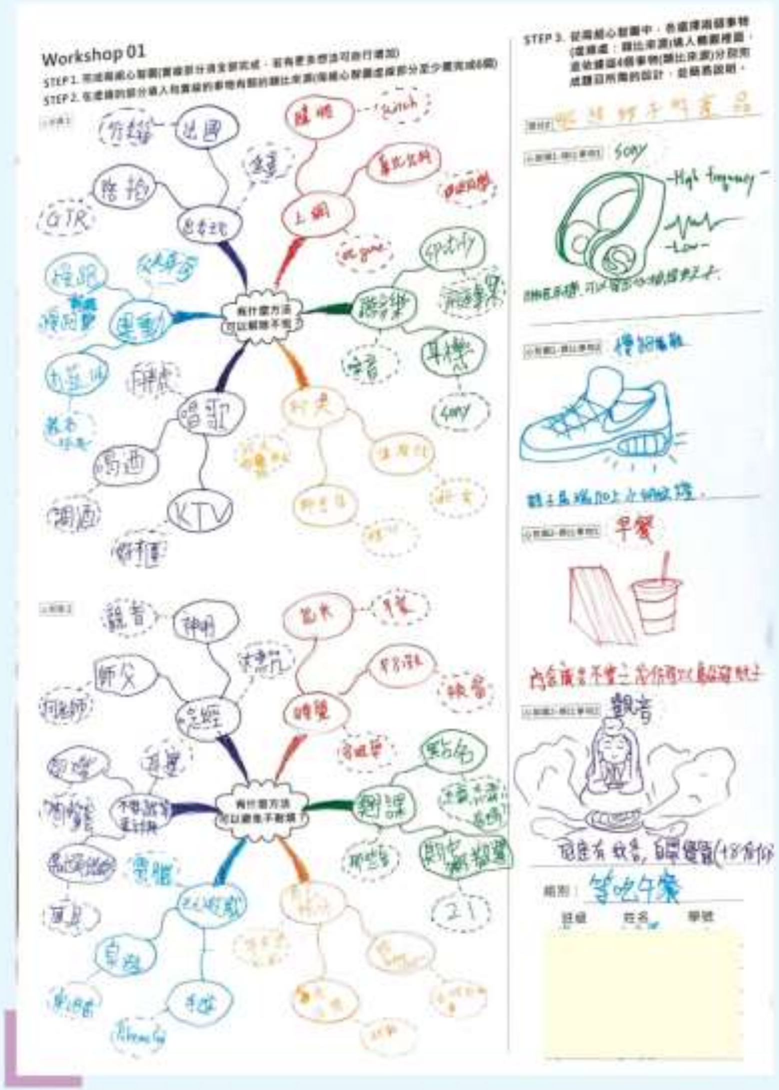

心智圖－腦力激盪工作坊的分組成果例子。分別從「有什麼方法可以解除不悅？」和「有什麼方法可以避免不耐煩？」為起點，自由聯想任何有關的概念當作分支出來的節點。例如先聯想到「聽音樂」、「運動」等概念，然後又從「聽音樂」聯想到「Spotify」、「耳機」等。最後再用這些概念當作類比來源，設計一種驅趕蚊子的產品。

可提升學生的創造力

在臺北科技大學「創新思考」通識課程的兩個班級進行這項教學實驗，看看字詞樹能不能有效提升學生的類比思考和創造力。第一班是使用字詞樹與腦力接龍的實驗組，第二班是使用心智圖與腦力激盪的對照組。

為了回答「第一班學生的創造力是不是比第二班進步得更多」，這兩班學生在進行工作坊之前和完成所有工作坊之後都填寫兩種創造力量表，第一種是涵蓋學術、表現、機械與科學、藝術、日常等五大領域創造力的 Kaufman 領域創造力量表，第二種是包括流暢性、變通性、獨創性、精密性等認知層面的威廉斯創造性思考活動量表。如果第一班的工作坊成果與創造力量表進步幅度普遍比第二班好，就比較有信心說，字詞樹－腦力接龍法比心智圖－腦力激盪法更能提升學生的創造力。

這兩個班都是一百多人選課的大班級，第一班和第二班分別有 100 位與 121 位學生完成所有實驗階段。結果令人振奮，無論是哪種量表，使用字詞樹－腦力接龍的第一班都比使用心智圖－腦力激盪的第二班有顯著的進步。

平均而言，第一班的五大創造力領域有大幅的進步（74%），是第二班的 8 倍以上；尤其是機械與科學、表現、藝術等創造力有很大的差距。此外，第一班的認知層面創造力平均進步幅度也不小（31%），是第二班的 7 倍多；其中第一班的精密力提升了兩倍以上（244%），將近第二班的 6 倍。在有效的類比式設計構想比率方面，第一班超過 6 成（67%），是第二班的 1.3 倍。

兩班產出的字詞樹和心智圖也有樹狀結構上的差異，第二班的節點與分支數量都比第一班多，主要是心智圖的繪製過程較自由鬆散，適合用來尋找及延伸更多元的點子。但字詞樹受到根必須是關鍵動詞、節點必須是動詞、分支必須是語法或語意關係等限制，一定程度約束了產生大量點子的發散思考，使得構想發展不如使用心智圖所找到的多與廣。

用新技術鍛鍊創造力

從某個意義上說，字詞樹就是一種特殊的心智圖，在工作坊裡甚至是僅能用動詞表達的心智圖。那些綜合運用字詞樹與腦力接龍解決日常設計問題的學生，比起使用心智圖與腦力激盪的學生更能集體產生有效的類比式設計構想，而且更能提高個人的創造力。為什麼字詞樹具有這樣的優勢？筆者的解釋是字詞樹限定動詞當作節點和語意關係為主的分支，雖然降低了思考過程中的類比來源與構想數量，但是提高了這些類比來源與構想的品質，在量與質的綜合效用上贏過了心智圖。換句話說，關鍵是由動詞構成的語意網路。

前面提到的 Linsey 等人曾報導他們的字詞樹－腦力接龍工作坊裡也使用一種稱為「詞彙網路」（WordNet）的結構化概念及概念關係的語言資料庫（參見 https://wordnet.princeton.edu/），幫助學生更有效地尋找相關的動詞，雖然實際的績效並不清楚。

無論如何，中央研究院語言學研究所也發展一套中文詞彙網路（Chinese WordNet）提供給各界檢索使用，目前由臺灣大學語言學研究所黃居仁教授的團隊維護（http://lope.linguistics.ntu.edu.tw/cwn/）。我們可以用這類系統增強學習創造力的效能，更值得開發出各種應用字詞、詞彙網路等新技術的創造力學習系統。

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Balancing abstraction of knowledge representations helps students generate novel ideas: A case study on biologically inspired design

Abstract

Introduction

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Abstract

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Can abstraction help ideation? A case study on biologically inspired design

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Abstract
In learning biologically inspired design (BID), the mapping process from problem to bio logical inspirations is crucial for generating novel ideas. This study determines the effect of knowledge representations related to design problems and inspirations on students' nov elty of ideas generated in BID. Forty-four industrial design undergraduates were divide into four groups in four BID workshops. In each workshop, the design problem was rep resented in rule- and case-based formats while 220 biocards (inspirations were in concret and abstract formats. Each group took turns to create ideas using one of four knowledg representation combinations of rule- or case-based design problems with concrete o abstract inspirations in each workshop and completed all of them throughout the work shops. Results showed that both ideas generated using the rule-based design problem wit the concrete inspiration and the case-based design problem with the abstract inspiratio had higher mean novelty scores than others. That implies that exclusively using highl structured representation in learning BID is not conducive to generating creative ideas Accordingly, this study proposes a dual-track process for helping students achieve bette innovation by balancing abstraction of knowledge representation in problem-solving.

