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奈米科技領域從業人員之專業職能研究

A Study of the Professional Competences of Employees in Nanotechnology Domain

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本論文係劉伊霖君（D95630001）在國立臺灣大學生物產業傳播暨發展學系、所完成之博士學位論文，於民國 100 年 12 月 19 日承下列考試委員審查通過及口試及格，特此證明

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漫長的博士生涯，隨著論文的完成暫告一段落。最感謝岳修平教授從碩士時期一直以來的指導、協助、及教誨，除了學術專業外，岳教授於待人處事上之哲學更讓我欽佩並體會到身教之重要性，也敦促我以此作為最佳榜樣。此外，岳教授不遺餘力的鼓勵我參與多樣學術性研究活動、提供創新之想法及策略，不但擴展視野，也讓我有足夠的空間及自由自主學習，謝謝您長期以來的體貼及關心。感謝陳姿伶教授總是像個亦師亦友的大姊姊般鼓勵我，並在我碰到困難時第一時間給予協助，謝謝您的耐心指導。感謝沈弘俊教授帶領我進入過去未曾瞭解之奈米領域及在奈米專業知識上所給予的幫助、感謝張基成教授及蕭崑杉教授於論文撰寫所給予之寶貴建議。

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摘要

近期許多研究活動與奈米科學相關之趨勢，促使奈米科技人力培養及發展成為新興科技進展之重要挑戰，其中，又以各階層之人力資源訓練及發展為影響奈米科技成功與否之關鍵因素。為有效發揮奈米科技潛力以增進社會福祉，必須具備充足人力以從事研究、發展及製造工作，因應此需求，自 2000 年起，全球大專院校開始投入於開設奈米科技相關之大學及研究所層級之學程。然而，綜觀目前大專院校之奈米科技相關教育研究，發現其缺乏奈米科技學程之完整分析，以及利害關係人期望之核心奈米職能為何之深入探究。因此，本研究意圖根據成果導向教育(outcome-based education)及職能觀點(competence-based perspectives)，採用課程地圖及 Q 方法探索臺灣高等教育之奈米科技學程，以進行學程規劃及職能定義，並突顯利害關係人對奈米科技職能之獨特觀點及共通模式。本研究針對臺灣 9 所大學、共計 13 個奈米科技相關之大學及研究所學程所開設的 600 門課程進行深入分析，建構出四個奈米科技課程地圖，並將由課程地圖所萃取之 47 個重要職能進一步運用於 Q 方法中。

本研究招募 33 位 Q 受試者針對 47 個 Q 描述進行排序，並於排序後進行訪談。根據 Q 排序及論述分析結果，可將受試者期望大學畢業生應具備之奈米科技職能的主觀意見區分為四類，包含奈米特定技能及個人特質導向、基礎知識及個人特質導向、奈米核心及特定知識導向、以及奈米核心知識導向。雖然各類型所強調之重要職能有所不同，但奈米材料、獨立思考能力、解決問題能力、以及創新為共通之奈米核心職能。本研究結果將提供奈米科技教育之教學設計及課程地圖運用建議。

關鍵字：奈米教育、職能發展、課程地圖、Q 方法

Abstract

The preparation and development of nanotechnology workforce represent a major challenge for the new technology progress in coming decades since most recent research activities of all varieties are directed towards nanoscience. One of the key factors determining nanotechnology success lies in training and development of human resources at all levels. A sufficient workforce for research, development and manufacturing is required for nanotechnology to reach its full potential to contribute to our society. As a result of this trend, many universities around the world have been devoted to the establishment of undergraduate and graduate nanotechnology programs since 2000. However, what seems lack of current nanotechnology university education studies is a thorough analysis of nanotechnology curriculum, and investigation of what the expected nanotechnology core competences really are of related stakeholders.

Research on university nanotechnology curriculum of the present study aims to introduce a new approach to curriculum planning and competence identification based primarily on outcome-based education and competence-based perspectives, as well as to highlight the unique viewpoints and patterns toward nanotechnology competences expressed by stakeholders. To achieve this study purpose, curriculum mapping and Q methodology are employed as a tool to explore nanotechnology curricula in higher education in Taiwan. The 600 course syllabi collected from thirteen nanotechnology-related undergraduate and graduate programs in nine leading universities in Taiwan are analyzed. Four curriculum maps of nanotechnology of the university level are constructed and verified.

Besides, the extracted competences from curriculum mapping are further employed by Q methodology. Thirty-three Q participants are recruited to sort the 47 Q statements and conduct the postsorting interviews. Based on the results of Q sorting and discourse analysis, four factors of subjective viewpoint toward expected general nanotechnology competences of university graduates are presented, including nano-sepcific skill and personal attributes oriented viewpoint, basic knowledge and personal attributes oriented viewpoint, nano core and specific knowledge oriented viewpoint, and nano core knowledge oriented viewpoint. Although the emphases are put to dissimilar statements by different factors, nanomaterials, independent thinking ability, solve problem ability, and innovation, together construct the core nanotechnology competences. In conclusion, implications of instructional design features as well as important applications of the developed curriculum maps for the preparation of nanotechnology education are discussed.

Keywords: Nanotechnology education, Competence development, Curriculum mapping, Q methodology

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Chapter One Introduction

1.1 Research Background

The preparation and development of nanotechnology workforce represent a major challenge for the new technology progress in coming decades since most recent research activities of all varieties are directed towards the nanoscience. The main advantages of nanotechnology are to advance molecular medicine, to increase working productivity, to extend the limits of sustainable development, and to increase human potential (Roco, 2003a). The future global production impacted by nanotechnology annually has been estimated to exceed $1 trillion by 2015, and an estimated workforce demand for sufficiently sustaining the growth of nanotechnology industry by 2015 is up to 2 million (Roco & Bainbridge, 2001). According to the workforce study of the information technology industry, it finds that for each worker needed in this industry, there are another 2.5 jobs created for them. By the same token, the forecast for the job market and related careers in nanotechnology is approximately 7 million by 2015 globally (Roco, 2003b).

Nanotechnology development is determined by a variety of factors, such as creativity of researchers, professional training of students, international context, and the connectivity among institutions, patent regulations, physical infrastructure, and legal regulations (Roco, 2003b). Specifically, it needs the collaboration among all stakeholders for advancing and developing nanotechnology. To be specific, the government is critical in the budget and leadership; universities play the main role in making and carrying out plans at training undergraduate and graduate students; national labs support long-term fundamental research; and industries navigate the direction and establish targets to be developed (Yamaguchi & Komitama, 2001).

Nevertheless, one of the key factors determining the success of nanotechnology development lies in training and development of human resources at all levels, which encompass students from K-12 to higher education, technicians, and postdoctoral fellows. In addition, attributes such as creativity of individual researchers and skilled workers with interdisciplinary perspectives are considered necessary for coping with the rapid changes of nanotechnology (Lee, Wu, & Yang, 2002; Roco, 2002a, 2003a). A sufficient and well-prepared workforce for research, development and production is required to achieve the potential positive impact of nanotechnology on our society.

To prepare the skilled and qualified workforces, universities around the world have devoted themselves to the establishment of undergraduate and graduate nanotechnology programs since 2000. Meanwhile, in addition to examination of what essential skills required for new graduates before entering nanotechnology industries, many studies focus on addressing the instructional design concerns related to the development of effective nanotechnology courses (Crouch, 2006; Luckenbill, Hintze, Ramakrishna, &

Pizziconi, 1999; Porter, 2007). However, most of studies merely explore how to teach competence and yet little attention is paid to discover what competence the instructors and employers want students to possess (Stoof, Martens, Merrienboer, & Bastiaens, 2002). Although the Industrial Development Bureau of Ministry of Economic Affairs in Taiwan provides well-defined competence descriptions in competitive industries, including information industry, semiconductor industry, image display technology industry, mechanical industry, biotechnology industry, and plastic industry, still there are no specific competence definitions in nanotechnology industry or careers (Ministry of Economic Affairs, 2010). Neither the Bureau of Employment Vocational Training of Executive Yuan in Taiwan provides nanotechnology-specific work classifications and competence descriptions (Council of Labor Affairs Executive Yuan, 2011). This phenomenon evokes the question of what exactly competences consist of nanotechnology workforce.

1.2 Research Purpose

Since the nanotechnology research is an ongoing and under development field, it is not surprise that most university nanotechnology programs in Taiwan still unable to integrate courses systematically and define specifically what the core competences students are expected to possess. In addition, the lack of specific existence of nanotechnology industry and careers make this research hard to conduct job analysis to extract competences such as what traditional competence researches did. Therefore, research on university nanotechnology curriculum of the present study aims to apply new approach to identify thoroughly nanotechnology workforce competences based primarily on curriculum mapping and Q methodology.

Q methodology referred to a population of n different tests (or essays, pictures, traits or other measurable material), each of which is measured or scaled by m individuals. Take advantages of these two methodologies, curriculum mapping is first used to construct the curriculum maps in university level, and Q methodology is further applied to represent the opinions and viewpoints of stakeholders about the relative importance of general nanotechnology competences. By way of this integrative process, this study can provide a logistic reference of what the nanotechnology core competences are. The specific research objectives of this study are:

(1) To construct the curriculum maps of university nanotechnology programs.

(2) To examine the stakeholders' viewpoints toward general competences of nanotechnology careers.

(3) To define what the core competences of nanotechnology careers are.

1.3 Research Significance

By the rapid development and broadly engineering applications of nanotechnology, it is clearly that the domain needs more specialized and skilled workforce involvement.

Since nanotechnology research is still under development and the field is not as mature as other advanced technologies, the professional education and training provided by universities seems somehow insufficient and there exists the gap between what have been taught at schools and what is in need in industry. To bridge the gap between academic and industry expected nanotechnology workforce requirements, this study aims to define core competences of nanotechnology workforce. This is the first exploratory and systematic research which focuses on the identification of nanotechnology competences in Taiwan and which will be a valuable resources and references for the program design and workforce development.

Q methodology is primarily be used in psychology, medicine, and marketing fields, but rarely be used in the human resource development field. The issue this study concerned and tried to solve not only to find out the patterns of different categories and give suggestions accordingly, what is more important is to extract the collective viewpoints which can be a valuable reference for the re-design of nanotechnology university curriculum. Therefore, this study will provide insights into the appropriateness of Q methodology to be applied to discover the constructive common opinions of stakeholders.

According to Hsu (2009), most of curriculum researches in Taiwan put more emphasis on the qualitative methodologies rather than quantitative methodologies. This phenomenon can be reflected on the projects supported by the National Science Council from 2000 to 2004 that 111 (65%) projects were qualitative-oriented, 26 (15%) projects were quantitative-oriented, 14 (8%) projects were mix-oriented, and 19 (12%) projects were unknown. Since both methodologies have its own advantages and weakness to curriculum research, this study apply mixed model which integrates qualitative and quantitative approach to achieve research purposes.

1.4 List of Definition

The definitions of key concepts utilized in this study are given below.

(1) Nanotechnology

Nanotechnology is the research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range. It provides a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

(2) Competence

Competence means the knowledge, skills, attitude and other attributes (KSAOs) that employees need to possess in order to perform effectively for specific job tasks. The competence concept is dynamic which will be revised as the working context or job goals change.

(3) Curriculum mapping

Curriculum mapping is an analytic technique which creates visual representation based on courses' information. It comprehensively integrates when, how, and what is taught to explain achievement of expected student learning outcomes.

(4) Q methodology

Q methodology is a mix-method research technique which enables the person to represent his/her viewpoints for purposes of holding it constant for inspection and comparison. The procedure consists a population of n different tests (or essays, pictures, traits or other measurable material), each of which is measured or scaled by m individuals. Through the sorting, it facilitates the identification of similarities, the construction of broad categories of the phenomenon being investigated and the exploration of patterns and relationships within and between these categories.

Chapter Two Literature Review

2.1 Nanotechnology Development

2.1.1 Nanotechnology perception

Nanotechnology is the study of the controlling of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller in at least one dimension, and involves developing materials or devices within that size. There has been much debate on the future implications of nanotechnology. Nanotechnology has the potential to create many new materials and devices with a vast range of applications, such as in medicine, electronics and energy production. On the other hand, nanotechnology raises many of the same issues as with any introduction of new technology, including concerns about the toxicity and environmental impact of nanomaterials, and their potential effects on global economics.

