行政院國家科學委員會專題研究計畫 成果報告

建立科技大學電子工程問題的數學解題能力指標與權重值之研究-教學與教材發展策略及其教學實驗
研究成果報告(精簡版)

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壹、前言

在進入二十一世紀且處於高科技研發的環境中，相關工程系學生應強調跨領域之科技學習能力，彰顯出工程問題的數學解題能力提昇之重要性，也決定科技整合與學習成效。換言之，應著重數學跨領域應用之工程解題能力。從產界訪談中發現電子工程問題的數學解題能力是目前科技大學電子工程系學生較弱且最需要學習與加強的，為確保學生在數學與物理等科學應用工程解題的能力，急需培養此能力以切合未來重點產業研發與創新之需求。而產業界與學校任課老師皆認為學生在工程問題解決之轉化、詮釋、驗證等解題能力普遍缺乏，為了能提昇學生此方面之解題能力，由第一年計畫(97 學年度)發展了一套適合學校教學用之電子工程問題的數學解題能力指標，以符合產業界選才、培才、用才之基本需求。其研究結論如下：

1. 建立層級架構與轉銜能力的構面在形成數學問題、數學問題解答、工程問題解答、實際工程問題等四個層級架構下，靠轉化、求解、詮釋、驗證等四種轉銜能力構面運作。
2. 從四種轉銜能力建立向度及其工程問題數學解題能力指標建立轉化、求解、詮釋、驗證等四部份之 10 個向度及 43 項工程問題數學解題能力指標，如表二。
3. 「引導式回答題」之比對及作答方式，可評量科技大學學生電子工程問題的數學解題能力的強弱數學解題與工程解題必需考量學習 ZPD，即要在學生最近之實際發展層次及 ZPD 之最佳化間距下命題或教學。
4. 工程解題的構面與向度之流程，可提供教師作為命題編製的參考在命題前可先依學習目標擬定試題雙向細目表，作為評量依據。
5. 工程問題解題能力指標有權重值的差異此能力指標是有連續性邏輯且不可分割，只是依各種類型與運用工具的不同，而有權重值的差異

為此，持續研究擬定本計畫(第二年計畫)之下列研究目的。

貳、研究目的

基於上述緣由，本研究目的如下：

1. 規劃適用於科技大學電子工程系之電子學教學設計策略。
2. 發展可行且適用科技大學電子工程系之電子學數位教材製作策略。
3. 發展兩種不同層級電子工程系之電子學單元數位教學教材。
4. 發展兩種不同層級電子工程系的單元電子工程數學解題能力指標之評量規準。
5. 建置電子學數位教學平台。

參、文獻探討

一、97 學年度國科會「電子工程問題數學解題能力指標及其權重值之研究」計畫

本計畫國科會 97 學年度(第一年)之研究，分兩階段實施：

第一階段：建立科技大學電子工程數學解題能力指標

經由文獻探討與文件分析所得發展德懷術問卷後，已請不同背景且與本研究專長相關之三位專家諮詢，經修正後實施三次德懷術問卷，獲得此能力指標之四項轉銜能力、十個構面、十八個向度、四十個能力指標。

第二階段：建立科技大學電子工程數學解題能力指標之權重值

本階段實施 AHP 權重值問卷與統計分析，發現四項轉銜能力中以轉化能力(37.06%)及詮釋能力(34.3%)最高；在十個構面方面：以轉化能力之解讀審題(22%)、詮釋能力之詮釋結果(22.7%)最高；在十八個向度方面：以理解題意與舊經驗結合(13%)、詮釋工程問題的解答(11.6%)、工程問題的最佳解(11.1%)最高。

表一　科技大學電子工程數學解題能力指標

能力	構面	向度	工程問題之數學解題能力
A 轉化能力 (37.6%)	A1 解讀審題 (22%)	A11 理解題意與舊經驗結合(13%)	A11.1閱讀理解能力
			A11.2閱讀觀察能力
			A11.2符號使用能力
		A12 理解術語(9%)	A12.1術語概念連結能力
			A12.2工程符號使用能力
A 轉化能力 (37.6%)	A2 分析問題 (6.5%)	A21 找出問題之已知與未知關係(4.1%)	A21.1綜合應用能力
			A21.2專業分析能力
		A22 數學與專業符號形式化(2.4%)	A22.1邏輯分析能力
			A22.2分析專業表徵能力
			A22.3符號表達能力
			A22.4符號連結能力
	A3 轉譯列式 (9%)	A31 擬定解決問題的數學語言(9%)	A31.1抽象概括能力
			A31.2轉譯列式能力
			A31.3轉譯概念連結能力
B 求解能力 (10.7%)	B1 解題策略 (6.5%)	B11 觀察、臆測、驗證 (6.5%)	B11.1選擇策略能力
			B11.2數學知識連結能力
			B11.3圖形連結能力
			B11.4數形連結能力
			B11.5運用邏輯思維能力
			B11.6數學建模能力
	B2 運算處理 (2.5%)	B21 選擇適當的數學方法、運算法則與公式 (1%)	B21.1數學推理能力
			B21.2數學運算能力
			B21.3數學表達能力
			B21.4運用概念連結能力
		B22 運用適當的運算工具 (1.5%)	B22.1運用計算器與圖表能力
			B22.2運用電腦軟體能力
	B3 求出解答 (1.7%)	B31 數學語言的解答 (0.6%)	B31.1數學表徵能力
		B32 判斷解答的合理性 (1.1%)	B32.1符號運算判斷能力
			B32.2專業判斷能力
C 詮釋能力 (34.3%)	C1 轉述解答 (11.6%)	C11 解讀數學語言 (3.9%)	C11.1數學語言轉換能力
			C11.2解讀專業表徵能力
		C12 轉述數學結果 (7.7%)	C12.1轉述數學結果能力
			C12.2轉譯列式結果能力
	C2 詮釋結果 (22.7%)	C21 詮釋工程問題的解答 (11.6%)	C21.1描述結果表達能力
			C21.2邏輯歸納能力
		C22 工程問題的最佳解 (11.1%)	C22.1詮釋表達能力
			C22.2連結使用具有模式能力

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表一　科技大學電子工程數學解題能力指標(續)

D 驗證能力 (17.5％)	D1 驗證結果 (11.3％)	D11 數值的正確性 (5.9％)	D11.1轉譯演算能力
		D12 波形的正確性 (5.4％)	D11.2驗算能力
			D12.1運用工具能力
	D2 應用評估 (6.3％)	D21 驗證結果解決問題 (3.8％)	D21.1專業建模能力
		D22 修正與改良 (2.5％)	D22.1專業設計的能力
			D22.2專業應用評估能力