Keywords Biologically inspired design · Conceptual design · Creativity · Design process · Innovation

Introduction

Analogical reasoning is a crucial method for acquiring new knowledge and solvin problems (Vosniadou, 1988). In this process, similarities are drawn between the existin knowledge (source) and the unknown concepts (target), followed by mapping from th source to the target in order to generate a new understanding or new solution for the tar get (Gentner & Markman, 1997). Analogical reasoning is used in the field of design-by analogy (DbA), which transfer knowledge from inspiration source to the design problem

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to be solved (Fu et al., 2013; Fu et al., 2014; Gentner, 1983; Gentner & Markman, 199 Linsey et al., 2012). Since analogical reasoning can assist the mapping of inform tion from biology to technology (Fayemi et al., 2017; Shu, 2004), it is commonly us in biologically inspired design (BID), a specific approach in the broader definition DbA by (Cheong et al., 2011). BID uses biological phenomena as inspiration sourc for novel products (Benyus, 1997; French, 1988), sustainable development, and innov tion (Helms et al., 2009). Thus, it has been widely applied to design education to bett match the requirements faced by professionals (Ahmed-Kristensen et al., 2014; Len et al., 2018; Luo et al., 2020; Santulli & Langella, 2010).

The problem-driven BID approach is a practical and common design approach BID. This approach starts with problem analysis, searches and selects biological ph nomena as inspiration sources, develops solutions, and finally generates design ou comes (Fayemi et al., 2017; Lenau et al., 2018). Considering that problem-driv approaches are usually used for industrial companies and creativity training (Co cia, 2017; Han et al., 2019; Shanta & Wells, 2020), we used the problem-driven B approach as the methodological framework of the current study. For a given desi problem in problem-driven BID training, students generally need to acquire and app two kinds of knowledge delivered by the teacher: knowledge of *design problems* a *inspiration sources*. The knowledge of design problems introduces design problems help students reframe the problem, define needs and constraints, and abstract desi problems into technical problems in problem analysis; the knowledge of inspiratio sources is the information from which students get inspiration and generate solutions.

The way of expressing and transferring knowledge is called *knowledge representati* (KR) (Davis et al., 1993; Markman, 2013). A significant feature of KR is that knowled can be expressed at the *high* levels of abstraction, which means lacking specific attri utes, or *low* levels of abstraction, which means full of specific attributes (Nokes & Ohl son, 2005). For example, in a design problem about "water filtration", the engineeri principle of water filtration is the knowledge at the high level of abstraction. In contra an actual water filter product is the knowledge at the low level of abstraction (see su section, Knowledge representation of design problems, for more details). For anoth example, in the inspiration source of "bat's echolocation system", "physical waves w be reflected back when they encounter obstacles" is the knowledge at the high level abstraction, whereas "sound waves emitted by bats will be reflected back when th meet insects" is the knowledge at the low level of abstraction (see sub-section, Biolog cal phenomena representation of inspirations, for more details).

Since the two kinds of knowledge are significant in the problem-driven BID and c be represented at different levels of abstraction, the question is: which abstraction lev (high or low) of KRs is more conducive to problem-driven BID innovation? So far is known, past studies did not have consistent views about knowledge of design pro lems: some studies argued that the knowledge of design problems at the high level abstraction was the basis for solving problems (Bernal, 1967, 1971; Chi et al., 198 Goldschmidt & Sever, 2011;Shanta & Wells, 2020), while other studies believed th the knowledge of design problems at the low level of abstraction could bring innov tion (Dutta & Bonissone, 1993; Herring et al., 2009; Khisty & Khisty, 1992; Schö 1983, 1987). As for the knowledge of inspiration sources, most studies argue that insp ration sources at the high level of abstraction positively impact students' creative thin ing (Casakin, 2004; Christensen & Schunn, 2007; Linsey et al., 2008; Toh et al., 201 Especially, biological phenomena represented at the high level of abstraction led innovation (Lenau et al., 2015).

Although previous researches pointed out the impact of KRs on innovation at different abstraction levels, these researches of KRs of design problems and inspiration sources were independent of each other and hardly discussed together in the problem-driven BID. Therefore, this study aims to investigate the combined effect of KRs of design problems and inspiration sources at the high or low level of abstraction on novelty in the problem-driven BID process. In this study, we reviewed the problem-driven BID process, introduced the KRs of design problems (rule- and case-based) and inspiration sources (abstract and concrete) at different levels of abstraction, and investigated the combined effect through a design workshop. The results implied that the *balance* of abstraction between KRs of design problems and inspiration sources for innovation should be considered for problem-driven BID in design education.

Related work

Problem-driven biologically inspired design processes

In the problem-driven BID, students reframe the problem in a specific representation of behavior or function and explore the mapping to some biological systems for inspiration. Lenau et al. (2018) compiled five conventional problem-driven BID processes, namely the five-step sequential model mentioned by the International Organization for Standardization (ISO (2015), the six-step design spiral established by the Biomimicry Institute (Deldin & Schuknecht, 2014)), the Georgia Tech model (Helms et al., 2009), the Paris Tech model (Fayemi et al., 2014), and the biocard model established by the Technical University of Denmark (Lenau et al., 2010). Although these problem-driven BID processes have different steps, they share a similar framework with alternation of *abstraction* and *concretization*: (1) the needs and constraints are defined from the given problem, and the concrete design objectives are abstracted into technical problems and biology requests (*abstraction*); (2) biological phenomena are identified and selected as analogical sources for the abstracted technical problems or biological terms (*concretization*). Subsequently, biological phenomena are abstracted into solutions (*abstraction*); (3) the solution strategies are concretized into design outcomes such as sketches and prototypes (*concretization*).

A case study of *polymer syringe* designed by Lenau et al. (2017) is used to illustrate the problem-driven BID process. This case pointed out a recycling problem: medical metal injection needles became hazardous waste requiring special treatment after use. When facing this problem, the designer first identified the need to use plastic needles and constraint that penetration performance of plastic needles was much worse than that of metal needles, which was abstracted into *penetrating by soft things* (*abstraction*). Next, the designer identified the biological phenomenon that the mosquito proboscis is quite flexible and thin that can penetrate the skin by the supporting organism and serrations with vibration and impulse (*concretization*). The designer then abstracted this biological phenomenon into a mechanical vibration solution to assist the plastic needle (*abstraction*). Finally, a plastic needle prototype with vibration unit was designed according to this solution (*concretization*).

Both abstraction and concretization are significant in problem-driven BID processes. Abstraction helps designers find unfamiliar biological phenomena to avoid design fixation (Ahmed-Kristensen et al., 2014; Lenau et al., 2018). For example, when facing the issue of *keeping warm*, if it is not abstracted into a technical problem, designers may generally find the biological phenomena of polar bears or penguins keeping warm by their fur, and

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solutions are easily limited to *using warm materials*. If the problem is abstracted into *controlling temperature*, designers may find the biological phenomenon of butterflies opening or closing wing scales to control temperature, and then produce unique solutions. Concretization is essential for finding appropriate biological inspirations for abstracted technical problems and implementing solutions (Fayemi et al., 2017). Therefore, a problem-driven BID process with explicit abstraction and concretization phases should be helpful for innovation.

Fayemi et al. (2017) unified twelve different problem-driven BID models within the last decade into the Paris Tech model after extending their previous work (Fayemi et al., 2014). Compared to other BID processes mentioned above, the Paris Tech model provides the most detailed steps (eight steps in two 4-step phases) to describe biomimicry design and is thus one of the most comprehensive processes. Besides, the Paris Tech model proposes and illustrates a clarified summary of the alternations of abstraction and concretization, whereas other processes pay little attention to this. The process is divided into two 4-step phases designed as a double symmetrical *abstraction-specification* cycle: the first phase (step 1–4), including *problem analysis*, *abstract technical problem*, *transpose to biology*, and *identify biological models*, focuses on a technology problem to biology transition; the second phase (step 5–8), including *selecting the biological model*, *abstract biological strategies*, *transpose to technology*, and *implement*, in turn, continues a reverse process from biology to technology. Each phase starts at a lower abstraction level, through a higher abstraction level, and finally ends at a lower abstraction level. Because of the Paris Tech model clearly showing the most detailed steps and alternations of abstraction and concretization, this study used this model for the problem-driven BID process.