Although science-attentive members of the public reveal enthusiasm for the potential benefits of nanotechnology (Bainbridge, 2002), several surveys show that the majority of the public, as well as secondary school students and teachers, has little to no awareness or knowledge about nanotechnology (Fonash, 2001; Kahan, Slovic, Braman, Gastil, & Cohen, 2007; Macoubrie, 2005). Cobb and Macoubrie (2004) conducted a national phone survey of Americans' perceptions about nanotechnology. The results showed most Americans (over 80%) are unfamiliar with nanotechnology, but hold positive and helpful attitudes about nanotechnology rather than worried. In the United Kingdom, less than 30% of the population had heard of nanotechnology and only 19% of individuals were able to define nanotechnology, whether accurate or not (Royal Society and Royal Academy of Engineering, 2004). In a 2002 European survey that asked respondents if nanotechnology will improve our way of life in the future, the result showed over half of them selected the "I don't know" response which implied the public lack of knowledge about nanotechnology (Gaskell et al., 2003). Besides, 34.1% of Japan respondents express they had heard the word of nanotechnology and 20.3% of them indicate they know the simple definition of nanotechnology (Fujita, 2006).

The significant benefits of nanotechnology applications that respondents indicated were on the medical, consuming products, society progress, and environmental protection aspects (Fujita, 2006; Macoubrie, 2005; Mehta, 2008). Contrarily, some of the participants also worried about this emerging technology will bring damages on the human health, safety issue, ecology environment, and loss of privacy (Cobb & Macoubrie, 2004; Fujita, 2006; Macoubrie, 2005; Scheufele & Lewenstein, 2005). Zheng (2010) surveyed the nanotechnology perceptions of Taiwan employees and found 97% participants possessed positive attitude toward the issue that nanotechnology can increase industry competitiveness and 72% argued that nanotechnology will bring beneficial influences on human lifestyle in future 20 years.

For the significant advantages of nanotechnology applied in board ranges, most of the countries realized the importance of nanotechnology and tried to put more and more resources to support its research. Among them, U.S, Japan, and European Union were the most active participants. According to the government report (Wang, Liu, Ye, Li, & Huang, 2008), the U.S. Federal Government started to pay attention to nanotechnology in 1996 that all government departments and agencies needed to discuss the future nanotechnology planning and development direction periodically. In 1998, Interagency Working Group on Nanotechnology (IWGN) was established to formally initiate nanotechnology-related tasks. Under the promotion of IWGN, the former President Bill Clinton of United States announced the National Nanotechnology Initiative (NNI) in 2000, and which was regarded as the overriding program among all technology research and development plans.

2.1.2 Investment in developing nanotechnology

Nanotechnology research and development (R&D) investment has increased from $432 million in 1997 to $4681 million in 2006 worldwide (Table 2.1) (Wang et al., 2008). The U.S. NNI annual investment in research with education and societal implications is estimated at about $30 million in 2003 (Roco, 2003b). By different agencies, the President's Budget provided $464 million in 2001 and rapidly raised to 1912.8 million in 2010. Moreover, the proposed NNI budget in 2012 will attain to nearly 2130 million (NNI, 2011). From Table 2.2, it is clear that nanotechnology has multidimensional applications and attracts varied government departments to get involved in it, such as National Science Foundation, Department of Defense, Department of Energy, Department of Health and Human Services, Department of Commerce. The massive and continuous investment and promotion of nanotechnology development imply that US views nanotechnology as the key competitive technique to lead the world's economic growth and it will become nano-century in 21th century.

Europe is the first region that actively gets involved in the nanotechnology R&D. From the mid-1980 to 1990, there were many nations in Europe started to promote the nanotechnology respectively. The establishment of European Union further fostered the development and comprehensive planning of nanotechnology research network. From the Seventh Framework Programme 2007~2013, NMP (nanosciences, nanotechnologies, materials and new production technologies) plays the focal point and 34.67 hundred million budgets are allocated to the long-term program. Specifically, the workforce competence development obtains the attention which projected on the four sub-special action plans, contain cooperation programme, ideas programme, people programme, and capacities programme (Wang et al., 2008).

For assessing Australia's capabilities and potential to undertake nanotechnology development, the stakeholders, included academic, industry, and government, first convened in 2001. And the Australian government research laboratories - the Commonwealth Scientific Industrial Research Organization (CSIRO) - plays the key role in nanotechnology with a strong focus on nanomaterials (Braach-Maksvytis, 2002).

In Asia, the South Korean Government invested $1315 million for ten-year plan to nurture nanotechnology since 2001. One of the major focuses of the nanotechnology plan is to prepare as many qualified nanotechnology scientists and engineers as possible. For this purpose, the plan creates interdisciplinary nanotechnology programs by collaboration of departments at major universities and the re-education of researchers educated by traditional discipline (Lee, 2002). Besides, the total funds supported by the China government for nanoscience and nanotechnology research reached about $7 million during 10 years. From their experiences in developing nanomaterials, the necessity to strength the collaboration between the research units with the expertise of industrialization is important to stimulate the transfer of laboratory techniques to production strength (Bai, 2001).

Table 2.1 Estimated government nanotechnology R&D expenditures ($ millions/year).

	W. Europe	Japan	USA	Others	Taiwan	Total	% of 1997
1997	126	120	116	70	-	432	100%
1998	151	135	190	83	-	559	129%
1999	179	157	255	96	-	687	159%
2000	200	245	270	110	-	825	191%
2001	225	465	465	380	-	1,534	355%
2002	400	720	697	550	-	2,367	547%
2003	650	800	862	722	78	3,112	720%
2004	900	900	960	819	81	3,739	847%
2005	1,100	1,100	1,081	911	89	4,200	972%
2006	1,150	900	1,351	1,200	-	4,681	1,083%
2007	-	-	1,398	-	-	-	-
2008	-	-	1,445	-	-	-	-

Note. "W. Europe" includes countries in EU and Switzerland; "Others" include Australia, Canada, China, FSU, Korea, Singapore, Israel, Eastern Europe, and other countries with nanotechnology R&D programs. Estimations use the nanotechnology definition as in NNI, and include the publicly reported government spending. From "The outlook of nanotechnology application on new materials," By M.J. Wang, et al., 2008. Copyright 2008 by IT IS of Ministry of Economic Affairs.

Table 2.2 NNI budget by agency ($ millions/year).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	Actual										Estimated	Proposed
DOD	125	224	220	291	352	424	450	469	459.0	439.6	415.4	368.2
NSF	150	204	221	256	335	360	389	409	408.6	428.7	412.1	455.9
DOE	88	89	134	202	208	231	236	245	332.6	373.8	380.8	610.6
HHS (NIH)	40	59	78	106	165	192	215	305	342.8	456.8	456.8	464.8
HHS (NIOSH)					3	4	7	5	6.7	8.5	9.5	16.5
HHS (FDA)									6.5	7.3	7.3	15.0
DOC (NIST)	33	77	64	77	79	78	88	86	93.4	114.7	95.9	115.7
NASA	22	35	36	47	45	50	20	17	13.7	19.7	20.1	32.3
EPA	5	6	5	5	7	5	8	12	11.6	17.7	17.6	19.8
USDA (NIFA)			1	2	3	4	4	7	9.9	13.2	13.2	11.6
USDA (FS)						2	3	6	5.4	7.1	5.0	5.0
DOJ	1	1	1	2	2	0.3	2	0	1.2	0.2	0.0	0.0
DHS		2	1	1	1	2	2	3	9.1	21.9	12.3	10.2
DOT (FHWA)						1	1	1	0.9	3.2	2.0	2.0
CPSC									0.2	0.5	2.2	2.0
Total	464	697	760	989	1,200	1,351	1,425	1,554	1,601.5	1,912.8	1,850.3	2,129.6

Note. DOD = Department of Defense; NSF = National Science Foundation; DOE = Department of Energy; HHS (NIH) = National Institutes of Health; HHS (NIOSH) = National Institute for Occupational Safety and Health; HHS (FDA) = Food and Drug Administration; DOC (NIST) = National Institute of Standards and Technology; NASA = National Aeronautics and Space Administration; EPA = Environmental Protection Agency; USDA (NIFA) = National Institute of Food and Agriculture; USDA (FS) = Forest Service; DOJ = Department of Justice; DHS = Department of Homeland Security; DOT (FHWA) = Federal Highway Administration; CPSC= Consumer Product Safety Commission. From *Supplement to the President's FY 2012 Budget* (p. 8), by National Science and Technology Council, 2011, Copyright 2011 by the National Nanotechnology Coordination Office.

2.1.3 Nanotechnology education

From the observation in 2001, the majority of the nanotechnology workforce comes from semiconductor microelectronics field. Taking into account the nanotechnology is broadly utilized and play a critical role across varied fields from information storage to biotechnology, it is urgent for students to experience a science education or an engineering education that emphasize “broadening” or “interdisciplinary learning”. Therefore, for preparing students to have interdisciplinary knowledge and skills, colleges and universities are aware the importance to provide students with the board science and technology background needed to carry out nanotechnology manufacturing, as well as the state-of-art nanotechnology facilities for students to have hands-on experience (Fonash, 2001).

From 2000, universities and institutions worldwide initiate various types of strategies and collaborations to prepare students to meet the future nanotechnology challenges. Flinders University in Australia established the first undergraduate degree nanotechnology program in 2000, which focuses on equipping students with computational skills and an awareness of the roles and uses of computers in science and society (Flinders University, 2010). University of Washington also established the first nanotechnology doctoral degree program in the U.S. in 2000, which allow students to access interdisciplinary research and education expertise (University of Washington, 2010). In Taiwan, with regard to the importance of education for students to enter this field, the first interdisciplinary curriculum of nanotechnology was developed by National Tsing-Hua University in 2001, which was organized collaboratively by the varied fields of materials science, chemical engineering, electrical engineering, power mechanical engineering, engineering science, physics, chemistry, life science, biomedical engineering and environment science. Through this curriculum, a series of basic and advanced courses in relation to the nanoscience and nanotechnology are offered by the respective departments for students to study.

Recognizing it is too specialized and expensive for every research universities or industrial research center to access facilities, equipment and expertise suitable in nanotechnology education, Pennsylvania State University and 14 Pennsylvania's community colleges collaborate to establish the Pennsylvania Nanofabrication Manufacturing (NMT) Partnership. The objectives of the NMT Partnership include providing semester-long, hands-on educational experiences for students from community colleges and other institutions, offering professional development workshops in nanofabrication for educators, and holding nanotechnology chip camps for middle and high schools students. The emphasis of preparing students for the full range of nanofabrication applications allowed students gain the ability to move among industries as the needs for their skills evolve. In addition, industry advisors also considered that hands-on experiences in the course provided by NMT Partnership made the students more valuable (Hallacher, Fenwick, & Fonash, 2002).

National Science Foundation (NSF) in U.S. funded the Integrative Graduate Education and Research Traineeship (IGERT) since 1998, where graduate students receive fellowships for interdisciplinary topics (i.e. aid people with disabilities offered by Arizona State University and California State University, clean energy development instructed by Rutgers University and Princeton University, or manufacturing logistics provided by Lehigh University) and conduct researches under the guidance of professors with various expertises. Drexel University and the University of Pennsylvania co-created a nanoscale science and engineering IGERT program at the PhD level in 2003. Drexel/UPenn IGERT not only provides lecture courses, but also seminars, poster sessions, workshops, and international exchange. Among all the program activities, international exchange are a crucial component of the Drexel/UPenn IGERT for it gives students the opportunity to cross political, cultural, and scientific boundaries, therefore broadening their perspectives even further (Cowan & Gogotsi, 2004; IGERT, 1999; Kullman, 2011; Roco, 2002a; Rutgers University, 2010).

In addition to the establishment of university-level programs, some researchers put more efforts on the innovative design of nanotechnology instruction. In order to prepare students to gain an appreciation of other professions' viewpoints and provide them insights in solving traditional problems through novel approaches, Porter (2007) designed an undergraduate-level chemical nanotechnology course to challenge students to consider the political, economical, environmental, and ethical issues relating to nanotechnology and its potential impact on modern society. Roco (2003a) argued that instructors should provide freshmen and sophomores with unifying concepts for matter and biology systems at the beginning, and then advance to various disciplines that focus on phenomena and averaging methods for related length scales. In this way, students can move the same basic concepts from one filed to another, and create a comprehensive view for potential interdisciplinary applications.

Besides the specialized and interdisciplinary knowledge, it is also important for engineers to be educated to think broadly in fundamental and integrative ways about engineering. Apart from the application of mathematics and the sciences as core engineering subjects, engineering curricula also must stress more on the humanistic, as opposed to scientific and mechanistic, aspects of problem solving or project implementation (Zaharim, Omar, Basri, Muhamad, & Isa, 2009a). Such as since 2000, a practical industrialized curriculum in engineering had engaged to the Japan Accreditation Board for Engineering Education (JABEE) guideline to integrate employable personal qualities and requirements into the academic curriculum in order to generate skilled engineers. In 2004, Singapore Workforce Development Agency

(WDA) introduced the Singapore Employability Skills System (Zaharim et al, 2009b). Zaharim et al. (2009b) further compared the employers' perception toward engineering employability skills among Malaysia, Japan, Singapore, and Hong Kong, and the results suggested that the engineering graduates should acquire a set of generic skills such as communication skills, solve problem skills and interpersonal skills.