二、從鷹架學習理論架構建立系本位課程之教學設計策略與教材製作策略之理論基礎

從國內外文獻之獲得對本研究的啟示有下列四項：

1. 一個學習活動或評量的最佳化 ZPD(最近發展區)的上限與下限都不能超出學習者的能力範圍，否則若能力範圍訂的太低，會讓學習者的 ZPD 停留在原地，導致學習沒效果；若能力範圍訂的太高，會讓學習者的學習鈍化導致放棄。
2. ZPD 的間距必須考量學習者之學前能力(過去的學習與經驗背景)與學習目標之潛在能力。
3. 學習鷹架的設計應包含垂直鷹架與水平鷹架兩個層次：
   在垂直鷹架方面：依學習者的學前能力及 ZPD 的間距，不但可加強銜接課程的能力且可逐漸將認知的學習複雜化，以培養其應用能力。在水平鷹架方面：引導者在教學或評量活動設計時，其學習內容應配合學習者的學前能力與經驗，統整相關課程的思維與應用。
4. 需要藉助外來的媒介作為激化酵素的動力，此媒介即為教材或評量中之邏輯、符號轉換、概念、符號、數字與文字等心理學工具。對學習者而言，是權威性的、值得信賴的，否則激化動力不會產生。

三、克伯屈(W. H. Kilpatrick)的理論--主學習、副學習、附學習

克伯屈(W. H. Kilpatrick)主張課程與教學設計，應以學生為中心，將課程目標區分為主學習、副學習、附學習等三項。

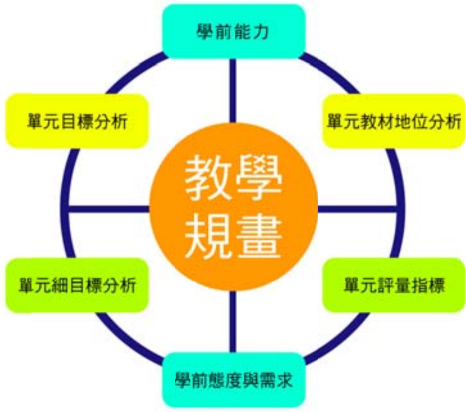
1.主學習：學習時所欲直接達成的教學目的，其內容以知識為主，技能、理想或態度為輔。

2.副學習：以教學相關之概念或延伸思考等知識、技能的學習。

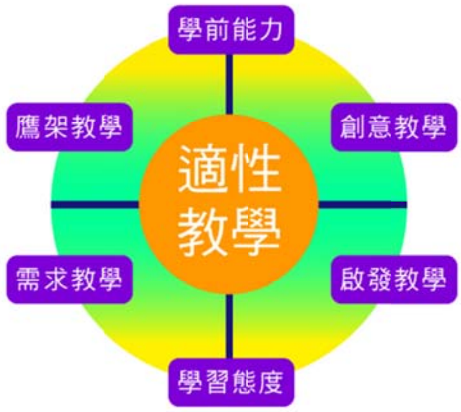
3.附學習：學習時所養成之有關理想、工作態度、學習態度等的學習。

四、教學設計策略與適性教學

依學生學前能力、學習態度與需求等兩個向度，擬定單元教材地位分析、單元目標分析、單元細目標分析、單元評量指標等教學設計策略，如圖二。並依圖三所示在考量學生學習能力與學習態度下，擬定適性之教學目標，即從四個象限中選擇適宜的教學目標，此適宜目標可依學生成長及學習成效的不同做彈性的調整。



圖二　教學設計策略



圖三　適性教學

肆、研究方法

本計畫採文獻探討、文件分析、專家訪談、專家諮詢、焦點團體等研究方法，實施教學策略與教材發展之可行性評估，

一、文獻探討與文件分析

本計畫在能力分析、教學設計、能力評量、鷹架學習等相關理論探討下獲得研究之成果，計包括下列五大部分：

1. 瞭解鷹架學習理論如何應用於電子工程相關科目中，並設計出鷹架學習歷程架構。
2. 研擬科技大學電子工程問題之數學解題能力之教學設計策略草案。
3. 研擬科技大學電子工程問題之數學解題能力之教材製作策略草案。
4. 研擬在能力指標架構下之電子學單元能力指標評量規準草案。
5. 以鷹架學習歷程為架構自編能達成科目教學目標之電子學數位教材。

二、專家訪談與專家問卷

一方面全面了解不同層次之教學現況、學生能力及面臨之教學問題；另一方面評估教材與教學平台之適用性。

三、專家諮詢會議

本研究將配合研究進程的需要，召開專家諮詢會議。其目的旨在對所擬定之科技大學電子工程問題數學解題能力之電子學教學策略、教材製作策略、能力分析架構下之能力指標評量規準、自編電子學單元教學之數位試用教材等草案提供意見，並修正實施焦點團體訪談問卷與問題等草案。確保本研究之建構效度。

四、焦點團體

本計畫所實施之焦點團體訪談法，在考量樣本偏差下分兩組團體，每一組成員分別為：與電子領域相關且具有電子學實際教學經驗的科技大學公立與私立教師各二位、五年內從科技大學電子工程系畢業生一位、與電子相關產界主管一位、與電子相關產界工程師一位等同質性高的專家共七位。兩組焦點團體(北部與南部各辦一場)合計十四位，兩組分別在不同時間內針對問卷之每一道題進行焦點團體互動與討論，取得每一組一致性的結果填答，並作紀錄與錄音。訪談結束後，以兩組專家討論之結果做一致性分析，取其結果作為本研究的資料。