Knowledge representation of design problems

The mental processes and representations involved in designing means design cognition (Hay et al., 2017), including employing a practical approach to frame problems and generate solutions (Cross, 2001). Problem framing is frequently identified as a critical feature of design expertise (Cross, 2004; Dorst, 2011). Oxman (1997) stressed the importance of *knowledge representation* (KR) in problem framing for creative design, including transforming from the implicit knowledge to representational structure that enables modification and change. The transformation from knowledge into representational structures makes novel modifications and changes within, or through, those representations. As the first step of the Paris Tech model, *problem analysis* aims to frame the problem, and identify needs and constraints (Fayemi et al., 2017). Students need to know the knowledge related to the design problem before the problem analysis (Becker & Mentzer, 2015; Chi et al., 1981); otherwise, they may not know how to start or what to do with this problem. For instance, supposing students face the design problem of *water container design for maritime distress* without relevant knowledge, they may not know what functions the water container should have. However, if students have the knowledge of water filtration related to this design problem. In that case, students may probably define the needs that the water container should filter and store water.

Considering students' knowledge of a given design problem is generally limited, the KR of design problems is usually provided to students in design training and it is usually presented in forms at high and low levels of abstraction: *rule-based* and *case-based* (Dutta & Bonissone, 1993; Kolodner, 1997). Rule-based knowledge is usually formed by abstract rules for problem-solving, whereas case-based knowledge contains similar concrete cases

that have already been completed (Chi et al., 1981; Dutta & Bonissone, 1993)). In example of water filters (Fig. 1), rule-based knowledge contains water filtration princi that introduce the water purification procedures. In contrast, case-based knowledge c tains the existing filter case that illustrates how to use a portable water filter and its com nents (see more details in Rule- and case-based design problems).

Since knowledge of design problems can be expressed in rule- and case-based repres tations, which one is better for the problem-driven BID? So far as is known, there are lo standing conflicting views of supporting rule- and case-based knowledge leading to in vation, but few of them had directly looked into the problem-driven BID. Opposite vi of supporting rule- and case-based knowledge have existed for a long time. In the view supporting case-based knowledge, the case-based study will help students learn conc and practice in more usable ways (Dutson et al., 1997; Kolodner, 2002). Designers v hold insufficient rule-based knowledge relevant to the design problem can alternatively related product cases to overcome these cognitive limitations and lack of inspiration (H ring et al., 2009). Other studies also suggested that rule-based knowledge lacks creativ and that engineering education should include case studies (Khisty & Khisty, 1992; Sch 1983, 1987). Schön proposed the reflective practice viewpoint (Schön, 1983, 1987), wh questioned the effectiveness of traditional knowledge structuring methods for professio and proposed that rule-based knowledge applications have greater effectiveness in i environments. Moreover, because virtual environments are highly complex, undefined, uncertain, applying rule-based knowledge in problem-solving is difficult.

Contrary to this, some research has proposed that rule-based and scientific knowledg essential. When encountering certain problems, students must first acquire general kno edge before solving concrete problems (Bernal 1967, 1971). Once the problem has b framed, textual stimuli are helpful as a part of the design process due to their knowle inside (Goldschmidt & Sever, 2011). The scope of the knowledge used is rather broad engineering design, for example, experts tend to use physics principles that will be use solutions to analyze and categorize problems (Chi et al., 1981). Some students' abilit such as physics and maths, are significantly correlated to their overall success in engin ing problem solutions (Shanta & Wells, 2020). Additionally, cases were usable only solving certain problems and under specific conditions because they are not as universa rules. (Dutta & Bonissone, 1993). Furthermore, students may misunderstand case stud thus hindering them from obtaining knowledge (Kolodner et al., 2005). They may e

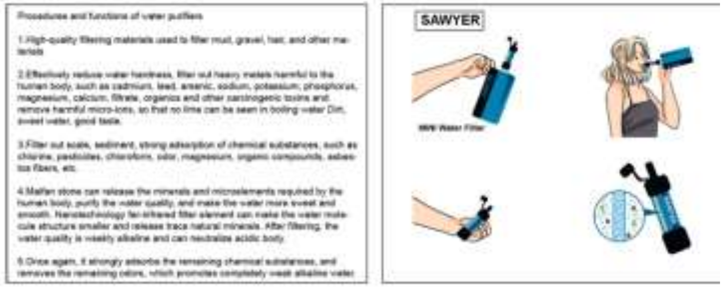

Fig. 1 Rule-based (left) and case-based (right) knowledge of water filter

become accustomed to case studies that provide default solutions, which would result in them being unable to innovate (Linsey et al., 2010; Sio et al., 2015).

Problem analysis, as the first step, has a significant impact on problem-driven BID innovation, while KR of design problems influence the problem framing in problem analysis, which means that KR of design problems may play a significant role in problem-driven BID innovation. Although the above studies have pointed out the impacts of rules- and case-based knowledge on innovation, few of them directly investigated their impact on problem analysis in the problem-driven BID. Therefore, the influence of rules- and case-based KR of design problems on problem-driven BID innovation is worth investigating.

Biological phenomena representation of inspirations

According to the Paris Tech model, searching and determining the biological phenomenon as inspiration is a significant step. Students must select existing biological phenomena as the analogical source to apply in their design, during which the representation of analogical source affects the students' thinking and design performance (Goldschmidt & Smolkov, 2006; Lenau et al., 2015). Biological phenomena can be represented in low and high levels of abstraction, namely, *concrete* and *abstract* descriptions. Concrete descriptions are usually used in biology to characterize actual natural phenomena, mainly focus on the form of the phenomenon, or briefly describe the process and behavior; abstract descriptions are typically used in engineering to express abstract and structural relationships in functional principles, mainly explain the principles and the reasons behind biological phenomena. For example (Fig. 2), a concrete description for the biological phenomenon, *bat echolocation*, would be "the bat makes the sound waves in order to find insects, sound waves are reflected back to the bat's ear after they encounter the insect, and then the bat positions the insect's location", which describes the process by which bats find food through echolocation. An abstract description of this biological phenomenon would be "when waves encounter the object surface, all waves are reflected off except vertical waves", which explains the fundamental principle of echolocation (Denny, 2004; Wilson, 2015).

Concrete descriptions of biological phenomena may result in fixation, which limits innovation (Jansson & Smith, 1991; Purcell & Gero, 1992, 1996). Lenau et al. (2015) indicated that abstract descriptions of biological phenomena are conducive to overcoming design fixation. In previous studies, when faced with the design problem of "positioning", the concrete description of bat echolocation may limit students' thinking regarding using sound waves for positioning. However, the abstract description of this biological phenomenon enables students to consider other waves (such as electromagnetic waves) for positioning. Studies have indicated that the abstract structural relationship between the target and source has a considerable innovation-guiding effect in analogical thinking (Casakin,

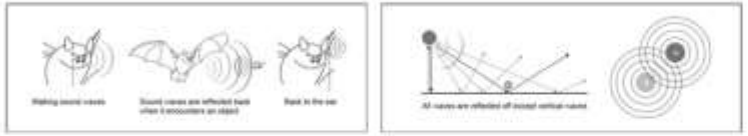

Fig. 2 Concrete (left) and abstract (right) biological phenomena of bat sonar. Images are redrawn from Denny (2004) and Wilson (2015)

2004; Christensen & Schunn, 2007; Gentner, 1983; Gentner & Markman, 1997). However, Casakin (2004) revealed that only some students could understand this abstract structure. Toh et al. (2013) noted that complex abstract structures might inhibit student innovation and Lenau et al. (2015) indicated that not all students have abstract thinking abilities. Additionally, concrete forms (e.g., colors, materials, and shapes) are essential for product innovation in certain fields. For example, the appearance of a doorknob indicates whether users should push or pull to open the door; the computer operating system interfaces commonly use the concrete symbol of a trash can to represent the delete functions. Well-designed products employ familiar forms to transmit the unfamiliar connotations of new designs (Hekkert & Cila, 2015; Krippendorff, 2007).