Roco (2002b) summarized key areas of education and training activities supported by NSF in the nanoscale science and engineering areas from 2001 to 2002, including university courses, student fellowship programs, education and training in centers and networks, combined research-curriculum development, local and long-distance outreach education, technological education, public education, and international education exchanges. In addition, the establishment of two national networks, Network for Computational Nanotechnology in 2002 and National Nanotechnology Infrastructure Network in 2003, with extensive e-learning capabilities, will also allow broad access to nanotechnology education in the U.S. (Roco, 2003a). National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) established in 2004 is another professional institution which aims to equip future generations by advancing science, technology, engineering and mathematics education. Ten universities and one laboratory in U.S. joined NCLT and all partners collaborate together to provide educators and students sufficient online nanoscience and engineering materials for them to use as supplemental resources (NCLT, 2009).

To accelerate the research and development of nanotechnology, the government of Taiwan launched National Science and Technology Program for Nanoscience and Nanotechnology in 2002 (NHRD Program, 2010). In addition to research and development, this program includes a human resource development component which is in charged by the Ministry of Education (MOE). The Nanotechnology Human Resource Development (NHRD) Program is established to promote education and professional development. Under the supervision of MOE, the NHRD Program includes NHRD Program Office, K-12 Nanotechnology Education and Development Centers, Advanced Nanotechnology Education Centers, and E-Knowledge Exchange Platform. The main missions of Advanced Nanotechnology Education Program are establishing interdisciplinary nanotechnology curriculum programs, conducting training courses on laboratory instrument operation, hosting local and international nanotechnology conferences, and hosting national competitions on innovative nanotechnology and conferences on industry-academic cooperation.

While nanotechnology is experiencing considerable growth due to its significant impact on society, the demand for nanotechnology experts may far exceed the number of students pursuing academic paths leading to careers in nanotechnology (Roco, 2003a). For satisfying the requirements of well-trained workforce, it is important to determine if the programs or courses put in place have an effect on students' awareness, exposure, and motivation to pursue the study of nanotechnology. Therefore, researchers (Dyehouse, Diefes-Dux, Bennett, & Imbrie, 2008) developed a Nanotechnology Awareness Instrument to measure the constructs of nanotechnology awareness, exposure, and motivation. The concept of awareness is meant self-reporting of an ability to name or describe basic things about nanotechnology, the concept of exposure deals with activities that a student really completed, and motivation is meant to capture the kinds of nano-related studies or work that a student plans to do in the future. According to the results, it showed that the subscales of nano-awareness and nano-exposure were similar enough to be considered a single construct. And this instrument is useful in detecting whether a particular intervention or program can influence students' motivation to study nanotechnology.

In summary, nanotechnology is not well-known among population in European, United Kingdom, American, and Japan, in spite of American and Taiwan participants showed positive attitude toward it. Considering the remarkable advantages of nanotechnology bring to the varied engineering fields, the estimated government R&D investment in nanotechnology worldwide increase rapidly from 1997 to 2006. Besides, universities around the world also perceived the importance of nanotechnology and started to establish nanotechnology-related programs since 2000. The funding supported by the government agencies and active collaboration among universities fostered the development of cross-universities nanotechnology workforce training programs. Japan and Singapore tried to integrate engineering employability skills into academic curriculum for preparing qualified workforce. To accelerate the competiveness of R&D capabilities, Taiwan launched a National Nanotechnology Program in 2002 and advanced human resource development is of its concerns.

2.2 Competence-Based Workforce Development

2.2.1 Definition of competence

According to Webster's Dictionary, the competence's roots go back to 1596. Stephenson (1998) argued that capability is the integration of knowledge, skills, personal qualities and understanding used appropriately and effectively, not just in familiar and highly focused special contexts but in response to new and challenging circumstances. Contrarily, competence is primarily about *the ability to perform effectively in familiar contexts when face with familiar problems*. Capability embraces but extends beyond competence; it involves ability and a willingness to apply understandings, knowledge and skills to unfamiliar contexts and unfamiliar problems.

Stoof et al. (2002) suggested that there is no absolute and true definition of competence. From a constructivist point of view, the criterion for a competence definition is not whether the definition is true but the constructed definition is adequate in the context in which it is used. Therefore, the key point constructivist approach emphasized is viability. There are three variables that increase the viability of competence definition.

(1) People

Since constructing the competence definition is an activity that is being performed by many stakeholders representing different opinions and positions, it is crucial to be aware of the existence of these differences to construct an agreed-on definition with clear underlying assumptions.

(2) Goal

Before constructing a competence definition, we should understand what the definition is going to be used for. Defining competence which covers a whole range of possible applications often leads to definitions that are too global and abstract. Such definition may be unworkable and decreasing the viability.

(3) Context

The context is important when a competence definition is going to be used in the organization. What does the organization do? What products or services does it supply? Who are the intended users of the definition? The definition should fit into existing organization processes and should be easy to handle by the intended users.

In addition, according to Stoof et al. (2002) the boundary approach of competence is a visual representation aid which supports people in thinking about the meaning of competence, as well as in defining competence properly in a constructivist way. Figure 2.1 shows the concept of competence in an amoeba-like form. The "inside-out approach" focuses on dimensions of competence, and the "outside-in approach" incorporates terms that are related but not equal to competence. Since people increase and decrease some forces when they define competence, thus the boundary is dynamic.

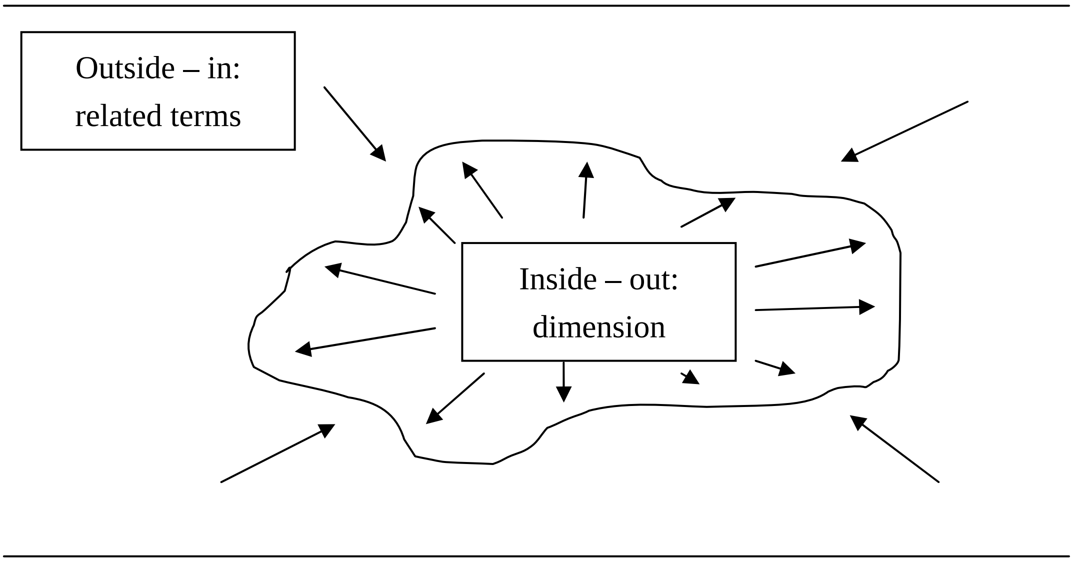

Figure 2.1 The boundary approach of competence (Source: Stoof et al., 2002)

There are five main dimensions in inside-out approach when defining competence.

(1) Personal versus task characteristics

Personal characteristics focus on which personal characteristics lead to superior performance. On the other hand, task characteristic is what the essential elements of the task need to be fulfilled. In short, the personal characteristics approach is about the people who do the work, whereas the task characteristics approach is about work and achievement.

(2) Individual versus distributed competence

Competence may be viewed as something belonging to individual and the focus is on the training and development of an employee or on the assessment of a student's competences. However, a distributed view on competence holds that competence is spread out on several agents whose competences are interdependent.

(3) Specific versus general competence

A specific competence definition just taking account for one specific task in one specific company (e.g. manager in company X). While general definition refers to competences within an entire domain of a profession (e.g. managers in general) or even to professions in general, covering all possible professions and domains by considering competence as something that goes beyond specific professions and domains.

(4) Levels of competence versus competence as a level

Levels of competence refer to gradations. In this view, a person has a certain amount of competence, such as an expert will be more competent than novice. In contrast, competence can be regarded as one particular level, which means competence is a delineated stage between other stages.

(5) Teachable versus nonteachable competence

Competence definitions often contain elements such as knowledge, skills, attitudes, personality, and motives. The elements can be distinguished between soft and hard competence. Hard competences refer to job-specific abilities, which is somehow more teachable. Whereas soft competences refer to personality traits, values, and styles, which are more nonteachable.

Although the inside-out approach explores the meaning of the concept of competence, the outside-in approach focuses on the selection of terms that best express the intended meaning of competence.

(1) Competence versus performance

Performance is closely related to an observable, objective result, whereas competence seems to refer to more to personal abilities that underlie this result.

(2) Competence versus qualification

Qualification is associated with vocational standards, certificates, and diplomas. It is some sort of an objective guarantee that a person has proved to have at least the minimal requirements to do a good job. Ideally a qualified person is competent, but it is not always true in real situations. Hence, qualification is a sub-area of competence.

(3) Competence versus capability

Capability refers to personal features that are not necessarily used or that the owner is not even aware of. Competence, on the other hand, seems to be related to personal features that are required to perform a particular activity.

(4) Competence versus knowledge, skills, and attitudes

Competence encloses knowledge, skills, and perhaps attitudes. However, meta-cognition is a possible addition to knowledge, skills, and attitudes. Meta-cognition is a higher order skill, referring to awareness and monitoring of one's own cognitive state or condition. Meta-cognition also refers to allocation, which means setting in knowledge, skills, and attitude at the right moment, in an economical way.

(5) Competence versus expertise

It is clearly that competence and expertise are closely related. Competence refers to minimal efficiency, whereas expertise refers to optimal efficiency.

2.2.2 Competence-based education and training

Recently in Britain and Canada, the method be used to analyze competence has shifted from educational input model to *outcomes-based approach* (Figure 2.2) (Harrison & Mitchell, 2006; Willett, 2008). It means the emphasis changed from what qualities the individual should posses and what has been taught, to how that person is expected to perform, now and in the future. An outcomes-based approach stress the initial and essential step is to develop clear concepts of occupational standards, from which are derived the curriculum – what the individual needs to learn to achieve the standard – and the assessment system – how the individual will demonstrate that he/she has achieved the standard. The de-linking of standards, learning and assessment means that different learning process and previously acquired competence can be considered.

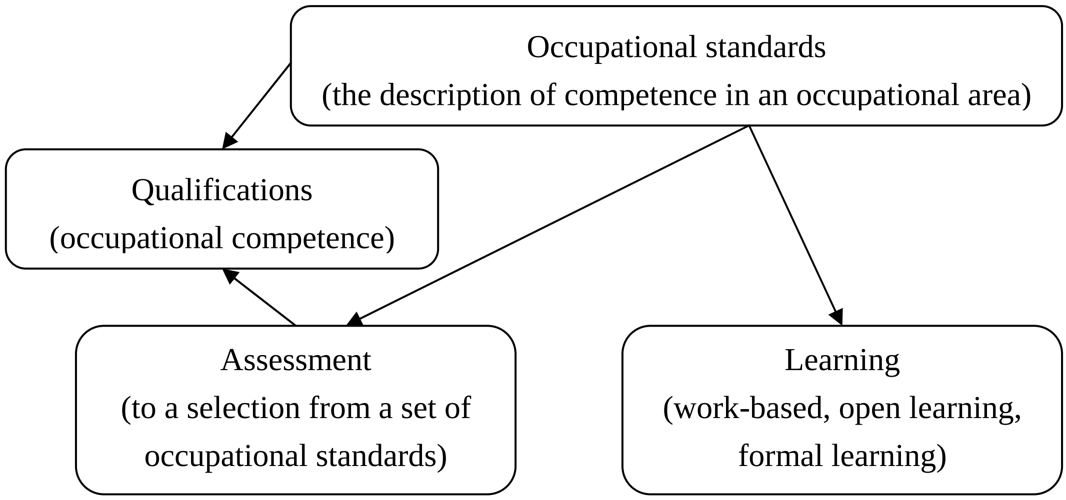

Figure 2.2 The outcomes-based model of competence (Source: Harrison & Mitchell, 2006)

Note: Standard can be used for other purposes such as job descriptions, evaluations, and appraisals.