伍、結果與討論

一、研究結果與討論

(一)擬修科技大學電子工程問題的數學解題能力之電子學教學策略

依據第一年研究所得之「科技大學電子工程問題數學解題能力指標與權重值」，以鷹架學習歷程架構擬定與修正科技大學電子工程問題的數學解題能力指標之電子學教學策略。

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1.多元學習—重視學習行為的改變

本研究依克伯屈(W. H. Kilpatrick)的理論，所提出之主學習、副學習與輔學習，擬訂了學習行為改變之多元學習構念，如圖四所示。

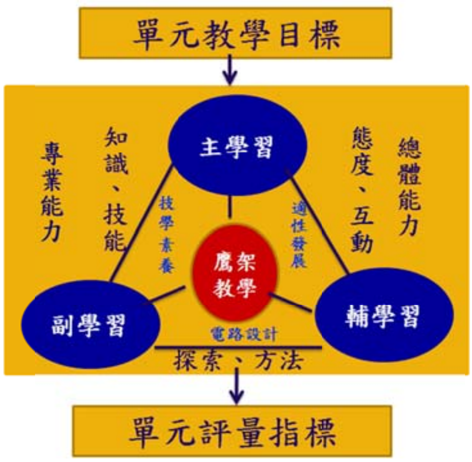
2.整合型之鷹架教學概念架構—找出適宜之 ZPD

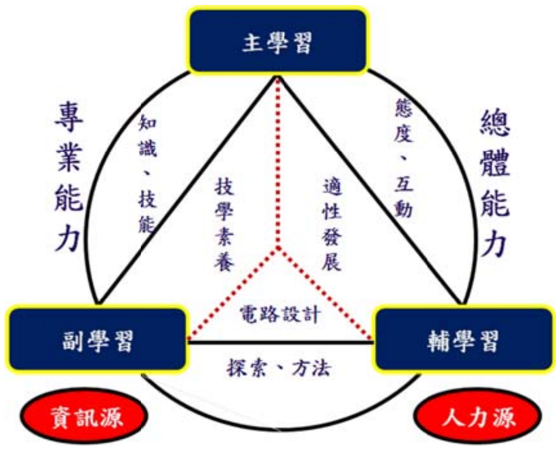
學習內容應配合學習者的學前能力、學習經驗及 ZPD 間距，統整相關課程的思維與應用，如圖五所示。。

3. 重視個人的資訊源及人力源—培養解決問題及設計應用的能力

運用各種資源與學習方法，從學習經驗中，不斷擴增個人的資訊源—專業能力，不斷增強個人的人力源—總體能力，進而從經驗學習中培養解決問題及設計應用的能力，如圖六所示。

圖四　學習行為改變之多元學習概念架構



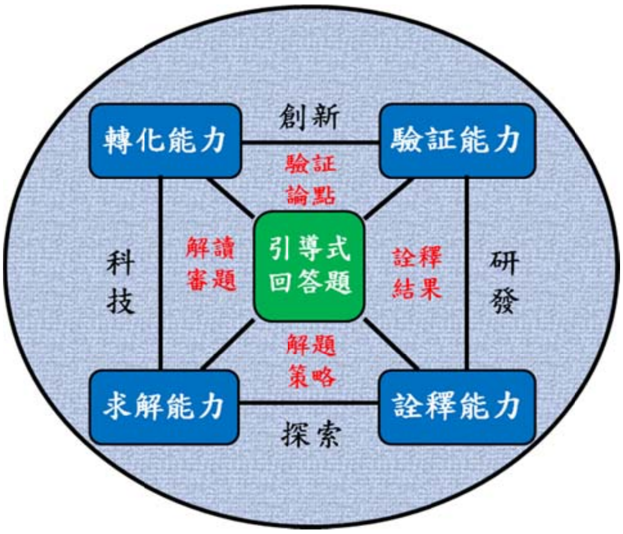


圖五 整合型之鷹架教學概念架構

圖六 電子工程問題之數學解題能力的電子學教學設計策略

(二)擬修科技大學電子工程問題的數學解題能力之電子學教材設計策略

從鷹架教學的概念架構，配合學習者的學前能力、學習經驗及 ZPD 間距，編製「引導式回答題」，並依電子工程問題數學解題的四種能力為架構，在考量各構面的權重值下，擬定了本研究之電子學教材設計策略模式，進而編製適合各種層級及各年級之五種引導式回答題的型式：一般式、詮釋式、建模式、運用工具式、合作學習式等五種，如圖七所示。



圖七 電子工程問題之數學解題能力的電子學教材設計策略

(三)發展兩種不同層級電子工程系之電子學單元數位教學教材。

以鷹架學習歷程為架構自編「引導式回答問題」,使其能達成科目教學目標之電子學數位教材,共有九個單元,其單元名稱如下:

1. 單元一:運算放大器
2. 單元二:二極體
3. 單元三:BJT 雙載子接面電晶體
4. 單元四:FET 場效電晶體
5. 單元五:差動放大器
6. 單元六:頻率響應
7. 單元七:回授
8. 單元八:輸出級與功率放大器
9. 單元九:濾波器與調諧電路

(四)發展兩種不同層級電子工程系的單元電子工程數學解題能力指標之評量規準。

本研究自編單元電子工程數學解題能力指標之評量規準及評分表,以本研究預試第二題之五位學生測試為例,如下表二。

二、研究結論與建議

(一) 研究結論

1. 在電子學教學策略方面

(1)採多元學習方式,重視學習行為的改變,如圖四所示。

(2)學習內容應配合學習者的學前能力、學習經驗及 ZPD 間距,統整相關課程的思維與應用,如圖五所示。

(3)重視個人資訊源及人力源的培養,以強化解決問題及設計應用的能力,如圖六所示。

2. 在電子學教材設計策略方面

(1)重視解讀審題、解題策略、詮釋結果、驗證論點等教材設計,如圖七所示。

(2)在命題前可依學習能力及學習目標,擬定試題雙向細目表。

(3)依各年級學生的能力及需求,選擇適宜之五種引導式回答題型式,編製教材與命題。

(二)建議

1. 對採本研究教學之任課老師建議

對於下列各項應能全盤之認同與了解:

(1)建立鷹架學習之觀念

(2)了解所任教班級之學生之學前背景

(3)引導式回答題如何建立在鷹架學習的觀念上

(4)引導式回答題的命題原則

(5)引導式回答題的評量原則

(6)以評量的結果修正試題「可能發展區」的間距

(7)本模式若學生適應性沒問題，可延伸至能發揮創造力或研發性的問題上

2.對電子工程學系發展的建議

(1)重視高中職數學與微積分與工程數學之銜接落差

(2)編輯「電工數學」之增廣與補救之銜接教材

(3)建立以培養科技大學學生電子工程問題的數學解題能力為主之系本位課程

(4)建立以理論與實驗科目，由同一位教師任課的課程安排

表二 工程問題數學解題能力指標之評量規準及教師總評表--預試第二題

科技大學學生電子工程問題的數學解題能力機制	預11	預12	預13	預14	預15	總評	能力分析
1.1 我能理解題意與舊經驗結合	A	A	A	A	A		
1.2.我能理解題目中的術語	B	B	A	B	A	對A類放大器之「意義」與「特性」之轉述能力較差	1.2-2
2.1 我能找出問題之已知與未知關係	A	A	B	A	B	預13、預15學生不太會逆向思考，口試提醒後預15可以答出	2.1-1 2.1-2
2.2 我能分析數學符號與形式	A	A	A	A	A		
3.1 我能擬定解決問題的數學語言	A	A	A	A	A		
4.1 我能觀察、臆測、驗證此題目							
5.1 我能選擇數學解題方法、運算法則與公式	A	A	B	B+	C	1.功率三個公式忘掉，爾後考試應給予參考公式 2.有兩位學生計算錯誤	5.1-2 5.1-3
5.2 我能運用適當運算工具(計算器或電腦軟體)	A	B+	A	A	B		
6.1 我能求出本題數學語言的解答	A	B+	A	A	B	受上一題的影響	6.1-1
6.2 我能判斷本題解答的合理性	A	A	A	B	C	題目中所指的「結果如何」不會判斷，顯示表達能力不足	6.2-1
7.1 我能解讀本題的數學語言	A	A	C	A	C	不會解讀轉換效率與A類放大器的最大效率之比較	7.1-2
7.2 我能轉述本題的數學結果	A	A	B	A	B+	對於轉換效率與A類放大器最大效率比較，轉述的不完整	7.2-2
8.1 我能詮釋本題的工程問題的解答	A	A	A	A	A		
8.2 我能詮釋本題工程問題的最佳解	A	A	B	A	A	預15學生表達能力不足	8.2-1
9.1 我能驗證本題數字的正確性	A	A	A	A	A		
9.2 我能驗證本題波形的正確性	A	A	E	C	E	預12、預13、預15學生直流工作負載線不會畫	9.2-1

10.1 我能驗證本題的結果解決問題	A	A	E	A	A	預 15 學生不知如何驗證是否為最佳的設計方式	10.1-1
10.2 我能修正與改良本題	A	A	E	E	E	預 12、預 13、預 15 三位學生實務經驗明顯不足	10.2-1
本題總評討論所得的總分	98	94	69	87	73		

說明：1.預試學生以「預××」表之，如:「預 11」為第一所預試學校之第一位預試學生
2.試測學生答對百分比：A--100% ; B--70% ; C--50% ; D--30% ;E--0%

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姓名	支紹慈	**單位**	資訊傳播系	**職稱**	助理教授
出差事由 **(會議、研習名稱)**	參加 BAI2010 International Conference				
出差期間	99 年 7 月 5 日 ～ 99 年 7 月 9 日，共計 5 日				
出差地點	Kitakyushu, Japan		**主辦單位**	International Business Academics Consortium	
參與人員	有 28 國家發表人(約 400 人)參加，包括本院鄭國順院長、支紹慈老師、熊亮原老師等參加。				
主席或貴賓致詞摘要	Conference Chair Dr. Wenchang Fang：Welcome to the 2010 International Conference on Business and Information. The opening ceremony provides the opportunity to honor the best papers and to recognize the contribution of the many people who made this meeting possible. I also like to thank the support from local host and program co-chair Dr. Hajime Tozaki, Weseda University. We want to express our appreciation for the valuable assistance form Kitakyushu city in organizing BAI2010 Conference.				
會議或研習內容概述	1.7 月 5 日下午註冊。 2.7 月 6 日--7 月 7 日兩天論文發表，共十二場次(A—L)每場次約 4-8 篇發表人，涵括資訊管理、電子商務、企業管理與各種相關科學類論文發表。				
會議或研習心得與建議	大會將各場次分類：本人為 7 月 7 日上午 08：20—10：00(H6 場次)第六順位發表【Applying Math Problem-Solving Competence Indicators and It's Weight-Value to Engineering Problems】講演十二分鐘，聽講者提問踴躍，有兩位國外教授提問有關能力相關問題，均一一答覆。 1. 大會分為三天發表共分為 A-L 十二場次包括：商管、科技、休閒管理、電子商務、健康管理、技職教育、資訊等來自二十多國之教師、博班、碩班等研究生英文報告，是一項嚴謹的研討發表會，可以建議本校也可舉辦國際研討會為本校爭取經費。 2. 大會的活動每 session 有一名 chairperson 會做介紹，尤其是在報告後的問答題問非常深入，顯現各 chairperson 能對報告者之文章有深入了解，大會有許多台灣國立大學研究生也有須多科技大學學生參加，建議本校研究生多多參與。 3. 大會選出 22 篇最佳論文並在開會中頒獎，是一項良好的規劃，最佳文章作者一一出列受獎，並在發表中提出精闢論點，顯現大會對於文章評審制度之水準。 4. 大會主席報告有 471 篇文章被接受，也特別提出福崗市長的協助並熱烈歡迎台灣及世界各國學者專家來參加會議，盼能建立良好關係，也為當地帶來盛大學術氣息，尤其是教育部張司長特別以官方身分出席大會並講話希望建立日本與中華民國兩國永續學術關係。 5. 大會宣布明年將在泰國曼谷舉辦 BAI2011 國際研討會，本人擔任論文評審委員，建議本校教師多多參予，可強化我校學術地位。				

後續應辦工作	將獲得與會人員相關建議與提問，彙整與修正後修正本文英文之撰寫，轉相關高階期刊之投稿。
會簽單位	無
附註	1. 出差人須先上人事室網頁下載「出差情形報告表」填妥後，至學校網頁首頁之使用者登入後點選「出差報告管理系統」，再點選「上傳出差報告」會出現「出差報告作業系統」頁面。將此頁面中的教職員工編號與表單序號填入出差人所填寫「出情形報告表」中之教職員編號與表單序號.並填妥「出差報告作業系統」的頁面（主旨說明須與出差事由一致）.上傳出差報告表等資料後點選確定送出。會議有重要宣達或後續應辦工作，務必儘速陳報主管，並會簽相關單位。 2. 列印本表與出差旅費報告表粘至粘存單併同請款。 3. 申請差旅費時，須一併附上開會(或研習)通知單。 4. 紙張不夠時，可自行拷貝後再撰打。 5. 請將本表單粘貼至粘存單後面。

Applying Math Problem-Solving Competence Indicators and Its Weight-Value Engineering Problems

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ABSTRACT

The aim of this paper is focus on the problem-solving ability which related to engineering education and mathematic problems. Based on the Delphi and AHP approaches, this research constructed four-dimension competence indicators and components about mathematical transition, resolution, explanation, and verification, as well as their framework firstly. Next, comply with the scaffolding theory and concept of Vygotsky's zone of proximal development *(*ZPD), a semi-structured guidance questionnaire was developed to collect the evidence and feedback so that it could be used to modify and verify the feasibility of competence indicators. The findings of this questionnaire included: 1) the transform ability took 37.6% of whole weight and was paid attention to the most, and the interpretation ability took second place of 34.3%; 2)The consequence of interpretation took 22.7％ of whole weight, and the interpretation moderation took 22.0％. 3) Understanding the meaning of the questions in every key element weight which combined with old experience accounted for 13.0% of whole weight, 11.6% of interpretation engineering in project question took second place. The main conclusions are as follows

1. A 4-tier structure and 4 dimensions on the abilities to transform and articulation were established.
2. A 10 elements and 43 items of math problem-solving abilities to engineering problems.
3. The transforming and interpreting abilities should be emphasized during the process of the instruction.
4. The Contrast of leading questions and its answering approaches can be used as the way of assessing the strength of math problem-solving abilities to engineering problems.
5. These competences indicators are continuously and inseparably *based on the logicality and on the difference of each weight*ing *value.*