Previous studies have indicated that although abstract structural relationships positively impact the innovation of designs, concrete forms are indispensable. Take the example of Excalibur Toilet Brush, designed by Phillippe Starck. First of all, the design problem is to elevate the everyday activity about the toilet brush. The student searched for inspiration in a DbA approach. He caught the implicit similarity of abstract structure between the activities that "a user draws the brush from the stand to clean a dirty toilet humbly" and "King Arthur pulled the Excalibur sword out of the stone to do battle with the enemy epically". Starck adopted some concrete elements to shape the brush to enforce the user to acknowledge the negative emotion when using the toilet brush and flip that negative into a playful adventure. For example, the form of the protective scabbard and round point of fencing sword are related to the handle and bristle of the brush, respectively, invoking an image of jousting with the dirty toilet in fencing épéé for joyful user experience (King & Chang, 2016). Therefore, reexamining the effects of concrete descriptions on the biological phenomena in BID is needed.

Biologically inspired design tools

BID requires tools that provide the *knowledge representation* (KR) of biological phenomena at suitable levels. Because of the limited duration of workshops, BID tools should be convenient, enable participants to understand biological phenomena quickly and support the BID abstraction process (Fayemi et al., 2014)). Numerous databases on BID are available for acquiring innovations from biological phenomena and applying them to BID (Fu et al., 2014). For example, AskNature (https://asknature.org) (Deldin & Schuknecht, 2014), an online, social media-based database aiming to share knowledge in biology, contains essential information on biological phenomena and BID applications. The categorization and navigation methods of the AskNature database are similar to those of typical search engines and are suitable for nonprofessional users. Besides, biocards are a BID tool used to cultivate students' innovation (Ahmed-Kristensen et al., 2014; Lenau et al., 2015). Biocards employ short and precise text descriptions and sequential figures to describe biological phenomena (see more details in sub-section, *Concrete and abstract biocards*), thus facilitating user understanding and aiding in the abstraction process. Because the content in BID databases may be cumbersome, workshops that directly apply BID databases must expend considerable time to search and understand biological phenomena. Therefore, we employed AskNature as the search engines to obtain biological phenomena and then presented these phenomena as biocards. The present study used biocards to describe biological phenomena and as a tool to support the BID process.

Research objectives

In light of previous studies, the current study was developed to explore effect of KRs of design problems (i.e., rule- and case-based) and inspir (i.e., concrete and abstract) on novelty in the problem-driven BID pro investigated whether rule- or case-based design problems provides more port for innovation. Some research posited that rule-based knowledge i science or design fields (Bernal, 1967, 1971; Chi et al., 1981). Howeve knowledge is more practical when encountering new problems (Schön, while rule-based knowledge may limit creative thinking (Dutta & Boni To determine these inconsistent arguments, we proposed the following hy

Hypothesis 1 (H1). *The case-based design problem representation has impacts on the novelty of ideas than the rule-based design problem represent*

Next, we aimed to determine whether abstract or concrete descriptions phenomena provide greater support for innovation. Concrete descriptions design fixation, which is unconducive to innovative thinking (Jansson & However, abstract descriptions of biological phenomena are conducive t design fixation (Lenau et al., 2015). Although abstract structural relations lenging to understand (Casakin, 2004; Toh & Miller, 2013), abstract d the structural relationships between the target and source can provide support for innovation than concrete descriptions (Casakin, 2004; Gent man, 1997). Therefore, we proposed the following hypothesis.

Hypothesis 2 (H2). *The abstract inspiration has more positive impacts on ideas than the concrete inspiration.*

Finally, to determine the combination of design problem with insp sentations that provides the most support for innovation, we proposed hypothesis established based on the theoretical foundations of H1 and H2

Hypothesis 3 (H3). *The combination of case-based design problem repre abstract inspiration has more positive impacts on novelty of ideas than the c rule-based design problem representation with concrete inspiration.*

Method

Participants

The experiment participants in this study were 44 students (14 males ar aging from 20 to 23 [$M = 20.9$, $SD = 0.73$]). All participants were underg the Department of Industrial Design of National Taipei University of Tec

Materials

This study conducted four workshops on the following topics: (A) mouse trap design; (B) water container design for maritime distress; (C) design to reduce premature infant mortality rate in developing countries; and (D) smart logistics transportation system design. Each workshop included four types of materials based on combinations of knowledge representations, namely *rule-based* design problem with *concrete* inspiration (RN), *rule-based* design problem with *abstract* inspiration (RA), *case-based* design problem with *concrete* inspiration (CN), and *case-based* design problem with *abstract* inspiration (CA).

Rule- and case-based design problems

Fig. 3 illustrate the rule- and case-based design problem representations used in topic B (water container design for maritime distress). The rule-based design problem representation introduces water categories, procedures and functions, and design principles. For example, tap water, which has undergone chlorine filtering and impurity removal, must be boiled before drinking; the first step of a five-step procedure requires high-quality filtering materials used to filter mud, gravel, hair, and other materials; demands or issues that must be clarified and defined during maritime disasters. In the case-based design problem representation, the usage processes and scenarios were employed to illustrate a water purifier product. When camping with children in overseas countries, the hygiene of tap water and bottled water is questionable. The water filter uses numerous U-shaped hollow microfiber tubes that filter out 99.9999% of pollutants and provides a 0.1-μm absolute filter to filter bacteria, protozoa, and microplastics. Besides, a 16-oz reusable pressurization bag can be folded when empty, thereby conserving packaging space.

Concrete and abstract biocards

Biocards are used as inspiration representations in this study. Two hundred and twenty (220) pairs of concrete and abstract biocards were designed by the 44 participants under the authors' guidance. By searching biological phenomena examples in AskNature and referencing the existing biocards (Lenau et al., 2015), each participant created five concrete and abstract biocards encompassing topics related to mammals, fish, insects, and plants. The biocards comprise *biological phenomena*, *biological mechanisms*, and *functional principle*. The content of biological phenomena and biological mechanisms in concrete and abstract biocards are the same, whereas functional principle differs. Functional principle's discrepancy embodies in the different terminology, emphasis, and schematic diagram: the concrete biocard uses terminology from biology and focuses on biological behavior and processes, and the schematic diagram reflects the morphology of biological organism; the abstract biocard uses terminology close to the engineering field, focuses on presenting underlying principles, and the schematic diagram reflects the abstract underlying principle. For example, in "selective penetration of mouse aquaporins" (Fig. 4), both of them describe how aquaporins help the cells regulate their osmotic pressure (i.e., biological phenomena) by allowing water molecules to pass through the aquaporins (i.e., biological mechanism). About functional principle, the concrete biocard details the process of aquaporins allowing water molecules to flow in and out of the cell membrane rapidly, with biological terms such as "aquaporins"

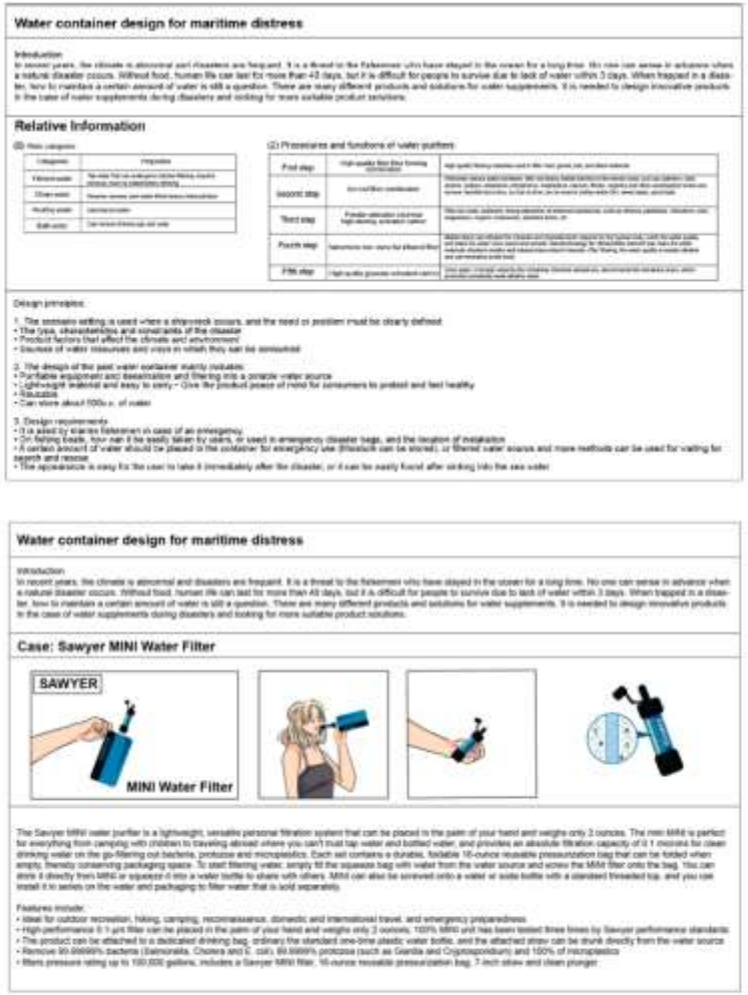

Fig. 3 Rule-based (top) and case-based (bottom) design problem representations of water filter container