Occupational standards are standards of quality that are applied to the performance required of people when they undertake specific work functions. The development of occupational standards first needs to do functional analysis. Functional analysis is a systematic and consistent analysis of the work activities and job roles, which helps to develop functional map. A functional map and its constituent standards represent all the roles in an occupational sector. Further, functional map is beneficial to develop occupational standards, which have four components – what should happen, how things should happen, range of applications, and the knowledge and understanding required to achieve the standard. Obviously, the occupational standards can be used for curriculum development, and competence-based education make explicit that education is tailored to the requirements of practice rather than the interests of those who provide the education.

According to the study of 422 companies from six various industries in Malaysia, the employers reported that they were most satisfied toward existing engineering workforce with the aspect of utilizing a systematic approach to design and evaluate operational performance and team working. However, the employers were most dissatisfied with the aspect of entrepreneurial skills of the workforce. In expectation of the future engineering workforce, the basic entrepreneurial skills got the lowest scores which reflected this attribute is less important to the employers. On the other hand, communicate effectively was viewed as important competency in engineering workforce (Zaharim et al, 2009a). These findings echoed to Hassan et al. (2007) viewpoint that there is an urgent need for engineering programs to improve in all areas, especially in non-technical aspects of engineering education.

To bridge the gap between what the employers expected and what the graduates possessed, institutes of higher professional education and several universities in Australia and New Zealand, European and other places adopt the concept of competence to guide the development of educational programs (Stoof, Martens, & Merrienboer, 2007). Competence-based training means training geared to the attainment and demonstration of skills to meet industry specified standards (Vocational Education, Employment and Training Advisory Committee, 1992, p5-8). Australia introduced competence-based training to provide vocation education and training since 1992. The results of case studies of enterprises showed that competence-based training is not a singular and universal model of vocational education and training. Rather, it is performed in particular and specific situations (e.g. in particular industry sector, specific enterprises), and when re-situated, it also needs re-constituted or transformed (Mulcahy, 2000).

The Ministry of Education in Taiwan has started to conduct systematic and consistent technology education planning since 1997 (Hwang, 2000). The main principles of course planning emphasize the connection between school and workplace, prepare the workforce fit in with the industry needs, carry out competence-based education, understand students' experiences, capabilities, and demands, and increase the correlation and appropriateness. This plan executed by the collaboration of Ministry of Education, Technology System Course Directing Committee, Technology Course Development Centers, and Professional/General Course development Committees.

To summarize briefly, competence means the knowledge, skills, and personal attributes that employees need to possess to perform effectively for specific job task. There are different variables and approaches need to be concerned when defining the competence, such as the variables of people, goal, and context, and the boundary approach displays the dynamic characteristic of competence definitions. Moreover, competence-based education means training or education geared to the attainment and demonstration of skills to meet industry specified standards. The concept has already adopted by Australia, New Zealand, and European. From the introduction experience of Australia, the competence-based education is better performed in specific situation and need to be transformed when re-situated.

2.3 Curriculum Maps

2.3.1 Definition of curriculum maps

The concept of curriculum consisted of two elements: the content or what the students learned, and the assessment methods which were used to assess the extent to what students had learned the content. This concept further expanded to include the learning strategies and instructional strategies adopted, and the aims and objectives of the program (Harden, Crosby, & Davis, 1999). The concept of curriculum mapping is pioneered by Hausman (Hausman, 1974), and the role of computers in the process is introduced by Eisenberg (Eisenberg, 1984). Since there is diversity in the terminology that is used to describe conceptual and curricular structures, Allen, Hoffman, Kompella, and Sticht (1993, p2) defined these terms as follows.

> ***Curriculum maps*** *are representations of the structures employed by schools and other educational organizations as a means for assessing activities and allocating time intended to facilitate the development of student knowledge.*
>
> ***Concept maps*** *are representations of the structure of "public" conceptual systems, where "public" implies shared use of common terminology and language including – but not restricted to – forums such as publications, lectures and other presentation, discussions, and other formal and informal communication.*
>
> ***Cognitive maps*** *are representations of the internal mental structures of individuals*

that emphasize the meaning that individuals attribute to concepts; they may be used to describe expert knowledge, to diagnose or assess an individual's understanding of a knowledge domain, or to compare and contrast differences in the conceptual systems of individuals or groups.

2.3.2 Definition and process of curriculum mapping

Curriculum mapping is a procedure which promotes the creation of a visual representation of curriculum based on real time information (Jacobs, 1997). A curriculum map can be seen as a roadmap of a curriculum, guiding its users, such as students, faculty members, teachers, and curriculum planners, evaluators and coordinators, through the various elements of the curriculum and their interconnections. Curriculum elements may include people (learners, teachers), activities (learning and assessment events), courses, outcomes and objectives, learning resources, topics and locations Therefore, curriculum mapping is a consideration of when, how, and what is taught, as well as the assessment measures utilized to explain achievement of expected student learning outcomes (Harden, 2001).

All stakeholders involve in curriculum development together find out the strengths, gaps, and overlaps through the process of reviewing curriculum map. Once the review is complete, the faculty identifies the focus of a given grade level, the patterns across grade levels, the potential for interdisciplinary collaboration, and determines what and where to add or eliminate contents or strategies, which results in a more streamlined curriculum and integrated program (Eisenberg, 1984; Plaza, Draugalis, Slack, Skrepnek, & Sauer, 2007; Uchiyama & Radin, 2009). As a result, the curriculum map is viewed as a useful tool to facilitate the process of curriculum review and evaluation; moreover, the curriculum transparency and accessibility give stakeholders, including teachers, students, curriculum developers, managers, public and researchers, a board overview of the curriculum (Harden, 2001; Plaza et al., 2007; Willett, 2008).

English (1978) described the interrelationship of varied curriculum types. The declared curriculum, what is assumed the students are learning, may differ from the real or taught curriculum, the curriculum as it is delivered to the students. It may also be different from the learned curriculum, what students actually learn. The curriculum map is beneficial in making explicit the implicit curriculum and helps to ensure what is assessed is in line with the declared curriculum (Figure 2.3).

Willett (2008) surveyed 31 Canadian and UK medical schools, and identified 14 elements included in curriculum maps and further categorized them into 4 clusters (Table 2.3). Since some map elements tend to co-occur, means that there may be different types of curriculum maps depending on the desired functionality of the map.

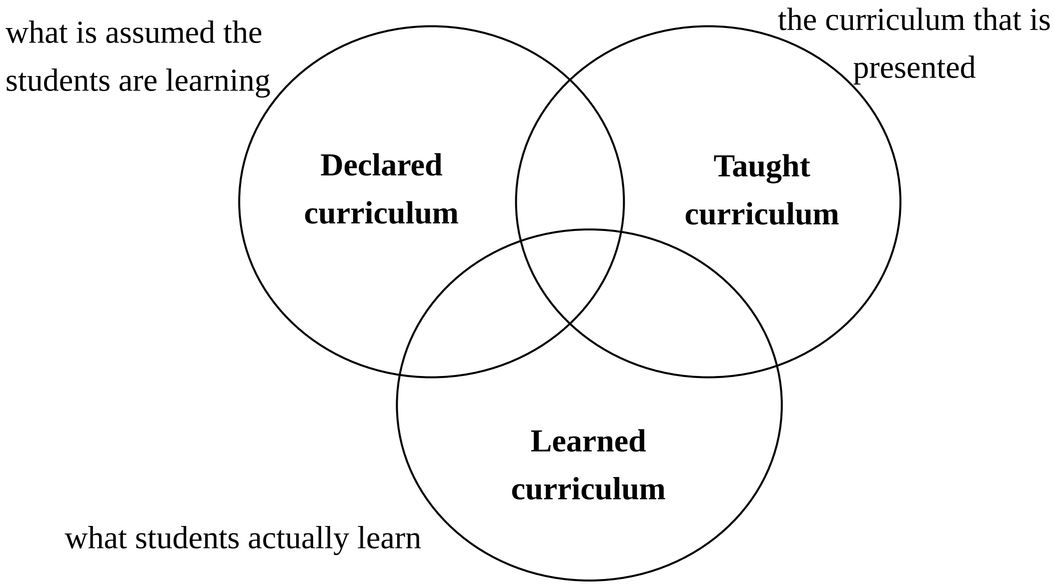

Figure 2.3 Difference among declared curriculum, taught curriculum, and learned curriculum (Source: English, 1978)

Table 2.3 Elements included in curriculum maps

Cluster	Purpose	Elements
1	necessary for courses' scheduling and chronological program evaluation	teachers, date, time, student, location
2	allow a more sophisticated evaluation of the chronology and methodology of the curriculum	assessments, assessment method descriptors, teaching or learning method descriptors
3	allow the curriculum to be evaluated from an **outcomes-based perspective**	learning outcomes, specific learning objectives, learning opportunities or events, courses
4	facilitate searching of the curriculum for specific topics, themes or concepts	freeform keywords, controlled vocabulary or ontology

Source: Willett (2008)

Harden (2001) provided another framework to describe what can be included in a curriculum map. Figure 2.4 represents four key areas covered in a curriculum map. In this representation, learning opportunities are placed at the center. These may include lectures, a session in the community or an experience in laboratory. Related to learning opportunities are the learning outcomes to which the learning opportunities contributed, the content in the courses and how the development of the students' competences to be assessed. In this way, the curriculum map provides a broad multidimensional overview of the curriculum and its different components. The emphasis placed on each of the four areas characterizes different educational approaches or philosophies as shown in Table 2.4.

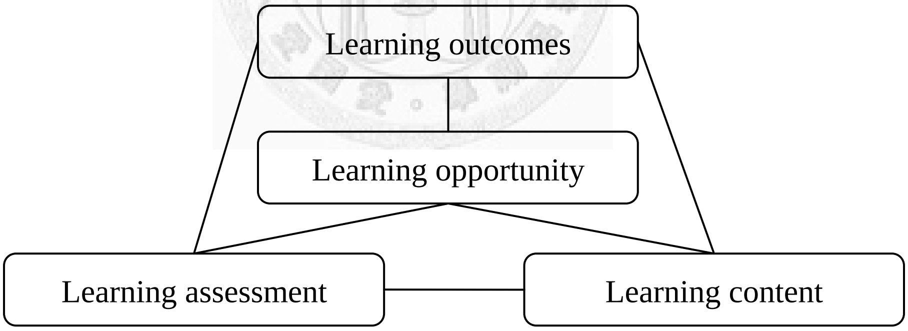

Figure 2.4 Four key areas of a curriculum map (Source: Harden, 2001)

Table 2.4 The areas in a curriculum map characterize different educational perspectives

Educational perspective or approach	Area emphasized in curriculum map
Resource-based learning	Learning opportunities
Outcome-based education	Learning outcomes
Problem-based/task-based learning	Content/areas of expertise
Community-based education	Location or venue
Mastery learning	assessment

Source: Harden, 2001

Outcome-based education is an approach to education in which decisions about the curriculum are driven by the outcomes the students should demonstrate by the end of the course. Outcome-based education can be viewed as results-oriented thinking and is opposite of input-based education where the emphasis is on the educational process. In outcome-based education, the educational outcomes are clearly specified. In addition, the decisions of selecting and organizing the contents, instructional strategies, teaching methods, assessment procedures, and learning environment are made in the context of the stated leaning outcomes. Outcome-based education provides a powerful and robust framework for creating the curriculum. It helps unify the curriculum and prevents it from fragmented. More importantly, the outcome-based learning approach encourages students to take more responsibilities for their own learning. Thus, two pivotal factors are required to construct an effective outcome-based education. First, the learning outcomes are identified, made explicit and communicated to all concerned. Second, educational outcomes should be the overriding issue in decisions about the curriculum (Harden et al., 1999; Willett, Marshall, Broudo, & Clarke, 2007).

In Taiwan, Lee (2009) introduced an outcome-based curriculum development model. The model mainly based on the concepts of outcome-based education, as well as integrates the various mechanisms, competence map, quality assurance model, adjustment model, and AACSB International Accreditation Coordinating Committee & Quality Committee. The outcome-based curriculum development model includes external circle and internal circle. The purpose of external circle is to maintain adequate university educational goals and core competences. To conform to the requirement of external circle, it not only needs to take consideration of the society and educational development, university positions, students' capabilities and development, parents' expectation, and industrial development and needs, but also the results of three-level courses and activities assessments. Moreover, the internal circle intends to maintain the appropriate instructional effectiveness, and ensures students possess required competences when they graduated. The procedure of internal circle is (1) define three-level instructional objectives and core competences; (2) develop the competence indicators which can be assessed directly; (3) utilize competence indicators to adjust and design courses, learning activities, and supplementary measures; (4) implement the courses and learning activities again; (5) carry out the three-level courses and activities evaluation; (6) apply the evaluation results as a reference to the learning and work performance; and (7) revise the three-level instructional objectives and core competences.