Keywords: engineering education, mathematic problem-solving, competence indicators

INTRODUCTION

Statement of Purpose

In the 21 century when the technology is highly developed and applied around us, students in the engineering related field should focus on the cross-border technology learning abilities. It manifests the importance of improving the abilities of applying math problem-solving competence to engineering problems, which also determines the effects of learning and technology integration. In other words, the importance of applying mathematics to engineering problems should be emphasized. From the interviews with the industry, applying math problem-solving abilities to electronic engineering problems is the weakest link and yet most needed skill among the students in the technology universities. But these abilities are crucial for the R&D in the future focused industries. Thus, it is an urgent task to ensure that problem-solving abilities in the science applications, such as in the mathematics and the physics, being developed among students. Both the industry and teachers in the universities agree that, in general, students lack of the problem-solving abilities to transform, interpret, and verify for engineering problems. In order to develop such abilities among students, competence indicators of applying math problem-solving abilities to engineering problems that is suitable for teaching in schools need to be developed so as to fulfill demand from the industry.

Objectives of the Research

As described in the previous section, the objectives of this research are as follows:

(1) to review problem-solving theories in mathematics and the content of the core competence theory;

(2) to establish the competence indicators of applying math problem-solving abilities to engineering problems in the technology universities.

(3) to establish the weight value of math problem-solving competence indicators to engineering problem in the technology universities

Methodology

The research methods in this study, including literature review, interviews and consultations with experts, and Delphi Technique, are elaborated as below:

Literature Review

In this research, two leading researches and literatures will be reviewed to explore the problem-solving theories in mathematics, the content of core competence theory, and the theories in competence analysis, so as to compare and contrast various competence analysis methods.

Interviews with experts

Through the interviews with teachers in the universities who have the first-hand information about the characters and abilities of the students, the major content of the Delphi questionnaires are used as the modifications of the competence indicators of applying math problem-solving to the engineering problems in the technology universities.

Consultations with experts

The first consultation was conducted with 3 experts with different backgrounds: the competence indicators developed from literatures and interviews with experts were modified from a qualitative perspective and adopted as the base of the Delphi questionnaire design.

The second consultation meeting was held with teachers in the universities, managers and engineers from the electronic companies, graduates (left school for more than 5 years) from Department of Electronic Engineering, National Taipei University of Technology who completed the Delphi questionnaires. Coupled with the results from the Delphi questionnaires and the modifications of the questionnaires with the experts, it was to ensure that the competence indicators of applying math problem-solving to the engineering problems in the technology universities were developed to achieve the objectives of this research.

Delphi Technique

Based on the literature review and the interviews with experts, the Delphi questionnaires were conducted three different times. The experts who were dispersed in different locations expressed their opinions and views through a structured communication procedure. Each time when the questionnaires were collected, the opinions and views from the experts were consolidated and the value of mean, mode, and standard deviation of each indicator item were calculated as the reference statistics for the next round. Finally, the consistency of the results was verified and the qualitative analysis was conducted as the conclusions and the base of suggestions of this research.

The 11 targets of the questionnaire included 2 experts with practical experiences in the electronic related field, 5 teachers with practical experiences in teaching electronic related courses in the technology universities, 2 teachers with mathematics background, and one manager and one engineer from the related industry.

Testing Evaluations

10 students from both National Taipei University of Technology and Lunghwa University of Science and Technology were tested with the “leading questions”, based on ZPD (the Zone of Proximal Development) theory, both in writing and in oral, to understand the possibility of improving the abilities of applying the math problem-solving abilities to electronic engineering problems among students in technology universities and its feasibility.

Data Analysis

The data analysis methods in this research include:

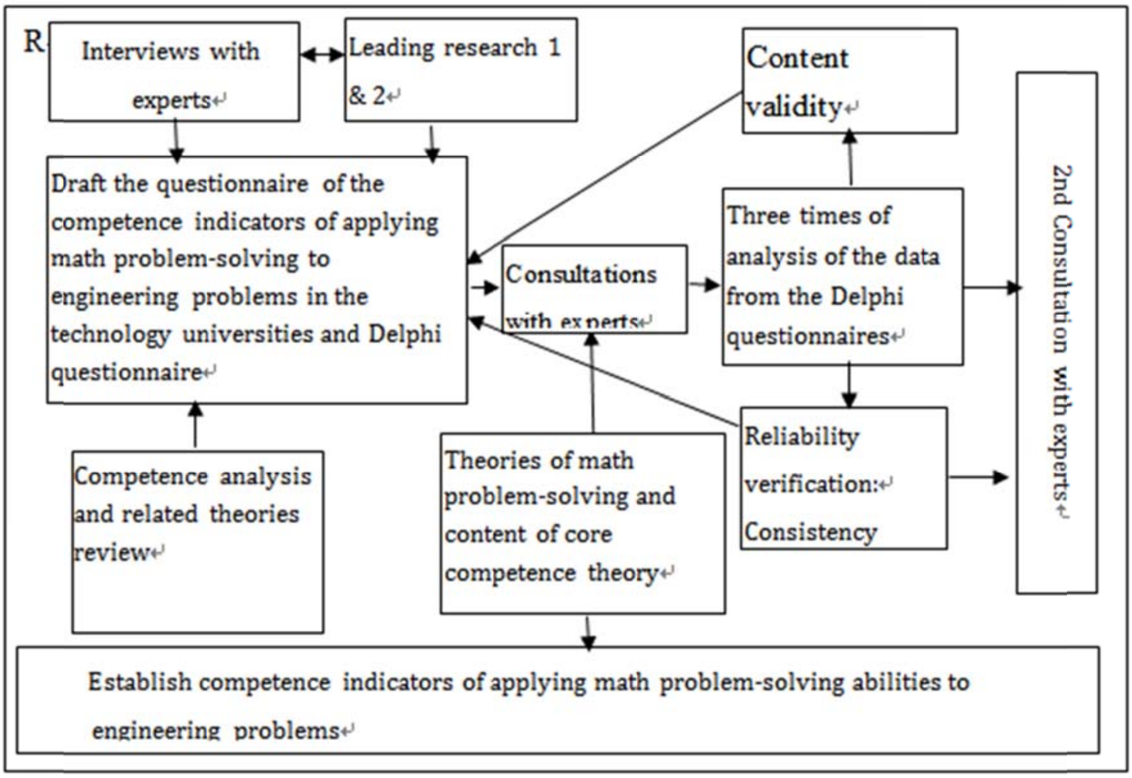
1. Concentrated opinions from Delphi experts: The value of Mean (M) represents the tendency of opinions concentrated from Delphi experts; the value of Standard Deviation (SD) is the best indicators for the degree of the data dispersed. The larger the number is, the more dispersed the data are, and vice versa.