and "cell membrane", and the schematic diagram illustrates the appearance of water molecules and aquaporins. In contrast, the abstract biocard details how positive dipoles enable water molecules to rearrange and pass through, with engineering terms such as "positive dipoles", and the schematic diagram illustrated interaction between molecules.

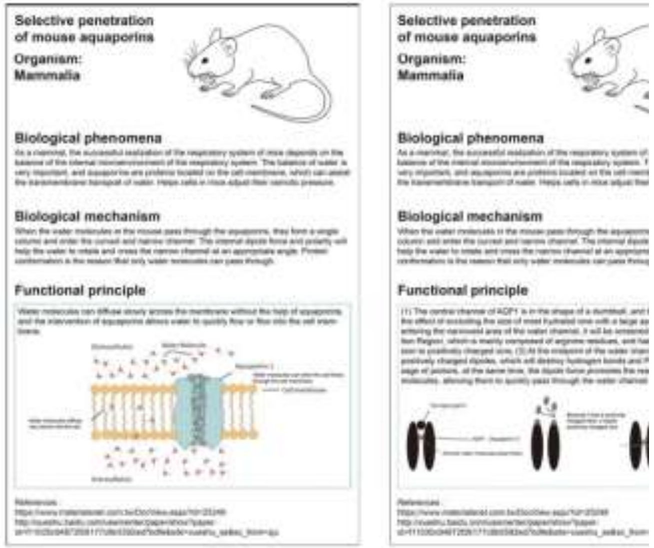

Fig. 4 Concrete (left) and abstract (right) biocards of selective penetration of mouse aquapori

Design worksheet

The design worksheet was printed in A3 size. Each participant was required the title of biocards in the bottom quarter of the worksheet. The remaining th of the worksheet were blank for the participants to draft design ideas for their s cards topic and note a brief design description.

Procedures

The experiment process adhered to the BID process of the Paris Tech model (F 2014). Because of the workshop duration limitations and training purpose, the focused on steps 1–8. In Step 9, three judges conducted the novelty assessmen judges are one first-year industrial design doctoral student and two first-yea design master's students with industrial design training experience from 5 to they are trained for two semesters of design creativity and BID. Before the firs the overall process of four workshops (that were held weekly) was introduce ticipants, who were then divided into four groups. In each workshop, each of th of materials (RN, RA, CN, and CA, see sub-section *Materials*) was distribute ticipants in one of the four groups; the types of materials received by the four not repeated. Afterward, the participants in each group received different types during the four workshops. At the beginning of each workshop, each particip the same set of materials in his or her group and a design worksheet, and then

explained the design topic of the current workshop, the workshop duration, and how to use the design material and worksheet. All participants conducted the workshop in the same classroom, and each participant individually inspected their design material for four hours and completed the innovative design on their design worksheet. Once a workshop was finished, ideas generated during this workshop were evaluated for novelty. After completing all four workshops, all ideas were divided into four idea groups according to the type of materials received, named RN, RA, CN, and CA idea groups.

Novelty assessment

Ideas generated through BID can be evaluated in terms of various factors, and the most common one is creativity. Furthermore, creativity can be evaluated using various indicators, including the quantity, quality, diversity, and novelty of the ideas (Peeters et al., 2010). In particular, novelty is commonly used to evaluate the creativity of ideas (Fu et al., 2013; Lenau et al., 2015) and refers to uniqueness or rarity in ideas (Dean et al., 2006). Fu et al. (2013) proposed a novelty evaluation method centering on idea rarity. This method employed the definition of function proposed by Hirtz et al. (2002) to determine whether the idea provides functional solutions for the design problems. Besides, this method assumed that ideas conceived by fewer people exhibit novelty. Therefore, we employed the method proposed by Fu et al. (2013) to evaluate the novelty of ideas.

In the novelty assessment method, a sub-function group consists of possible solutions. Each idea provides one or more solutions for the sub-function group. Moreover, each sub-function group comprises three components: (1) *what*, the type of sub-function (e.g., energy or a part of the human body such as the foot; (2) *how*, the components that implement the sub-function (e.g., pedal); and (3) *compound*, descriptions of the compound functions of *what* and *how* (e.g., the foot stomps on the pedal). The novelty (n) of each idea is calculated as follows:

$$n = \frac{1}{i} \times \sum_{i} \frac{\sum_{j} w_j \times R}{1} \tag{1}$$

R represents the rarity score for the idea's solution for the jth component of ith sub-function. The overall rarity score of ith sub-function is calculated as the weighted mean of jth component in ith sub-function, and the recommended weights of *what*, *how*, and *compound* are 0.5, 0.3, and 0.2, respectively (Fu et al., 2013). Furthermore, the novelty score of each idea is obtained by calculating the unweighted means of rarity scores of all i sub-function. R for each idea's solution is computed in the following equation:

$$R = \frac{T - C}{T} \tag{2}$$

T, in this study, is the total number of solutions for a given component of a given sub-function, and C is the number of solutions of the same type as the current solution. Before the novelty assessment, the three judges (same as the three judges in the section, *Procedures*) individually assessed ideas for inter-rater agreement at two levels: (1) whether an idea provided a solution to a given sub-function; (2) type of *what*, *how*, and *compound*. The first level got a good agreement (*Cronbach's* α=0.901, and the second level also got a good agreement of *what* (*Cronbach's* α=0.926), *how* (*Cronbach's* α=0.958) and *compound*

(*Cronbach's* α = 0.961). The three judges reached an agreement after discussing differences and then assessed the novelty of ideas.

For example, in the filter concept design (Fig. 5), the filter only allows water to run through by extruding it, inspired by the selective penetration of mouse aquaporins. This idea provides the solution for one sub-function, "transfer objects" (i = 1), and this idea's *what* is "pressure", *how* is "extrusion device", and *compound* is "using the extrusion device to filter water by pressure". There are twenty-one solutions (T = 21) for "transfer objects" in design outcome, and the number of solutions with the same *what*, *how* and *compound* of the given idea are seven (C_{what} = 7), one (C_{how} = 1), and one ($C_{compound}$ = 1), respectively. So, calculations of the rarity score in *what* (j = 1), *how* (j = 2) and *compound* (j = 3) are 0.67 (R_{what} = 0.67), 0.95 (R_{how} = 0.95) and 0.95 ($R_{compound}$ = 0.95) according to Eq. (2). And, according to Eq. (1) and the suggested weights (0.5, 0.3, and 0.2 for *what*, *how*, and *compound*, respectively) (Fu et al., 2013), the calculation of the novelty score in this idea is 0.81.