In order to achieve the mobility and employability promoted by the European Higher Education Area (EHEA), researchers (Toral, Martinez-Torres, Barrero, Gallardo, & Ayala, 2006; Toral, Martinez-Torres, Barrero, Gallardo, & Duran, 2007) adopted five stages of concept-mapping techniques based on Kolb and Shepherd (1997) to the design of the master's level ICT course developed between the University of Seville (Spain) and the Catholic University of Asuncion (Paraguay), and undergraduate Electronic Engineering Degree at the University of Seville (Spain), respectively. The five stages are as follows.

(1) Selecting and preparing the participants

The participants forming the working group must be knowledgeable about the specific profession, as well as the instruction experience of the institution in which the curriculum is going to be implemented.

(2) Brainstorming session (item's selection)

The identification of the knowledge and skills considered important as outcomes of a specific profession curriculum.

(3) Structuring and rating items

To obtain the information related to their relative importance and inter-item relationship. Both tasks constitute the stage of item's rating and structuring in the concept mapping development process.

(4) Representing items in a concept map

The representation of the items in a concept map implies a double data processing. Firstly, a multidimensional scaling is carried out obtaining a two-dimensional representation of the items. Then, it is necessary to classify the items in homogeneous groups, and the categorization is carried out with cluster analysis based on the Ward's algorithm.

(5) Interpreting the maps

Generally, the results derived from the cluster analysis are more difficult to interpret than those from the multidimensional scale. The key is to maintain the integrity of the multidimensional scale results by achieving a solution that will not allow the clusters to overlap.

In addition, Uchiyama and Radin (2009) applied cyclical curriculum mapping process that consists five stages (Figure 2.5) to constitute curriculum maps. In stage 1, individual instructors develop maps of their separate courses in real time as they teach over the span of a semester. Stage 2 begins with all instructors of a particular course working together to aggregate the maps. In stage 3, all faculty members involve reviewing all maps in a program. Stage 4 includes all faculty members focusing on identifying areas in need of alignment, revision, and/or elimination. Then the group develops an action plan in stage 5. Following this procedure, a program that is fluid and adaptable as the needs of students, policies, and new research findings change over time is constructed. Therefore, curriculum mapping is an ongoing process that requires continual upgrading and maintenance (Willett, 2008).

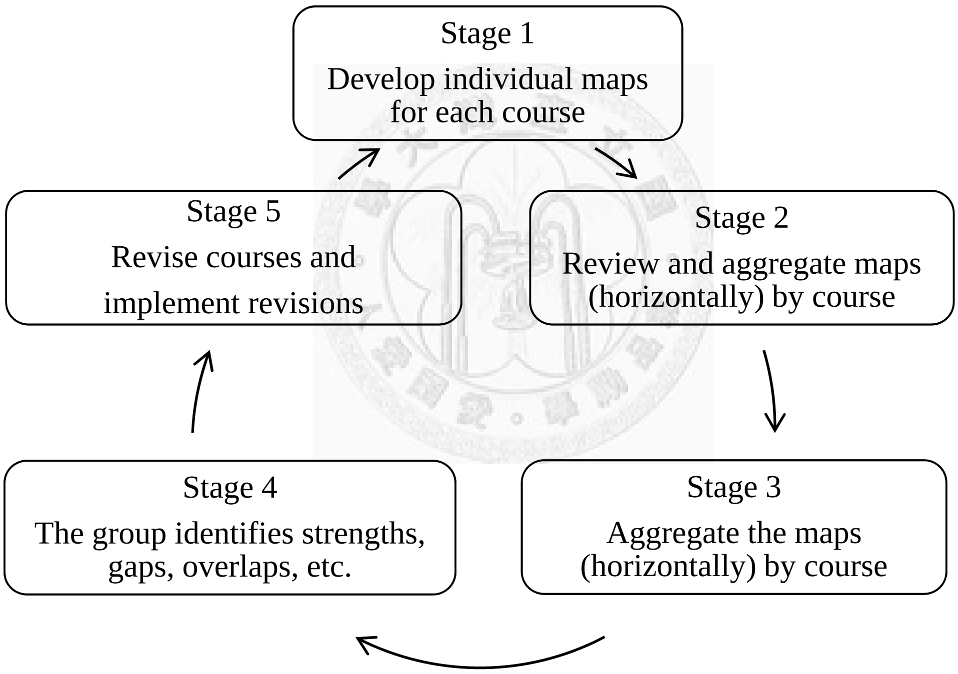

Figure 2.5 The process of curriculum mapping (Source: Uchiyama & Radin, 2009)

2.3.3 Curriculum mapping in higher education

Curriculum mapping is an essential tool for the development and implementation of a curriculum in higher education. Mapping not only assists with planning and implementation of the curriculum, but also helps to facilitate the discussion and reflection about the curriculum and resource allocation (Harden, 2001). Through the collaborative process of curriculum mapping, instructors came to an agreement as what content should be kept in the course sequence, what should be dropped, what new content should be added, as well as an increase in collaboration and collegiality among participants (Uchiyama & Radin, 2009).

Understanding of the advantages of curriculum maps in higher education, many universities have started to apply it in curriculum planning. In Canadian and UK schools, Willett (2008) found 74% of undergraduate medical schools are building or have built curriculum maps. In medical-related field, the University of Oklahoma College of Pharmacy implemented a peer-review process of curriculum mapping and evaluation. Standardized data collection instrument, question categories including course procedures, course contents, skills, preparation for future courses, relationship to learning outcomes, balance of course activities, student assessment, and integration within the curriculum, was developed to ensure the consistency and completeness of data. The work in curriculum mapping helped faculty members identify those courses that needed content revision, rearrange courses that were related in terms of content and accountable to each other to build knowledge and skills, and adjust assessment methods to correspond to learning objectives (Britton, Letassy, Medina, & Er, 2008).

Plaza et al. (2007) employed a descriptive cross-sectional study design based on learning outcomes documents, course syllabi, and students' reflective reports to examine the differences between the perceptions of what competences had been taught by faculty members and what had been learned by pharmacy college students. The results showed that there was concordance between student and faculty members ranking of domain coverage in their respective curricular maps. The medical curriculum in surgery and internal medicine at the University of Munich applied an online tool for developing a curriculum map based on specific learning objectives and standard catalogues (e.g. the Swiss Catalogue of Learning Objectives) (Hege, Siebeck, & Fischer, 2007).

Besides, Cottrell, Linger, and Shumway (2004) adopted competence-based framework to map the undergraduate medical school curriculum at West Virginia University. First, West Virginia University of Medicine developed a framework to distinguish what students are expected to learn according to the roles of a physician. Then put two sources of data, Secure OnLine Environment and the syllabi of required courses and clerkship, into the AAMC Curriculum Management Information Tool (CurrMIT). The curriculum map produced by the CurrMIT is viewed as a beneficial tool to determine whether the program's components, such as learning objectives, learning approaches, and assessment methods, are well-designed and linked to further students' learning.

In addition to identify the specific competences expected to be developed by the students, some researchers focused on the identification of generic skills through curriculum mapping. Sumsion and Goodfellow (2004) advanced the integration of generic skills in an undergraduate education program in Macquarie University, Australia. The process of curriculum mapping enabled researchers to identify general patterns within the program in relation to the promotion of generic skills, as well as provided faculty members valuable opportunities to reflect on their course and assisted them to identify directions to pursue.

In summary, curriculum mapping uses visual representation to reveal the interconnection of various elements of the curriculum. It is beneficial to facilitate curriculum review and evaluation, increase the curriculum transparency and accessibility, and encourage the collaboration among stakeholders. Outcome-based education means the curriculum decisions are driven by the outcomes the students are expected to demonstrate by the end of the course, and curriculum mapping is a method of operationalizing outcome-based education. The significant advantages of curriculum mapping stimulate universities start to apply different strategies to build curriculum maps. Moreover, some researchers make use of curriculum mapping to identify general and specific competences.

Chapter Three Research Methodology

This is a mixed-method research which integrates qualitative and quantitative approach to achieve research purposes. The content analysis used for curriculum mapping and Q methodology in combination with interview investigations are utilized to solve the question about what the nanotechnology workforce competences really are.

The mixed-method research emphasizes the inclusion of a quantitative phase and a qualitative phase in an overall research study (i.e. determine the research question, determine whether a mixed design is appropriate, select the mixed-method or mixed-model research design, collect the data, analyze the data, interpret the data, legitimate the data, and draw conclusions); however, mixed-model research mixes qualitative and quantitative approaches within and across the stage of the research process (Johnson & Onwuegbuzie, 2004). Specifically, Johnson and Onwuegbuzie (2004) define mixed-method research as below.

Mixed-method research means the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study.

Greene, Caracelli, and Graham (1989) noted five major purposes or rationales for conducting mixed-method research. These purposes included (1) triangulation, which means seeking convergence and corroboration of results from different methods and designs studying the same phenomenon; (2) complementary, such as seeking elaboration, enhancement, illustration, and clarification of the results from one method with results from the other method; (3) initiation, represents discovering paradoxes and contradictions that lead to a re-framing of the research question; (4) development, intends to use the findings from one method to help inform the other method; and (5) expansion, represents seeking to expand the breadth and range of research by using different methods for different inquiry components.

The study integrates 3 interrelated stages to construct the complete research procedure. As shown in Figure 3.1, the content analysis of curriculum mapping is utilized to find out what the important KSAOs students need to learn in undergraduate and graduate levels, as well as to address the general competences of nanotechnology careers as the key reference for stage 2. Q methodology is the mixed research method which is suitable for identifying and classifying the possible competences categories based on the extracted competences from stage 1. The synthesis results are provided in stage 3 to define what the core competences of nanotechnology careers are for further workforce development.

For better understanding of the theoretical background of research methods used in this study, the fundamental concepts and general analysis procedure of curriculum mapping and Q methodology will be introduced first. Then the nanotechnology courses' information and principles of classification of this study in curriculum mapping will be provided. Finally, the detailed extracting and sorting procedures applied by Q methodology will be presented.

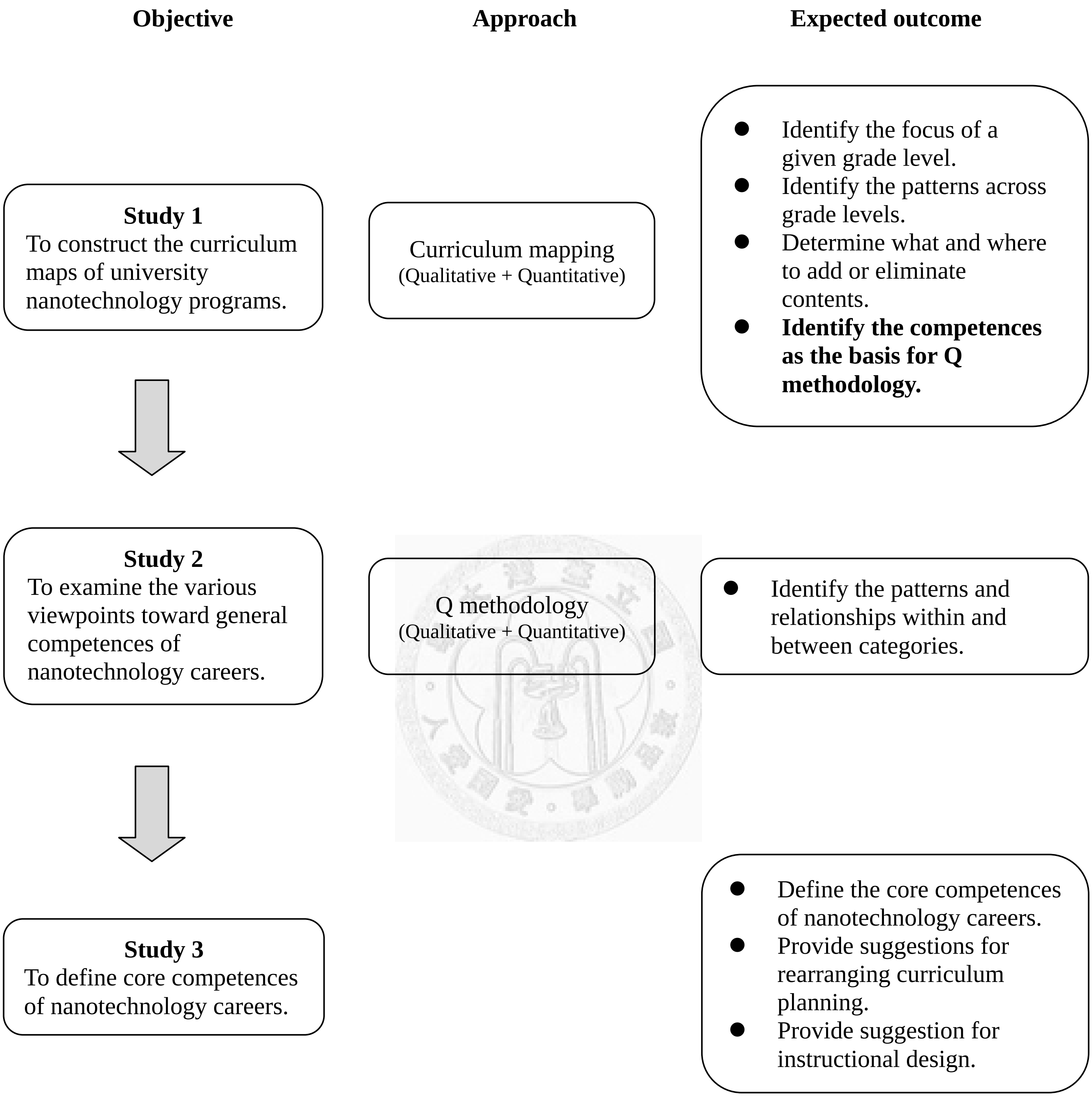

Figure 3.1 The research procedure of this study.