2. The consistency of the opinions from Delphi experts: While analyzing the data from the questionnaire, when $|Mo-M| \leqq 1$, it means the consistency of the opinions from Delphi experts is high. When $|Mo-M| > 1$, it means the opinions from Delphi experts are in disagreement.

3.The definition of the competence indicators of applying math problem-solving abilities to engineering problems from the Delphi survey is: When the value of M is larger than 3.80, and the value of $SD < 1.00$, $|Mo-M|) \leqq 1$ and the importance of the indicators is above 4.

Research Structure

Figure 1. Research Structure



ITERATURE REVIEW

After reviewing related math problem-solving concepts and theories and the content of core competence theory, the results from the literatures will be analyzed and discussed from the aspect of theories and applications as the research direction in this study. Research directions of this study in terms of math problem-solving related theories and applications are:

Establishing the structure of the topic

The objective of this research is to establish the model of applying math problem-solving abilities to the engineering problems. Math problem-solving abilities are also the abilities to solve problems both in daily life and in engineering. They are similar in terms of the structure. Therefore, the objective of this research is to turn the problem-solving process in mathematics into the problem-solving process in engineering.

How the abilities to transform and connect operate

Under the 4 main structures, namely forming a mathematics question, answering a mathematic question, answering an engineering question, and practical engineering problems, 4 abilities to transform and connect are operated, namely transforming, answering, interpreting, and verifying, are in use. Transforming, answering and interpreting abilities are related to mathematics. However, to review an engineering problem, electronic engineering knowledge is required for transforming, interpreting and verifying.

Procedure of problem-solving abilities

The math problem-solving theories can be applied to the processes of this research.

Transforming Process

(1). Examine the question: understand the meaning of the question and understand the technical terms

(2). Analyze the question: find out the quantity relation between the known and the unknown numbers

(3). Address the objective: transform the engineering language into mathematics language and address the objective function.

Answering Process

(1). Choose a problem-solving strategy and an operation approach and formula: choose a model and derive a formula;

(2). Execute operation: proceed mathematics operation and reasoning;

(3). Getting the answer: getting the mathematics result.

Interpreting Process

(1). Decode the answer: answer the question with the mathematics result

(2). Explain the answer: explain the meaning of the question based on the mathematics result.

Verifying Process

Verify the result: verify if the result answers to the question and the real-life condition.

The Concepts and Theories of Core Competence

1. Research directions of this study in terms of the concepts and theories of core competence

4 abilities to transform and connect, processes, and a mechanism, derived from the theories related to math problem-solving, coupled with the mathematics abilities and the general explanations of these abilities, can be used as the model structure and content of this research.

2. The differences between the math problem-solving abilities and applying math problem-solving abilities to engineering problems

Math problem-solving is based on mathematics models. However, the objective of this research is to establish the competence indicators of applying math problem-solving abilities to engineering problems. Therefore there are differences and limitations listed as below:

(1). Comparing math problem-solving to applying math problem-solving abilities to engineering problems, it seems that extra professional domain knowledge is required while solving engineering problems. One cannot answer an engineering question without the professional background.

(2). Math problem-solving abilities include partial transforming, answering, and partial interpreting abilities; while applying math problem-solving abilities to engineering problems requires abilities include partial transforming, partial interpreting, and verifying abilities.

(3). In terms of using computer software, software commonly used for math problem-solving includes Mathematical, Maple, and MATLAB; while applying math problem-solving abilities to electronic engineering problems usually uses Spice, and MathCAD.

(4).The abilities to establish models in math and abilities to establish professional models are different.

Table 1. A Draft of Competence Indicators of Applying Math Problem-solving Abilities to Engineering

Problems

Ability	Process	Mechanism	Problem-solving Abilities
Transforming Ability	Examine the question	Understand the meaning of the question	Abilities to read and comprehend, professional ability, and ability to observe
		Comprehending technical terms	Professional ability, ability to read math symbols, ability to present in mathematics
	Analyzing the question	Find out the relation between the known and unknown numbers	Profession ability, ability to understand concepts, ability to think mathematically, and ability to integrate and apply concepts
		The process of establishing mathematics language	Ability to transform mathematics language and symbols, ability to symbolize and formulate.
	Propose presumptions	Propose presumptions on the target	Ability to abstract, and ability to comprehend concepts
Answering Ability	Choose a math problem-solving strategy	Choose an appropriate math approach	Ability to choose a strategy, ability to answer the question, ability to think logically
		Choose an appropriate operation rule	Ability to memorize mathematics, ability to establish mathematics model
	Operation process	Mathematic operation and reasoning	Ability to proceed a mathematic operation and to transform symbols, ability to design mathematic operation rules, ability to present in mathematics, and ability to comprehend concepts
		Using an appropriate tool	Ability to use an engineering computer tool, and ability to use computer software
	Getting the answer	Answering in mathematic language	Ability to express in mathematics, and ability to symbolize and formulate
Interpreting Ability	Interpreting the answer	Recounting the result in mathematic language	Ability to transform mathematic language and symbols, ability to symbolize and formulate, and ability to comprehend concepts
		Decode the result in mathematic language	Ability to present in mathematics, ability to symbolize and formulate
	Interpreting the real-life problem	Proposing answers to the engineering problems	Ability to make a connection, ability to think logically
		Best solution for the engineering problem	Ability to present in mathematics, and ability to make a connection and use a model
Verifying Ability	Verifying the result	Verify the accuracy of the result number	Ability to answer a question
		Review the result	Ability to judge and design professionally

RESULTS & DISCUSSION

1. Modifying the competence of applying math problem-solving ability to engineering problems from literatures

After consulting with 3 experts, we found that on the dimension of “Application Review” in the category of

“Verifying Ability”, “Ability to evaluate applications” should be added. Other modifications are listed in Appendix 1.

2. The Analysis of the Importance of Math Problem-Solving Abilities to Engineering Problems: through the Questionnaires Survey of Delphi

(1). Comparisons in General

In this research, Delphi questionnaires were submitted to 11 experts from different backgrounds three different times. The general results of the questionnaires are listed in Table 1. From the definition in the Data Analysis section, it has shown that the results exceeded the standard, in terms of the value of either Mean, Standard Deviation or |Mo-M|)≦1.