Results

Ideas and novelty

In this study, 44 participants generated 519 ideas (Table 1), with an average of 11.8 ideas per participant (SD = 5.01). The novelty scores of these ideas ranged from 0.10 to 1.00 (N = 519, M = 0.826, SD = 0.145). First, we compared the effects of design problem

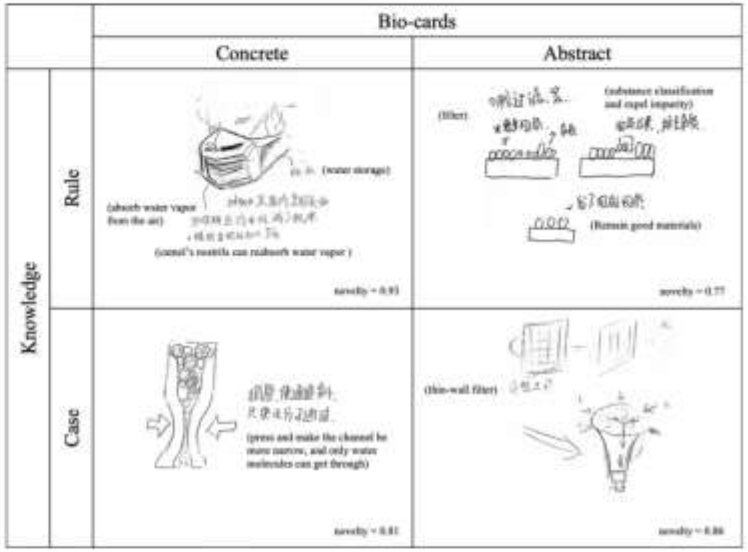

Fig. 5 Idea samples of the water container design for maritime distress

Table 1 Novelty scores of ideas

Ideas		N	Mean	SD	Min	Max
All		519	0.826	0.145	0.100	1.000
KRs of design problems	Rule	259	0.825	0.136	0.470	1.000
	Case	260	0.828	0.153	0.100	1.000
KRs of inspiration sources	Concrete	275	0.834	0.142	0.100	1.000
	Abstract	244	0.817	0.147	0.400	1.000
Groups	RN	135	0.850	0.118	0.470	1.000
	RA	124	0.798	0.149	0.470	1.000
	CN	140	0.820	0.161	0.100	1.000
	CA	120	0.837	0.144	0.400	0.980

(i) RN = *rule-based* design problem with *concrete* inspiration, RA = *rule-based* design *abstract* inspiration, CN = *case-based* design problem with *concrete* inspiration, CA = *case* problem with *abstract* inspiration

representations and inspiration representations, respectively, on the novelty of i tities of ideas and mean novelty score generated from the rule-based desi (N = 259, M = 0.825, SD = 0.136) and the case-based design problem (N = 260, SD = 0.153) are similar. In contrast, Quantities of ideas and mean novelty scor from concrete inspiration (N = 275, M = 0.834, SD = 0.142) are higher than ab ration (N = 244, M = 0.817, SD = 0.147). Second, we compared novelty scores groups (i.e., *rule-based* design problem with *concrete* inspiration, *RN*; *rule-b* problem with *abstract* inspiration, *RA*; *case-based* design problem with *conc* tion, *CN*; and *case-based* design problem with *abstract* inspiration, *CA*). Tal that mean novelty score of RN group was the highest (N = 135, M = 0.850, whereas mean novelty score of RA group was the lowest (N = 124, M = 0.798,

Idea samples are presented in Fig. 5 for topic B (water container design f distress). In this topic B, an idea of the RN group employed the idea that camel reabsorb water vapor as the analogical source and designed a mask that can a vapor from the air for water storage (novelty = 0.93). An idea of the RA gro biological phenomenon of crab filtering materials with its mouthparts as ins designed a water filter device (novelty = 0.77). Moreover, an idea of the CN the biological phenomenon of selective penetration of mouse aquaporins as ins designed a filter device that allows water to pass when pressured (novelty = 0. an idea of the CA group was generated with the inspiration of thin-walled filters ing a filter device (novelty = 0.86).

Hypothesis testing

In hypothesis H1, we anticipated that the case-based design problem represe more positive impacts on the novelty of ideas than the rule-based design proble tation. The purpose was to determine whether using different design problem tions (i.e., rule- and case-based) enables the ideas generation with different validate this hypothesis, we employed an independent-sample t-test to compa elty of ideas generated by the two types of design problems. The results revea novelty of ideas generated using rule- (M = 0.825, SD = 0.136) and the case-b

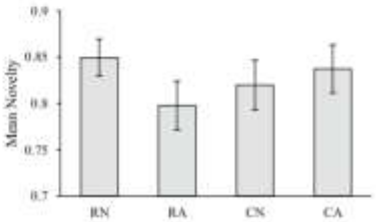

Fig. 6 Error bars (95% CI) of mean novelty of four groups of ideas (N = 519) (RN = *rule-based* design problem with *concrete* inspiration, RA = *rule-based* design problem with *abstract* inspiration, CN = *case-based* design problem with *concrete* inspiration, CA = *case-based* design problem with *abstract* inspiration)

Table 2 Post-hoc comparison between groups

J (Group)	I (Group)			
	RN	CA	CN	RA
RN	–			
CA	0.012 (0.883)	–		
CN	0.030 (0.302)	0.017 (0.793)	–	
RA	0.052 (**0.012**)	0.040 (0.153)	0.022 (0.654)	–

Bold value in brackets indicates that the comparison difference is statistically significant (p-value below 0.05)

(i) Groups are arranged by mean novelty scores

(ii) Mean difference (I—J); p-values are in between brackets (bold values indicate p-value < 0.05)

(iii) RN = *rule-based* design problem with *concrete* inspiration, RA = *rule-based* design problem with *abstract* inspiration, CN = *case-based* design problem with *concrete* inspiration, CA = *case-based* design problem with *abstract* inspiration

problem (M = 0.828, SD = 0.153) did not differ significantly (t = − 0.249, p = 0.804); thus, hypothesis H1 was rejected.

In hypothesis H2, we predicted that abstract inspiration had a more positive impact on the novelty of ideas than concrete inspiration. The purpose was to compare the novelty of ideas generated using the two types of inspiration representations (i.e., biocards with abstract descriptions and those with concrete descriptions). Similarly, we employed an independent samples t-test to compare the novelty of the ideas generated using the concrete (M = 0.834, SD = 0.142) and abstract (M = 0.817, SD = 0.147) inspiration. The results revealed no significant difference (t = 1.352, p = 0.177); therefore, this hypothesis H2 was rejected.

In hypothesis H3, it was supposed that the combination of the case-based design problem with abstract inspiration (i.e., CA) led innovation, whereas the combination of the rule-based design problem with concrete inspiration (i.e., RN) hampered innovation. We adopted the four types of materials as independent variables and the ideas' novelty as the dependent variable and applied a one-way ANOVA. As shown in Fig. 6, the results revealed a significant difference on novelty $F(3, 515)$ = 3.122, p = 0.026, η^2 = 0.018. Because the Levene's test reported that variances were not homogenous (p = 0.023), the Games-Howell test was conducted for post-hoc analysis. As shown in Table 2 (arranged by mean novelty scores), the mean novelty score of CA group (M = 0.837) was not significantly (p = 0.883) higher than RN group (M = 0.850). The results rejected hypothesis H3. Nonetheless, the only significance ($p = 0.012$) of the novelty of these four groups was that RN group was higher than RA group ($M = 0.798$). The mean novelty of CA group was slightly, yet not statistically, significantly higher than RA group ($p = 0.153$); meanwhile, the mean novelty of CN group ($M = 0.820$) was not significantly ($p = 0.654$) higher than RA group. The results indicated a latent boundary between CA and CN groups, meaning RN and CA groups were better than RA and CN groups, which implied that the combinations of low and high levels of abstract representations in either RN or CA groups were conducive to innovation.

Discussion

Completing the experiment, we obtained data about the effects of *knowledge representations* (KRs) of design problems (i.e., rule- and case-based) and inspiration sources (i.e., concrete and abstract) on novelty in problem-driven BID training (i.e., *rule-based* design problem with *concrete* inspiration, *RN*; *rule-based* design problem with *abstract* inspiration, *RA; case-based* design problem with *concrete* inspiration, *CN*; and *case-based* design problem with *abstract* inspiration, *CA*). The main findings from the study were as follows: (1) the effects of rule and case-based design problem representations on novelty did not differ significantly; (2) the effects of concrete and abstract biological phenomena on novelty did not differ significantly; (3) ideas' novelty scores of RN and CA group were the highest, followed by the CN group, and ideas' novelty score in RA group was the lowest.