3.1 Research Design

This section will introduce the basic concepts and principles about curriculum mapping and Q methodology. Since it is the first exploratory study deals with the nanotechnology competences, this study took into consideration about the features of existing nanotechnology-related courses and adopted curriculum mapping as the preferable way to analyze course syllabi. In addition, nanotechnology is still under the immature stage and stakeholders hold inconsistent viewpoints about its definition and future development potential, Q methodology can be utilized to classify the categories and present the similarities and differences among stakeholders.

3.1.1 Content analysis for curriculum mapping

Content analysis is a flexible research method that provides a systematic and objective means to make valid inferences from verbal, visual, or text data to describe and quantify specific phenomena (Cavanagh, 1997; Downe-Wamboldt, 1992). Content analysis describes a family of analytic approaches ranging from impressionistic, intuitive, interpretive analyses to systematic, strict textual analyses (Rosengren, 1981). Initially, content analysis was used either qualitative or quantitative way, then it was used primarily as a quantitative research method. In quantitative content analysis, data was coded into explicit categories and described using statistics, which is sometimes referred to as quantitative analysis of qualitative data (Berelson, 1952; Morgan, 1993)

The goal of content analysis is to enhance the inferential quality of the results by connecting the categories to the context or environment that produced the data (Downe-Wamboldt, 1992). Content analysis can be used for multiple purposes, such as revealing the focus of individual, group, institutional, or societal attention; determining psychological states of persons or groups; reflecting cultural patterns and beliefs; describing themes, trends, goals, or other characteristics in communication content; and analyzing open-ended survey data (Berelson, 1952; Krippendorff, 1980; Polit & Hungler, 1991; Weber, 1985). The analytic techniques facilitates the illustration of the manifest and/or latent content of communication by measuring the frequency, order, or intensity of occurrences of words, phrases, or sentences (Krippendorff, 1980; Weber, 1985).

Generally, content analysis research method encompasses eight steps, including selecting the analysis unit, creating and defining the categories, pretesting the category definitions and rules, assessing reliability and validity, revising the coding rules if necessary, pretesting the revised category scheme, coding all data, and reassessing reliability and validity (Downe-Wamboldt, 1992). To select a sample, the population of all sources of data must first be identified. The researcher can then choose samples that are representative of the phenomena of interest (Krippendorff, 1980). After sampling, researcher needs to consider the appropriate analysis unit, such as words, sentences, phrases, paragraphs, or whole text in written data (Downe-Wamboldt & Ellerton, 1986).

Category schemes are invented by the researcher to generate knowledge and to increase understanding of a particular phenomenon. The schemes are based on the research question, the selected unit of analysis, the relevant theories, a review of previous research, literature, and the data. Because there are multiple meanings can be identified depending on the purpose of the study, the coding scheme is appropriate if it is reliable and produces relevant results for the research questions. Therefore, the coding system should define the critical attributes of specific categories and distinguish the similarities and differences among categories. A small sample of text is necessary to be pretested to determine if the rules for classifications are clear or ambiguous. Samples of text that are not easily classified will provide insights for revisions to the coding scheme. The advantage of content analysis is it offers the opportunity for researcher to devise the most appropriate definitions of the categories based on his/her interactions with the data (Downe-Wamboldt, 1992).

Stability and agreement reliability are the most pertinent types of reliability for narrative data. The extent to which the results of content classifications are consistent over time when the data are coded more than once by the same coder (intrarater reliability) can be ascertained by using Cohen's Kappa coefficient (Weber, 1985). Agreement between two or more different raters coding the same data (interrater reliability) can be assessed using Cohen's kappa or percentage agreement (Polit & Hungler, 1991).

Multiple meanings are always present in data. There is no right meaning, only the most accurate meaning from a particular perspective. Validity is confirmed or denied by returning to the original text to find examples of categories and by relating relevant theory to text. Content analysis relies heavily on face or content validity that can only determined by the judgments of experts in the area (Downe-Wamboldt, 1992).

Since content analysis views syllabi as written records of planned communication from a professor to his/her student (Sullivan & Maxfield, 2003), using content analysis as a tool to construct curriculum map is beneficial in discovering the implicit norms and distributions from the macro view, and providing the specific reference basis about qualifications graduates may possessed.

3.1.2 Q methodology for identifying nanotechnology competences

Q methodology is a behavioral research technique that was invented by British physicist/psychologist William Stephenson (1902-1989). Q methodology is fundamentally qualitative, although it may more accurately be described as "qualiquantological" as it is a qualitative methodology with strong quantitative features (Watts & Stenner, 2005b). Brown (1996) believes that Q methodology bridges qualitative and quantitative research, with advantages of both. Such as it does not require a certain sample size for reliable quantitative analysis, and provides an opportunity to shift qualitative researchers' focus from a particular individual narrative to an analysis of the range of viewpoints that is shared by a particular group of participants (Previte, Pini, & Haslam-McKenzie, 2007).

For Stephenson, two separate data matrices were at issue, the one containing objective measures (R) and the other containing data of a subjective kind (Q). Stephenson (1935) made clear that R methodology referred to a selected population of n individuals each of whom has been measured in m tests, and that *Q methodology referred to a population of n different tests (or essays, pictures, traits or other measurable material), each of which is measured or scaled by m individuals*. The former case is the objective mode (message-centered, without self-reference) and the person's stance relative to measurement is passive; the latter case represents the person actively does something and is the subjective mode (meaning-centered, self-referential) insofar as measurement is from the person's standpoint. Therefore, Q methodology provides the basis for a science of *subjectivity* (Brown, 1994-1995).

Generally speaking, there are significant underlying differences between R methodology and Q methodology. The objective measurements, R methodology, provides the basis for correlating traits were also the basis for correlating persons, and so no new concepts were necessary, only a different way of looking at them. R methodology has almost wholly to do with assessment of one kind or another objective variables (e.g. intelligence, social anxiety, and such), and these assessments are typically of traits about which the participant is at best only dimly aware. The communicability represents specialized knowledge and stand outside life as it is lived moment to moment. On the contrary, the study of subjectivity, Q methodology, requires a different way of thinking that moved away from conventional factors analysis. The purpose of Q methodology is to enable the person to represent his/her viewpoints for purposes of holding it constant for inspection and comparison. Q methodology does not measure variables but states of mind. The communicability of this kind is typically shared about fairly ordinary things (Brown, n. d.). According to the distinction, the major difference between R methodology and Q methodology turned not on the mechanics of factor analysis, but on what it was that to be measured, and how (Brown, n. d.). Table 3.1 summaries the comparisons between R methodology and Q methodology.

Q methodology is considered particularly suitable for researching the range and diversity of subjective experiences, perspectives, and beliefs. It facilitates the identification of similarities, the construction of broad categories of the phenomenon being investigated and the exploration of patterns and relationships within and between these categories (Shinebourne, 2009). In Q methodology, subjective input produces objective structures (Watts & Stenner, 2005b). Validity matters little in Q methodology since there is no external criterion for a person's own point of view (Goldman, 1990).

If a subjective snapshot of stakeholder discourses on a certain issue of concern is required, then Q methodology provides a through and reliable tool. On the other hand, the requirement is for analysis of the dynamics of different discourses, such as how and why they achieve the relative policy influence that they do, then various techniques of textual discourse analysis provide a more suitable approach. This is because Q methodology is only capable of taking a snapshot in time of people's subjective constructions of any particular issue, and textual discourse analysis can focus on rhetorical exchanges between different stakeholders (Ockwell, 2008).

Table 3.1 Comparisons between R methodology and Q methodology

Dimension	R methodology	Q methodology
Goal	Find patterns in how respondents answered different questions	Find patterns in where Q statements appear in different Q sorts
Standpoint	Objective	Subjective
Dominant	Researcher-led	Participant-led
Purpose	Assessment traits	Represent individual's perspective
Measure	Variables	Persons (states of mind)
Subject's stance	Passive	Active
Communicability	Specialized knowledge	Ordinary things
Meaning	*A priori*	*A posteriori*
Orientation	Hypothetico-deductive	Exploratory
Emphasis	Message-centered	Meaning-centered
Self-reference	Not self-reference	Self-reference
Concern	Facts	Opinions
Sampling	Randomness	Representativeness
Researcher bias	Comparably high	Comparably low
Analysis	Variance analysis	Factor analysis

Source: Summary by the researcher of the study

Q methodology was primarily used in psychology until the 1970's for single studies into the subjectivity of a range of topics, and as a means of standardized measurement in, for example personality assessment and psychotherapeutic counseling (McKeown & Thomas, 1988). From the 1970's onwards it became more widely applied in other fields, such as gender, education, medicine, and marketing. The examples are summarized in Table 3.2, which shows the amount of participants differs significantly from 1 to 271 and most of the statements size is below 60. The widespread applications and openness in the research design give the researchers more autonomy to draw up the appropriate research procedure planning.

Table 3.2 Examples of Q methodology studies

Authors/ Year	Topic	Participants	Statements	Factors
Kitzinger & Rogers (1985)	lesbian identities	41	61	5
Brown & Mathieson (1990)	critical reading	13	30	3
Goldman (1990)	narcissism culture	1	60	4
Rogers & Rogers (1990)	addiction	68	160	12
Sanders & Morris (1990)	oral history	8	38	4
Stenner & Marshall (1995)	rebelliousness	40	60	8
Brown (1996)	health care	1	24	3
Mosyagina, Kashin, & Peck (1997)	consumer attitudes	56	32	6
Stenner & Rogers (1998)	jealousy	47	55	10
Barry & Proops (1999)	attitude toward environment	25	36	4
Stenner, Dancey, & Watts (2000)	illness	60	58	7
Robinson, Popovich, Gustafson, & Fraser (2003)	magazine advertisements	39	40	3
Watts & Stenner (2005a)	partnership love	50	60	8
Ellis, Barry, & Robinson (2007)	wind farm	54	50	8

Authors/ Year	Topic	Participants	Statements	Factors
Kallay (2007)	meaning systems	50	51	4
Shinebourne & Adams (2007)	addiction	13	60	4
Wright, Simmons, & Campbell (2007)	health marriages	41	48	3
Ramlo (2008)	physics education	18	30	4
Ockwell (2008)	fire management	32	36	4
Goto, Tiffany, Pelto, & Pelletier (2008)	participatory action research	30	54	3
Brown & Pirtle (2008)	sex education	40	36	4
Cools, Moons, Janssens, & Wets (2009)	travel	32	42	4
Angelopulo (2009)	corporate brand perception	80	49	6
Prateepko & Chongsuvivatwong (2009)	influenza pandemic	271	33	3

Source: Summary by the researcher of the study

Q methodology is a powerful pattern analytic for expressing the ensemble of discursively organized positions or voices around an issue (Stenner & Rogers, 1998). Q methodology is a gestalt procedure (Good, 2000). This gestalt emphasis means it can never break-up its subject matter into a series of constituent themes. What it can do is to show us the particular *combinations* or *configurations* of themes which are preferred by the participant group. It is these overall configurations (not test results or measures) which are then intercorrelated and factor analyzed in a Q study (Stephenson, 1936). The meaning and significance of these configurations must then be attributed *a posteriori* through interpretation rather than through *a priori* postulation (Brown, 1980, p54).