Table 1. The Importance of the Applying Math Problem-Solving Abilities to Engineering Problems: Results from the Questionnaire Survey of Delphi, Three Different Times

Opinions from the experts	Quantitative Value	First Time	Second Time	Third Time
General Concentration	Mean	4.13	4.21	4.24
	Standard Deviation	0.65	0.50	0.47
General Consistency	Mode	3.81	4.01	4.30
	$\|MO-M\|$	0.352	0.28	0.26

2. Analysis of the Third Questionnaire Survey of Delphi

The result of the third questionnaire survey of Delphi didn't meet the definition in the Data Analysis section. After analysis and further interviews through telephone calls, we found that:

(1). There are two abilities that are related to “using engineering symbols” and “expressing with symbols” and two abilities related to “decoding and connecting to concepts”, and “decoding and calculating”. Experts all agreed that these were natural reactions after the learning process and thus it was needless to emphasis them. Some argued that as far as technology universities were saying, symbols simply needed to be recognized and it was unnecessary to manipulate with the logic behind the symbols. Nonetheless, a manager from the industry believed that from the perspective of engineering research and development, the ability of using engineering symbols was important.

(2). In Table 2, there are 4 abilities related to transforming. For technology universities, there are differences between each individual. Therefore, the ability to make a conceptual connection and application should be more important. The abilities of “decoding” and “expressing in symbols” could be listed as advanced learning.

Table 2. Analysis of the Abilities That Didn’t Meet the Definition from the Data Analysis Section in the Third Questionnaire Survey of Delphi

M < 3.80 and SD≧1.0 and (|Mo-M|)≧1	Electronics					Math		Abilities		Industry	
	A1	A2	A3	A4	A5	B1	B2	C1	C2	D1	D2
A1.2.2 Ability to use engineering symbols	4	3	4	4	4	4	3	4	3	3	5
A2.2.3 Ability to express with symbols	4	4	4	4	3	3	3	5	3	4	4
A3.1.3 Ability to decode and connect to concepts	3	3	4	3	4	3	4	4	3	4	4
D1.1.1 Ability to decode a calculation	4	4	4	4	4	3	4	3	4	3	3

3. Experts believed that the competence indicators of engineering problem-solving were continuous and inseparable. However, the values of weight are different in different categories and when different tools used.
4. Experts all agreed that “B1.1.1. Ability to apply logical thinking”, and “C2.1.2. Ability to conclude logically” were very important.
5. The ability to establish mathematic models and the ability to establish professional models are different.

CONCLUSION & SUGGESTION

1.A tiered structure and dimensions on the abilities to transform and connect were established

Under the 4 tiered structure in forming mathematic questions, answering mathematic questions, answering engineering questions, and practical engineering questions, 4 abilities to transform and connect, namely transforming, answering, interpreting, and verifying, are in use in different dimensions.

2.The competence indicators of applying math problem-solving abilities to engineering problems derived from the 4 dimensions of transforming and connecting abilities were established

10 elements and 43 items of math problem-solving abilities to engineering problems, derived from transforming, answering, interpreting, and verifying dimensions, were established and listed in Table 2.

3.The competence of the math problem-solving abilities to engineering problems of the students in the technology universities could be evaluated by verifying the “leading questions” and the ways of answering these questions.

The ZPD should be considered when solving mathematic and engineering problems. That is to say that the level of students’ latest development and the utilized space of the ZPD should be concerned when formulating questions for a test or in teaching.

4.The procedure of the dimensions and elements of engineering problem-solving could be used as a reference for teachers to formulate questions for a test.

Before formulating questions, teachers could draw up a matrix table based on the objective of learning as the basis of the evaluation.

5.There are weight differences between the competence indicators of engineering problem-solving abilities.

These competence indicators are logically continuous and inseparable. However, the values of weight differ in each category and when different tools are used.

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Appendix 1. Modifications of Competence Indicators of Applying Math Problem-solving Abilities to Engineering Problems

Category	Dimension	Elements	Math problem-solving abilities to engineering problems	Abilities after modified
A Transforming Ability	A1 Understand the question	A11 Understand the meaning of the question and connect with personal experiences	A11.1 Ability to read and comprehend, and ability to observe	Ability to read and comprehend
				Ability to read and observe
			A11.2 Ability to use symbols	
		A12 Comprehend technical terms	A12.1 Ability to connect to concepts	Ability to connect to concepts of technical terms
			A12.2 Ability to use engineering symbols	
	A2 Analyzing the question	A21 Find the relation of the known and unknown numbers of the question	A21.1 Ability to integrate and apply concepts	
			A21.2 Ability to establish professional models	Ability to analyze professionally
		A22 Formulate in mathematics and professional symbols	A22.1 Ability to think logically	Ability to analyze logically
			A22.2 Ability to present professionally	Ability to analyze professional presentation
			A22.3 Ability to express	Ability to express with symbols
			A22.4 Ability to connect	Ability to connect to symbols
	A3 Decoding formulation	A31 Draw up problem-solving math language	A31.1 Ability to abstract	
			A31.2 Ability to decode formulation	
			A31.3 Ability to connect to concepts	Ability to decode and connect to concepts
B Answering Ability	B1 Answering strategy	B11 Observe, presume, and examine	B11.1 Ability to choose a strategy	
			B11.2 Ability to connection the knowledge in math	
			B11.3 Ability to connect to graphs and figures	Ability to connect to graphs
				Ability to connect to figures
			B11.4 Ability to think logically	Ability to apply logical thinking

			B11.5 Ability to establish mathematic model	
	B2 Proceeding operations	B21 Choose an appropriate math method, operation rule, and formula	B21.1 Ability to reason in mathematics	
			B21.2 Ability to execute math operations	
			B21.3 Ability to express in mathematics	
			B21.4 Ability to make a conceptual connection	Ability to apply conceptual connection
		B22 Apply an appropriate operation tool	B22.1 Ability to use computer and graphics	
			B22.2 Ability to use computer software	
	B3 Getting the answer	B31 Answer in math language	B31.1 Ability to present in mathematics	
		B32 Determine the rationality of the answer	B32.1 Ability to execute operation with symbols	Ability to determine the operations with symbols
			B32.2 Ability to determine with mathematic and professional knowledge	Ability to determine with professional knowledge
C Interpreting Ability	C1 Recounting the answer	C11 Interpret the answer in math language	C11.1 Ability to transform into math language	
			C11.2 Ability to present in math and professionally	Ability to interpret the professional presentation
		C12 Recount the result in mathematics	C12.1 Ability to make a connection	Ability to recount the result in math
			C12.2 Ability to decode the formulation	Ability to decode the result of the formulation
	C2 Interpreting the result	C21 Interpret the answer for the engineering problem	C21.1 Ability to express	Ability to explain the result
			C21.2 Ability to think logically	Ability to conclude logically
		C22 The best answer for the engineering problem	C22.1 Ability to express	Ability to interpret
			C22.2 Ability to connect to and use a model	
D Verifying Ability	D1Verifying the result	D11 The accuracy of the numbers	D11.1 Ability to decode and calculate	Ability to decode for calculation
			D11.2 Ability to verify the calculation	
		D12 The accuracy of wave form	D12.1 Ability to use tools	
	D2 Application Review	D21 Verify the result and answer the question	D21.1 Ability to establish professional models	
		D22 Modify and refine	D22.1 Ability to judge and design professionally	Ability to design professionally
				Ability to review applications