The first finding did not support hypothesis H1 that cases were better than rules, and it showed no bias towards supporting case-based knowledge (Dutson et al., 1997; Herring et al., 2009; Khisty & Khisty, 1992; Kolodner, 2002; Schön, 1983, 1987), or supporting rule-based knowledge (Bernal, 1967, 1971; Chi et al., 1981); Goldschmidt & Sever, 2011; Shanta & Wells, 2020). The second finding did not support hypothesis H2 and showed that abstract and concrete inspirations had little difference in leading innovation, which did not support previous studies that abstract inspirations were better than concrete inspirations (Jansson & Smith, 1991; Lenau et al., 2015; Purcell & Gero, 1992, 1996). In addition, the third finding showed that different combinations of design problems and inspiration sources impacted novelty. These three findings indicated that if KRs of design problems or inspiration sources were considered separately, it was difficult to judge whether knowledge at a high or low level of abstraction was more helpful for innovation.

The third and last main finding refuted hypothesis H3 that the combination of case-based design problem representation with abstract inspiration (i.e., CA) has more positive impacts on the novelty of ideas than the combination of rule-based design problem representation with concrete inspiration (i.e., RN). The actual result was that the ideas' novelty scores of RN and CA group were the highest, followed by the CN group. The most likely explanation is that students who received the CN materials had to face both KRs of design problems and inspiration sources at low abstraction levels (i.e., *case-based* design problem with *concrete* inspiration), which might increase cognitive loads of *abstraction* in the problem-driven BID process. In contrast, RN group started with the *rule-based* design problem at the high abstraction level, which reduced the cognitive loads when abstracting the design problem into technical problems and biology requests; CA group used *abstract* inspiration, which reduced the cognitive loads when abstracting inspiration into technology.

Although *rule-based* design problem or *abstract* inspiration reduced thinking loads of *abstraction*, the combination of them (i.e., *rule-based* design problem with *abstract* inspiration, RA) led to the lowest mean novelty score. This result might be due to cognitive

loads when facing materials at high abstraction levels. It was challenging to abstract structures and produce innovative ideas for students (Casakin, 2004; 2013), and not all students have enough abstract thinking abilities (Lenau et al., thermore, students must use metaphors to represent abstract functions in conc and products must express their intrinsic functions and image through their app form (Hekkert & Cila, 2015; Krippendorff, 2007). Students who received R could be difficult to understand both the rule-based design problem and abstr tion, which were subjected to considerable cognitive loads of *concretization* i lem-driven BID process.

Materials at overly high or low abstraction levels may obstruct BID's abstrac cretization processes, thereby influencing innovation. Using high abstract co such as RA materials, the participants had difficulty understanding and gener with the cognitive load on the concretization process, thereby leading to un innovation results. By contrast, CN materials were effortless for the participan stand and provided them with concrete forms to support their innovation, but the participants' cognitive load on the abstraction process. The experiment r cated that RN and CA materials facilitated innovation, which was not highly concrete and prevented the participants from sustaining excessive cognitive lo fore, an appropriate *balance* between abstract and concrete forms is crucial for neither is dispensable. This finding is significant for problem-driven BID edu the one hand, it pointed out that both KRs of design problems and inspiration essential for innovation. On the other hand, this finding provided a reference f driven BID training. When preparing knowledge for students, the balance of levels between KRs of design knowledge and inspiration sources should be cons

According to the last finding, we concluded that abstraction and concreti plement each other in the BID. Maintaining a dynamic balance between abst concretization is essential, and this dynamic balance should be integrated int lem-driven BID process. Therefore, we modified the Paris Tech model into a track problem-driven BID process which depicted two paths (RN and CA path

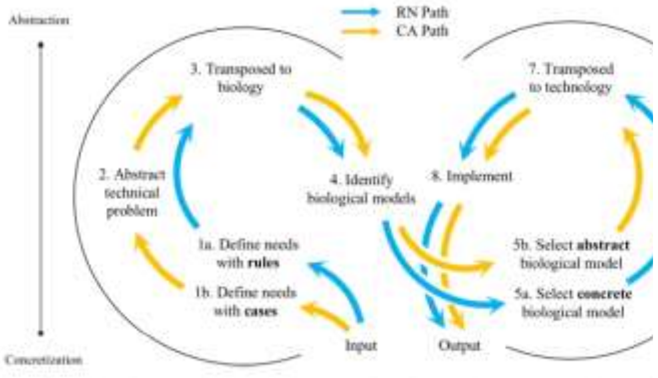

Fig. 7 Balancing abstraction between design problem and inspiration representations in RN = *rule-based* design problem with *concrete* inspiration. CA = *case-based* design problem inspiration

design innovation (Fig. 7). The two paths are roughly similar to each other, except for step 1 and step 5 (step 1a and step 5a for the RN path; step 1b and step 5b for the RN path). We use blue arrows to indicate the RN path and use a yellow arrow to indicate the CA path. RN path starts with *rule-based* design problem representation in step 1 (step 1a, problem analysis with *rules*), then skips step 2 and goes directly to step 3; in step 5, the path selects the biological model from concrete inspiration representation (step 5a, select *concrete* biological model). In contrast, CA path starts with *case-based* design problem representation in step 1 (step 1b, problem analysis with *cases*); in step 5, the path selects the biological model from abstract inspiration representation (step 5b, select *abstract* biological model), then the path skips step 6 and goes directly to step 7.

To better illustrate this modified model, we present two examples designed by students in workshops. The first example is "water vapor reabsorption mask" in the RN path (Fig. 8). When facing the problem, the student first identified the need, "A container that can collect and store water" (step 1a), which was directly abstracted into "Capture and store liquid" (step 3) and skipped the step of *abstract technical problem*. Next, the student identified the biological phenomenon of *camel nasal*, which can reabsorb water vapor (step 4), and select the concrete biological phenomenon that camel's nasal can reabsorb water vapor when the camel breathes (step 5a). And then, the student abstracted this concrete biological phenomenon into "absorb water vapor from the air" (step 6) and further abstracted it into "steam condenses to liquid" (step 7). Finally, an implementation of "a mask that can collect water vapor" was generated (step 8) with the sketch. The second example is "thin-walled filter" in the CA path (Fig. 9). The student first identified the need, "filter water and remove sand, rust and other things" (step 1b), which was abstracted into "remove the impurity and collect water" (step 2), and further abstracted it into "separate other things from liquid" (step 3). Next, the student identified the biological phenomenon of *crab oral cavity*, which can remove impurity in the oral cavity (step 4) and select the abstract biological

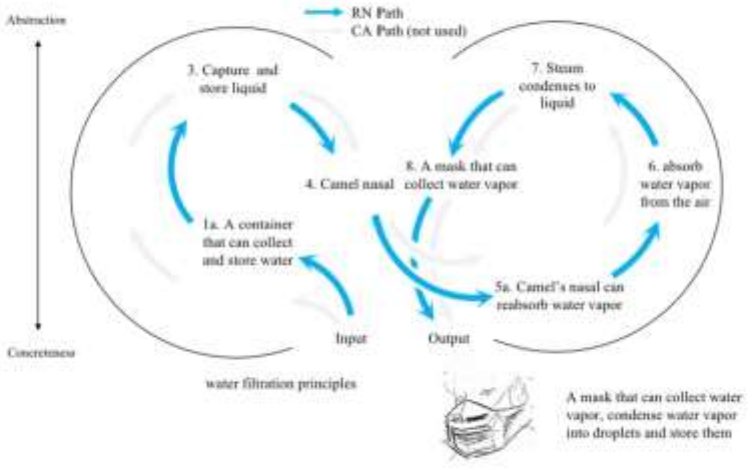

Fig. 8 Example of RN path: water vapor reabsorption mask. RN = *rule-based* design problem with *concrete* inspiration