Q methodology generally can be explained in five stages (Baker, Thompson, & Mannion, 2006), include selection of Q statements, selection of Q participants, Q sorting, Q analysis, and Q interpretation. Figure 3.2 depicts the flow and descriptions.

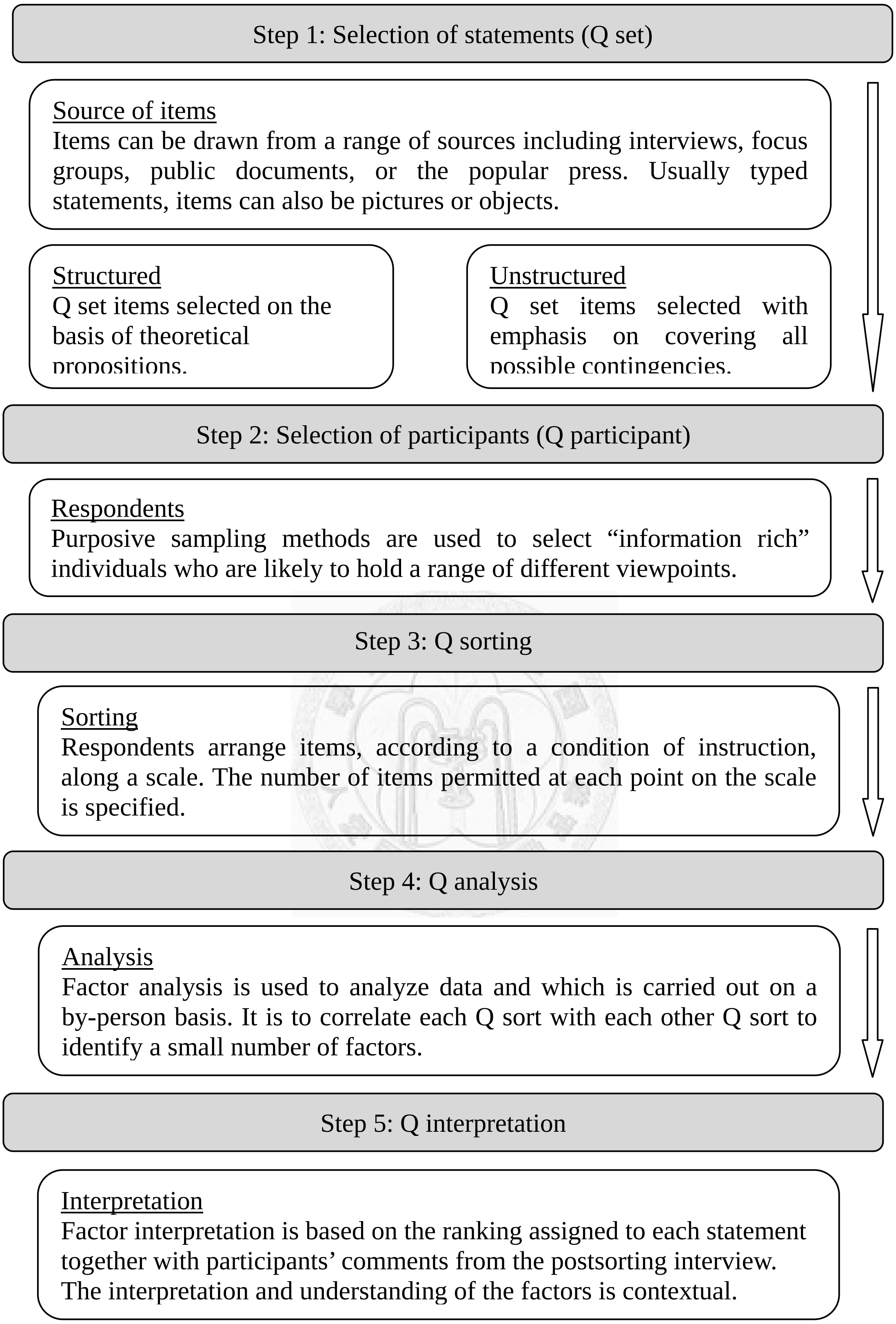

Figure 3.2 The flow of a Q study (Source: Baker et al., 2006)

Step 1: Q set

The first stage involves identifying the particular discourse which is under investigation. A discourse refers to a set of shared beliefs, opinions, understanding or meaning held by a population. The discourse in a Q study will be directly connected to one's research question (Previte et al., 2007). Then *concourse* needs to be identified. In Q methodology, the flow of communicability surrounding a topic is referred to as a concourse (Brown, 1991). This refers to the range of issues that exist on a particular discourse or topic. During concourse development, researchers build up a statement set which identifies different, but recognizable assertions about the social phenomena being studied (Previte et al., 2007).

Q set is the collection of heterogeneous items which the participants will sort, and it must be broadly representative of the opinion domain at issue. Developing the Q set assists researchers in refining and setting the research question. A clearly defined statement in the research question helps dictate the nature and structure of the Q set and act as a condition of instruction for participants during the actual sorting process (Previte et al., 2007). The selection of statements to be sorted by participants can be either unstructured or structured. In the former, statements are chosen which are presumed to be of relevance to the study but where the emphasis is on representation. In the latter, sample items are chosen to represent points in a theoretical matrix (Baker et al., 2006).

Q set only needs to contain a representative condensation of information. This is because the main concern in a Q methodological context is not the Q set itself (which is, in any event, not considered to possess any specific meaning prior to the sorting process), but the relative likes and dislikes, meanings, interpretations and overall understanding which inform the participants' engagement with the Q set (Watts &

Stenner, 2005b).

It is best to initially generate an overly large number of statements, which can be refined and reduced through processes of piloting. The piloting has advantages as reducing duplication and problematic expression, ensuring statements are presented in everyday rather than technical terminology, and ensuring the representativeness of the statement set (Watts & Stenner, 2005a). A final set of between 40 and 80 statements is considered satisfactory (Watts & Stenner, 2005b), although some studies contained more or fewer statements (see Table 3.2). A convenient method to determine the total number of statements in the Q set is by the number of effects and the number of replications of each condition (McKeown, 1990). For example, Goldman (1990) divided the photographs in Times Magazine into 10 subcategories in culture dimension and 2 subcategories in valency dimension. The 10x2 design replicated three times provided a Q sample size of n=60 out of the original 500.

Statements for the Q set can be gathered from a variety of sources, such as direct quotes and themes from interviews with participants (Brown & Pirtle, 2008; Ellis et al., 2007; Goto et al., 2008; Kitzinger & Rogers, 1985; Mosyagina et al., 1997; Ockwell, 2008; Stenner et al., 2000; Stenner & Marshall, 1995; Stenner & Rogers, 1998), academic literature (Angelopulo, 2009; Brown & Mathieson, 1990; Brown & Pirtle, 2008; Goto et al., 2008; Kitzinger & Rogers, 1985; Ockwell, 2008; Pratrrpko & Chongsuvivatwong, 2009; Ramlo, 2008; Shinebourne & Adams, 2007; Stenner et al., 2000; Stenner & Marshall, 1995; Stenner & Rogers, 1998), popular mass media (Goldman, 1990; Mosyagina et al., 1997; Pratrrpko & Chongsuvivatwong, 2009; Robinson, Popovich, Gustafson, & Fraser, 2003; Stenner & Marshall, 1995), videoed role-play session (Stenner & Rogers, 1998), informal conversations (Goto et al., 2008; Ramlo, 2008; Shinebourne & Adams, 2007), or set of scale items (from previous research) can be used to create a ready-made or adjusted Q set (Brown, 1996; Cools et al., 2009; Ramlo, 2008; Stenner & Marshall, 1995; Wright et al., 2007).

Step 2: Q participant

Q methodology ordinarily adopts a multiple-participant format and is most often deployed in order to explore highly complex and socially contested concepts and subject matters from the point of view of the group of participants involved (Stainton Rogers, 1995; Watts & Stenner, 2003). In practice, the participants in R methodology may be selected according to the researcher’s judgment, through strategic sampling, or through disproportional stratifies sampling, to ensure the identification of majority and minority views. Rather than randomness, the aim in selecting participants in Q methodology is to achieve representativeness of a cross-section of stakeholders, i.e. age, education, occupation, sex, cultural background, personal attributes, views they might express or on the basis of their social positions (Baker et al., 2006; Kitzinger & Rogers, 1985). The participants do not need to be evenly distributed across different backgrounds or interest groups while all backgrounds and interest groups are represented (Ockwell, 2008).

The number of Q participants usually is smaller than the Q set (Brouwer, 1999; Webler, Danielson, & Tuler, 2009). While variation in sample size is evident in the literature, small samples are common (see Table 3.2). Pilot studies require a small number, perhaps selected strategically to include participants who can provide a wide range of viewpoints, helpful comments, and additional statements from a variety of perspectives (Shinebourne, 2009). Between 40 and 60 participants are recommended in the formal studies, but effective studies with far fewer participants have been carried out (Watts & Stenner, 2005b), such as Barry and Proops (1999) illustrated that a larger Q participant would not be of benefit in a Q study as Q operates on the assumption of finite diversity.

Step 3: Q sorting

The sorting procedure generated observations by the sorters that most likely would not have been obtained in a traditional interview (Sanders & Morries, 1990). The research target of Q methodology is the configuration from participants' completed Q sorts (Watts & Stenner, 2005a). Fundamentally, Q sorting calls for a person to rank-order a set of statements or measurable stimuli according to an explicit rule (condition of instruction). Each statement is numbered and written on a separate card, and participants assign each statement a ranking position in a fixed quasi-normal distribution, usually from agree (+5) to disagree (-5), is helpful to assist the participant in thinking about the task. Although arguments concerning the influence of forced or free distribution in Q sorting on important information in terms of elevation, scatter, and skewness, Brown (1971) contented that factor types in Q methodology studies will be more influenced by ordering preferences than by distribution preferences. Figure 3.3 illustrates a distribution and number of items that can be assigned to a ranking position.

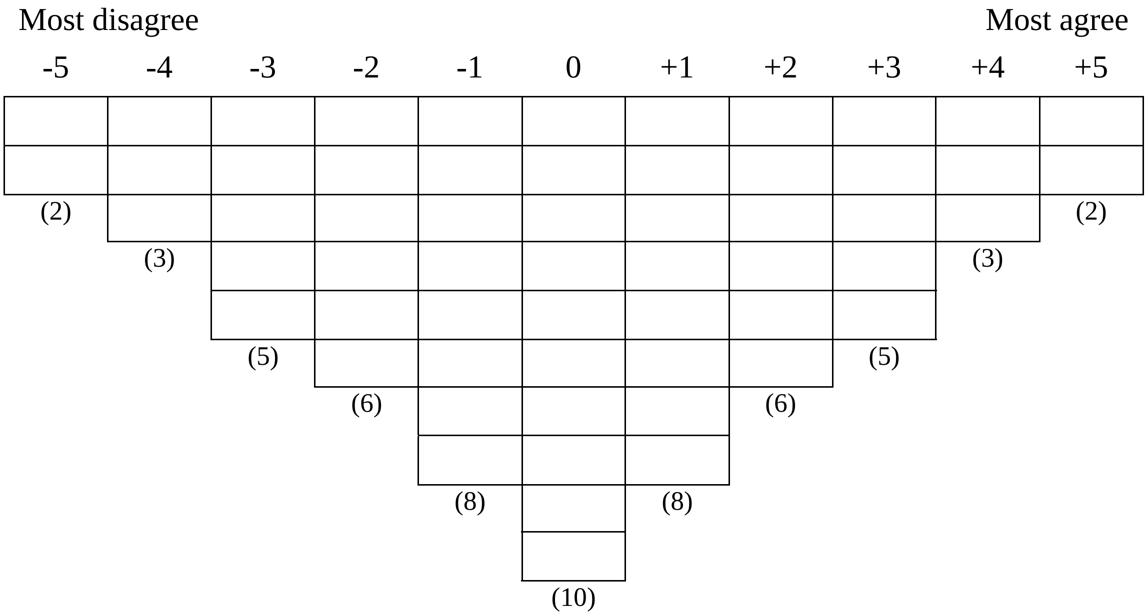

Figure 3.3 Response matrix

Each item is ordered in relation to each other item (all must be ranked somewhere on the continuum) and not in isolation as in a standard Likert-style scale (Stenner & Marshall, 1995). General practice in Q methodology is to have participants distribute the items along a continuum in which a few items are placed at the extreme ends, with a greater number of items in the middle. This convention follows from the understanding that in most cases there are fewer issues people feel most strongly about (McKeown, 1990).