Appendix 2. The Analysis of the Importance of the Third Questionnaire Survey of Delphi: Applying Math Problem-Solving Abilities to Engineering Problems

Ability	Importance (no. of ppl)					M	SD	MO	|MO − M|
	5	**4**	**3**	**2**	**1**				
A1.1.1 Ability to read and comprehend	10	1	0	0	0	4.9091	0.30	**5**	0.09
A1.1.2 Ability to read and observe	1	9	1	0	0	4	0.45	**4**	0.00
A1.1.3 Ability to use symbols	0	10	1	0	0	3.9091	0.30	**4**	0.09
A1.2.1 Ability to connect to technical terms and concepts	2	8	1	0	0	4.0909	0.54	**4**	0.09
A1.2.2 Ability to use engineering symbols	6	1	4	0	0	3.7273	0.65	**4**	0.27
A2.1.1 Ability to integrate and apply	5	6	0	0	0	4.4545	0.52	**4**	0.55
A2.1.2 Ability to analyze with professional knowledge	5	6	0	0	0	4.4545	0.52	**4**	0.45
A2.2.1 Ability to analyze with logic	9	2	0	0	0	4.8182	0.40	**5**	0.18
A2.2.2 Ability to analyze professional presentation	0	11	0	0	0	4	0.00	**4**	0.00
A2.2.3 Ability to express with symbols	1	6	4	0	0	3.7273	0.65	**4**	0.27
A2.2.4 Ability to connect to symbols	1	8	2	0	0	3.9091	0.54	**4**	0.09
A3.1.1 Ability to abstract	1	8	1	1	0	3.8182	0.75	**4**	0.18
A3.1.2 Ability to decode formulation	3	4	4	0	0	3.9091	0.83	**4**	0.09
A3.1.3 Ability to decode conceptual connection	0	6	5	0	0	3.5455	0.52	4	0.45
A3.2.2 Ability to choose strategies	3	6	2	0	0	4.0909	0.70	**4**	0.09
A3.3.1 Ability to connect to mathematic knowledge	2	9	0	0	0	4.1818	0.40	**4**	0.18
A3.3.2 Ability to connect to graphs	4	6	1	0	0	4.2727	0.65	4	0.27
A3.3.3 Ability to connect to figures	2	8	1	0	0	4.0909	0.54	4	0.09
B1.1.1 Ability to apply logical thinking	11	0	0	0	0	5	0.00	**5**	0.00
B1.1.2 Ability to establish mathematic models	2	9	0	0	0	4.1818	0.40	**4**	0.18
B1.1.3 Ability to reason in mathematics	5	6	0	0	0	4.4545	0.52	**4**	0.45
B1.1.4 Ability to execute mathematic operations	3	7	1	0	0	4.1818	0.60	4	0.18
B1.2.1 Ability to express in mathematics	2	8	1	0	0	4.0909	0.54	**4**	0.09
B1.2.2 Ability to apply conceptual connection	0	9	2	0	0	3.8182	0.40	**4**	0.18

B1.2.3 Ability to use computer and graphics	1	7	3	0	0	3.8182	0.60	**4**	0.18
B1.2.4 Ability to use computer software	8	3	0	0	0	4.7273	0.47	5	0.27
B1.3.1 Ability to present in mathematics	0	9	2	0	0	3.8182	0.40	**4**	0.18
B1.3.2 Ability to determine symbol operations	0	10	1	0	0	3.9091	0.30	**4**	0.09
B1.3.3 Ability to determine with professional knowledge	8	3	0	0	0	4.7273	0.47	**5**	0.27
C1.1.1 Ability to transform mathematic language	2	8	1	0	0	4.0909	0.54	**4**	0.09
C1.1.2 Ability to interpret professional presentation	4	6	1	0	0	4.2727	0.65	**4**	0.27
C1.2.1 Ability to recount mathematic results	5	6	0	0	0	4.4545	0.52	**4**	0.45
C1.2.2 Ability to decode formulated results	5	6	0	0	0	4.4545	0.52	**4**	0.45
C2.1.1 Ability to explain the results	8	3	0	0	0	4.7273	0.47	**5**	0.27
C2.1.2 Ability to conclude with logic	11	0	0	0	0	5	0.00	**5**	0.00
C2.2.1 Ability to interpret and present	8	3	0	0	0	4.7273	0.47	**5**	0.27
C2.2.2 Ability to connect to and use models	2	8	1	0	0	4.0909	0.54	**4**	0.09
D1.1.1 Ability to decode calculations	0	7	4	0	0	3.6364	0.50	**4**	0.36
D1.1.2 Ability to verify	1	10	0	0	0	4.0909	0.30	**4**	0.09
D1.2.1 Ability to use tools	7	2	2	0	0	4.4545	0.82	**5**	0.55
D2.1.1 Ability to establish models with professional knowledge	4	7	0	0	0	4.3636	0.50	**4**	0.36
D2.1.2 Ability to design with professional knowledge	6	5	0	0	0	4.5455	0.52	**5**	0.45
D2.1.3 Ability to apply and review	7	4	0	0	0	4.6364	0.50	5	0.36

無衍生研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

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其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
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	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

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3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本研究經文獻分探討，獲得學習行為改變之多元學習概念架構、整合型之鷹架教學概念架構、電子工程問題之數學解題能力的電子學教學設計策略等草案，經專家訪談與專家諮詢修正，並經兩次焦點團體及問卷做最後的修正後，擬定以鷹架學習架構為基底，及圖四、圖五、圖六、圖七之概念架構與策略下，擬定適宜之電子學教學及教材設計策略

本研究結論有四：

1. 採多元學習方式，重視學習行為的改變，如圖四所示。

2. 學習內容應配合學習者的學前能力、學習經驗及 ZPD 間距，統整相關課程的思維與應用，

如圖五所示。

3. 重視個人資訊源及人力源的培養，以強化解決問題及設計應用能力。

4. 重視解讀審題、解題策略、詮釋結果、驗證論點等教材設計。

本論文依電子學教學與教材設計策略，編製引導式回答題教材，做簡易試探試驗，可激發學生學習探索方法，獲得任課老師及一家企業的認同，認為有引導及改善當前學習方式，可運用於數位教材或行動學習方式的學習。