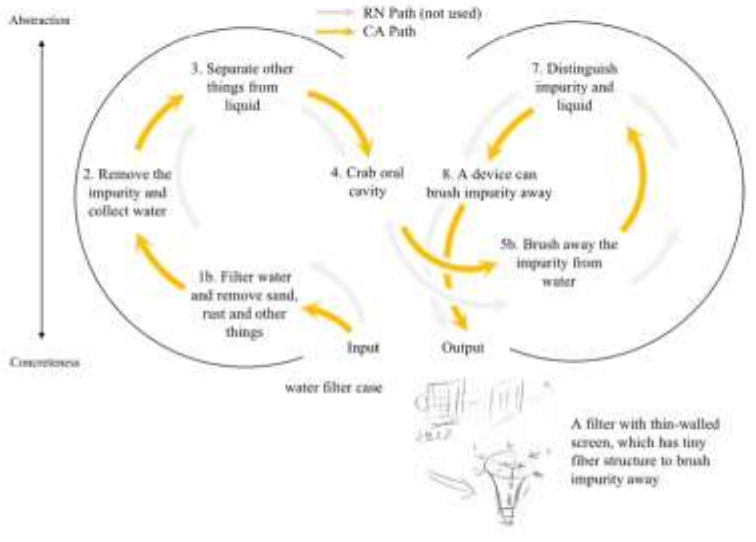

Fig. 9 Example of CA path: thin-walled filter. CA = *case-based* design problem with *abstract* inspiration

phenomenon that "brush away the impurity from water" (step 5b). The student directly abstracted this abstract biological phenomenon into "distinguish impurity and liquid" (step 7) and skipped the step of *abstract biological strategy*. Finally, an implementation of "a filter with thin-walled screen" was generated (step 8).

This study has limitations. First, only extrinsic knowledge (i.e., what all participants learned from the well-described design problems and inspiration provided by such external sources as worksheets) was discussed. However, intrinsic knowledge (i.e., what each participant used to relate the inspirations to solve the problems in a different thinking technique) was not considered, though it may influence the novelty of ideas generated. Second, because of the large number of participants and the focus on the novelty of products rather than processes, this study did not employ think-aloud protocol or participants' self-reports. Instead, all assessments on the novelty were exclusively based on the participants' ideas produced in the BID workshops. Further investigation is needed to explore the participants' intrinsic knowledge in deeper analyses.

Conclusion

The current study investigated the combined effect of *knowledge representations* (KRs) of design problems and inspiration sources at the high or low level of abstraction on novelty in the problem-driven BID process. We have conducted four workshops and provided participants with materials comprising two types of design problem representations (i.e., rule- or case-based) and two types of inspiration representations (i.e., concrete or abstract).

The results revealed that KRs of *rule-based* design problem with *concrete* insp
or *case-based* design problem with *abstract* inspiration (CA) was the most c
novelty in the BID, followed by KRs of *case-based* design problem with *conc*
tion (CN), and KRs of *rule-based* design problem with *abstract* inspiration (
least conducive to novelty. Based on these findings, a problem-driven BID m
balance abstraction of KRs. In order to achieve the balance, KRs could con
based design problem (e.g., product design requirement, function, or princip
crete inspiration (e.g., illustration of animals' behaviors), or *case-based* des
(e.g., product design case) and *abstract* inspiration (e.g., underlying principl
cal phenomena). Furthermore, we proposed a dual-track problem-driven BID
the balance to map the given problems to biological inspirations to help stude
novel ideas. Future research should consider the potential effects of the balanc
tion and more applications of the dual-track process to design education. Our
will guide students to establish a database containing design problems and in
balanced abstraction for the dual-track process. We will then identify challen
dents when applying the dual-track process with the database and optimize th
BID innovation.

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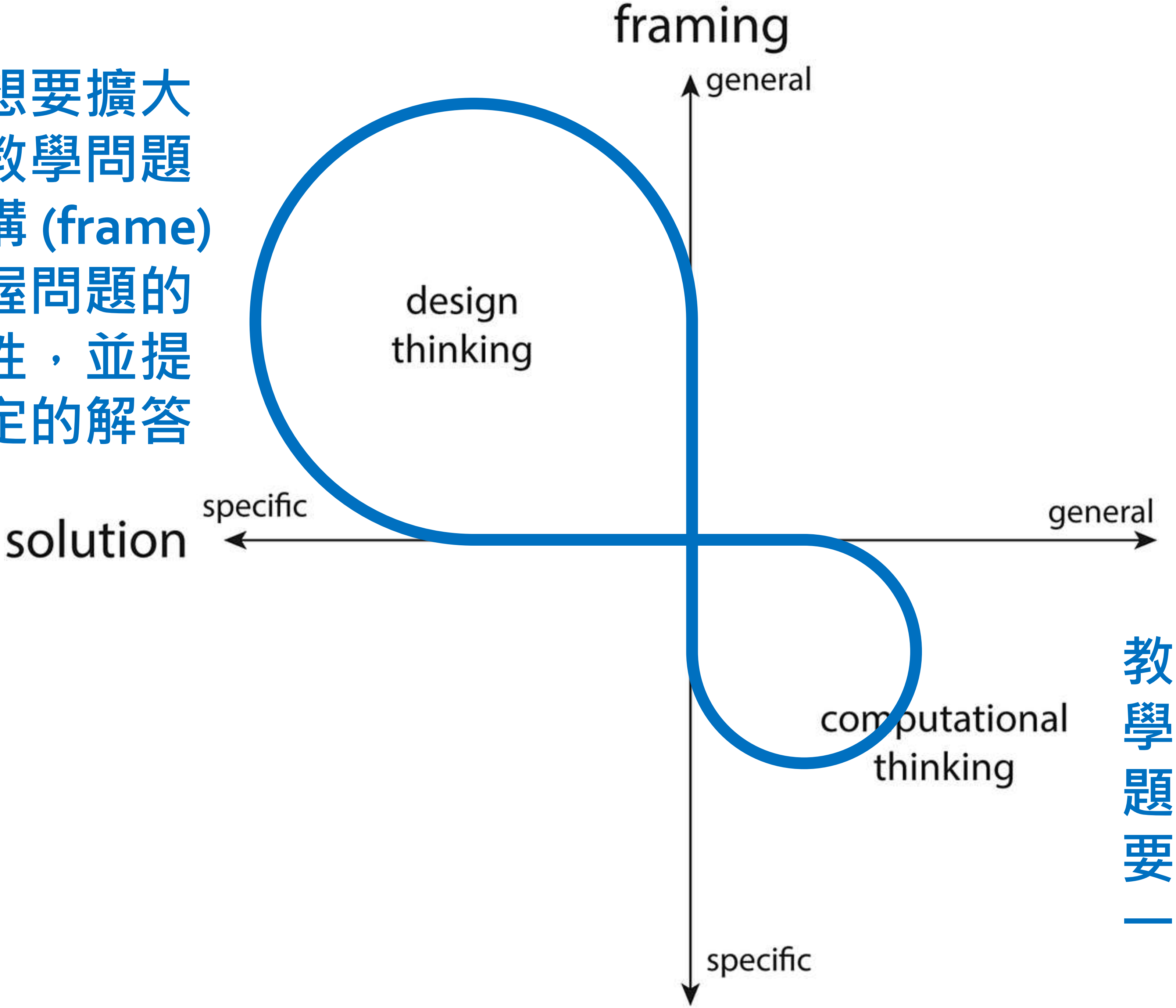
總 結

- 個人動機
- 同理心了解學生與評審的需求
- 善用學校的資源與支援
- 結合教育與專長領域知識，針對教學現場的重要問題，提出可驗證的解決方案
- 透過教學、演講、論文發表推廣成果
- 回饋個人動機、同理心、教學知能...的正循環

教師想要擴大現場教學問題的架構 (frame) 來掌握問題的複雜性，並提出特定的解答



教師想要縮小現場教學問題的架構來將問題抽象化，消除不必要的複雜性，並提出一般性的解答

Thank you.

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