A complete Q sorting indicates that a set of items have been differentially valued by a specific participant according to some face valid and subjective criterion due to the operation is inescapably subjective in the sense that the participant is sorting the statements from his or her own point of view (Brown, n. d; Watts & Stenner, 2005b). It is me rather than someone else who is providing a measure of my point of view, and the factors which emerge are therefore categories of operant subjectivity (Stephenson, 1977).

The use of the Q sorting within a constructionist framework does not impose an *a priori* structure of meanings or taps (their attitude, personality or schematizations) upon participants (Kitzinger & Rogers, 1985; Stenner & Rogers, 1998). Q methodology is not a researcher-led measurement; rather it pursues participant-led subjective expressions and viewpoints (Watts & Stenner, 2005b). In other words, rather than researchers testing their own pre-conceived ideas of what might exist in the public sphere, Q methodology allows researchers to reach out into the public sphere and let the public itself define what exists there. Therefore, the emerging factors are naturalistic in the sense that they are naturally-occurring events, and the level of likely researcher bias within a Q methodology-based study compares favorably with traditional R techniques as well as other non-hypothesis led approaches to deriving public opinion (Ockwell, 2008).

After completing the Q sorting, postsorting interview is generally conducted. Each participant is asked to comment on the statements, to suggest additional statements that might be included, and to point out statements that are not clear. Such open-ended questions are helpful to the interpretations of the sorting configuration (Shinebourne, 2009).

Step 4: Q analysis

What Q factor analysis does is keeping parts together in their interrelation (synthesis). Stephenson utilized *factor analysis* rather than variance analysis in analyzing data obtained from Q methodology. Variance analysis relies on the *a priori* meaning built into a sample of Q statements, hence it is tied to prestructured effects in precisely the same way as R methodology. On the other hand, Q factor analysis more keeps the meanings which participants give to the statements by preserving the operations involved in ordering the statements (Brown, n. d.; Watts & Stenner, 2005b). The factor analysis is carried out on a by-person rather than a by-item basis. Hence, it is the participants who load onto the emergent factors of a Q methodology study, their relationship to that factor being a function of the manner in which they have configured the statements during the Q sorting task (Watts & Stenner, 2005b).

By identifying distinguishing statements, researchers can create a distinct picture for each factor array (Previte et al., 2007). The process of Q analysis is to correlate each Q sort with other Q sort (not the relationship of each item with every other item) to identify a small number of factors that can represent shared forms of understandings among participants (Shinebourne, 2009).

PQMethod (detailed operation procedure can refer to Webler et al., 2009) and PCQ are factor analytic programs that quantify subjectivity and reveal patterns of perceptions in any situation. One of the benefits of PQMethod is the flexibility it allows researchers to compare and contrast hand-rotated factors with computer-generated factors (Robinson et al., 2003). Two types of the factor techniques, centroid analysis and principal components analysis, are generally preferred (Watts & Stenner, 2005b). The centroid factor analysis is attempted to extract common factors without taking into consideration all stages of calculation specific to the principal component analysis (Radu, 1993). The purpose of the centroid analysis is to find a simple, economic solution in order to get a smaller number of factors than the number of variables (Kallay, 2007).

In order to examine factors from several perspectives, the original set of factors is rotated (Exel & Graaf, 2005). The main purpose of rotation is to obtain a clear pattern of loadings, namely factors that are somehow clearly marked by high loadings for some variables and low loadings for others (Hill & Lewicki, 2006). The varimax rotation and judgmental rotation are most used in Q methodology (Baker et al., 2006; Kitzinger & Rogers, 1985; Pratrrpko & Chongsuvivatwong, 2009; Sanders & Morris, 1990; Stenner & Marshall, 1995). The statistical sophistication of varimax rotation results in higher levels of explained variance and a simple structure which maximizes the similarities within factors and the differences between them. Namely it reveals the range of discourses in the participant group (Baker et al., 2006; Watts & Stenner, 2005b). Judgmental rotation allows the researchers to view the factors from different angles before arriving at a factor solution, as well as enables exploratory hypothesizing about patterns of data (Baker et al., 2006). In practice, varimax rotation is preferable if the objective is the mathematical derivation of factors, and judgmental rotation is preferable if factors are to be generated according to the researcher's specific theoretical objectives (Angelopulo, 2009).

Brown (1980) recommends researchers run from a seven-factor to two-factor solution before accepting a final solution. Different criteria were used to determine the number of factors that have to be rotated. A first criterion is selecting only those factors with an eigenvalue in excess of 1.00 (Watts & Stenner, 2005b). Eigenvalues are a measure of the relative contribution of a factor to the explanation of the total variance in the correlation matrix. Factors with an eigenvalues greater than one explain more variance than a single variable would (McKeown & Thomas, 1988). A second criterion is that factors are viable if they contain at least two significant factor loadings at the .01 level (Brown, 1980; Watts & Stenner, 2005b).

Finally, the Q sorts of all participants that load significantly on a given factor are merged together to yield a single Q sort which serves as an interpretable best estimate of the pattern or item configuration which characterizes that factor. Confounded Q sorts (which load significantly on two or more factors) are excluded from this weighted averaging procedure (Pratrrpko & Chongsuvivatwong, 2009; Watts & Stenner, 2005b).

Step 5: Q interpretation

If significant clusters of correlation among Q sorts exist, they could be factorized, and described as common viewpoints (or tastes, preferences, typologies). Q sorts which load significantly upon one factor alone are called factor exemplars. Typically a factor will have a number of factor exemplars. However, factors with single exemplar can still be interpreted if theoretically salient (Stenner et al., 2000).

Q methodology focuses on the statements of opinion rather than statements of fact (Brown & Mathieson, 1990; McKeown, 1990). The interpretation and understanding of the factors is contextual, which means researchers need to recognize participants' personal experience of events (McKeown, 1990). Interpretation of the factors allows a structure to be developed, presenting different accounts of a specific topic by drawing together the commonalities and correlations between the sorts and revealing the competing but equivalent stories surrounding the topic of interest (Baker et al., 2006).

Factor interpretation is based on an examination of the ranking assigned to each statement together with participants' comments from the postsorting interview, which are integrated in narrative accounts of each factor (Shinebourne, 2009). The brief postsorting interview helps researchers to investigate how the participant has interpreted the statements given especially high or low rankings in their Q sort, and what implications those items have in the context of their overall viewpoint; if there are any additional statements they might have included in their own Q set; and if there are any further statements about which the participant would like to pass comment, which they have not understood, or which they simply found confusing (Watts & Stenner, 2005b).

3.2 Research Procedure

This research consists two studies which need to collect diverse but interrelated research samples and participants, respectively. Course syllabi from all Taiwan nanotechnology-related university programs are the main data sources for content analysis to construct curriculum map. The preliminary results of extracting competence descriptions from curriculum mapping are employed to be the Q set reference basis for pilot Q study and further formal Q study. The detailed sampling procedure, sample size, classification standards, and participant qualifications will be presented below.

3.2.1 Study 1 - Curriculum mapping

3.2.1.1 Sample

Totally 600 course syllabi were collected from thirteen nanotechnology-related undergraduate and graduate programs of nine Taiwan leading universities in November, 2010. The courses which are only listed on the program initial planning but not really open will be deleted. On the contrary, some elective courses are included although they were not covered in the initial program planning but be categorized in the nanotechnology-related programs later. Totally, 220 courses of them belong to undergraduate level and 380 courses are graduate level. The detailed course titles are showed in Appendix 1. Items analyzed include course titles, descriptions of target learners (undergraduate or graduate), course outlines, and course descriptions. Curriculum maps are then constructed based on the results of analyses.

3.2.1.2 Content analysis for syllabi

The analysis employs the following classical procedure of the content analysis method: the syllabus contents are first recorded on a standardized form by the researcher and items of the form taken into consideration are developed upon perspectives of competence- and outcome-based education. After completion of pretest, the category definition by three researchers with instructional background, several discussions about coding and classification are held to achieve the inter-rater agreement. The quality of the coding is assessed by Cronbach alpha. A value of 0.8 is put forward as an acceptable criterion for inter-rater reliability. The inter-rater agreements among three raters vary from 0.80 to 0.88, and the inter-rater reliability is 0.942 which attains a rather high reliable level.

The curricula in nanotechnology program from different universities are first mapped by course levels and domains based on the content analysis of syllabi. Part of the map consists of four course levels: (1) basic course, such as general physics, chemistry, or biology are prerequisite or foundation courses generally required for the advance study in field of engineering, material science, medicine, or agriculture and natural science, etc.; (2) core course, means to provide basic knowledge in nanotechnology, like introduction to nano-science and technology and so on; (3) nanotechnology-specific professional course, represents courses offering advanced knowledge in nanotechnology; and (4) nanotechnology-related professional course, which are commonly built upon basic courses and further linked to the advanced knowledge of other fields. In addition, basic science research, material science research, advanced technology research, resource and environmental science research, biotechnology research, management research, and others are seven major domains applied to analysis for curriculum mapping.

Besides the subject contents, curriculum maps are constructed by course levels and competences expected to learn in the courses. Expected competences are defined as the capabilities that instructors expect students to possess after they accomplish the courses. Conceptual knowledge covers those of introductory, rationale, strategic and theoretical knowledge interpreting what or why some phenomena happen. Procedural knowledge includes something about approaches, laws, principles and methods of how to operate the instruments and systems. Operational skills are the actual abilities of manipulating experimental equipments or analytical software tools. And the other ability attributes are something related to personal internal characteristics, such as the abilities of independent thinking, creativity, or solve problems and so on.

In order to extract the detailed and concrete competences descriptions which are valuable references for developing Q set, the proper name such as semiconductor, MEMS, or nanofabrication is selected as the analysis unit. After reviewing the course title, course outline, and course description, 410 competences were discovered (see Appendix 2). Further classification and application are discussed in the procedure of Q set.

Any course reviewed is possibly recorded and classified into more than one categories due to the nature of course contents may across multiple domains and provide different competences. However, each course is only subject to one specific course level.

3.2.2 Study 2 – Q methodology

In order to obtain the most core and representative competence descriptions, there are 3 sequential steps deployed in this stage (Table 3.3). Questionnaire was utilized to reduce the sample size from 410 to 120. The 120 competences further applied as the pilot Q set to find out the redundant and integrable competences. Finally, 47 competences were identified as the formal Q set for all stakeholders in the Q study.

Table 3.3 Three steps for confirming the Q set

Step	Purpose	Method	Subject	Competence amount
1	Narrow the size	Questionnaire	1 Associate professor	From 410 to 120
2	Pilot Q study and narrow the size	Pilot Q study	2 Postdoc researchers	From 120 to 47
3	Confirm the representative competences	Q study	12 Employees 3 Professors 18 Students	47

3.2.2.1 Questionnaire for narrowing the pilot Q set size

From the results of curriculum mapping in stage 1, 410 competences were discovered. To collect nanotechnology-related professional personnel’s response and opinions to these competences for narrowing the size, a questionnaire on a 5-point (1= not important, 5=very important). Likert scale was distributed to one associate professor who holds a post at college of engineering in National Taiwan University (NTU) for 12 years. The questionnaire was composed of 410 items to evaluate how much does the instructor think these competences would be essential to the practical nanotechnology-related work tasks. Besides, interview was conducted to collect instructor’s free feedbacks toward these competences and future application and development of nanotechnology.

3.2.2.2 Pilot Q study

There were 120 competences rated relatively high among 410 competences, and which were selected as the Q set for the pilot Q study. The 120 extracted statements are then evaluated by two postdoc researchers with nanotechnology-related experiences. First, the response matrix (Figure 3.4) from very important (+5) to totally not important (-5) and 120 statements were given to the Q participants separately. Then Q participants were informed the purpose of pilot Q study was to examine their subjective opinions about the general competences graduates should possess when dealing with nanotechnology-related job, as well as the detailed Q sorting procedure. After completing the Q sorting, postsorting interview was conducted. Each participant was asked to comment on the statements, the sorting procedure, the relevance of each statement, the statements that are not clear, and provide suggestions to the Q study.

After completing two pilot Q studies, the Q sorting results and interviews were integrated as a foundation for further competences clarification. In the beginning, the statements which were rated equal and above 0 by both Q participants were selected. Sixty-six statements conformed to the requirement, and the others were deleted due to the unclear vocabulary or insignificance. Considering the completeness, explicitness, and representativeness suggested by participants, some similar statements were integrated to a more comprehensive representation. Finally, forty-seven statements are selected as contributing to the final Q-set.

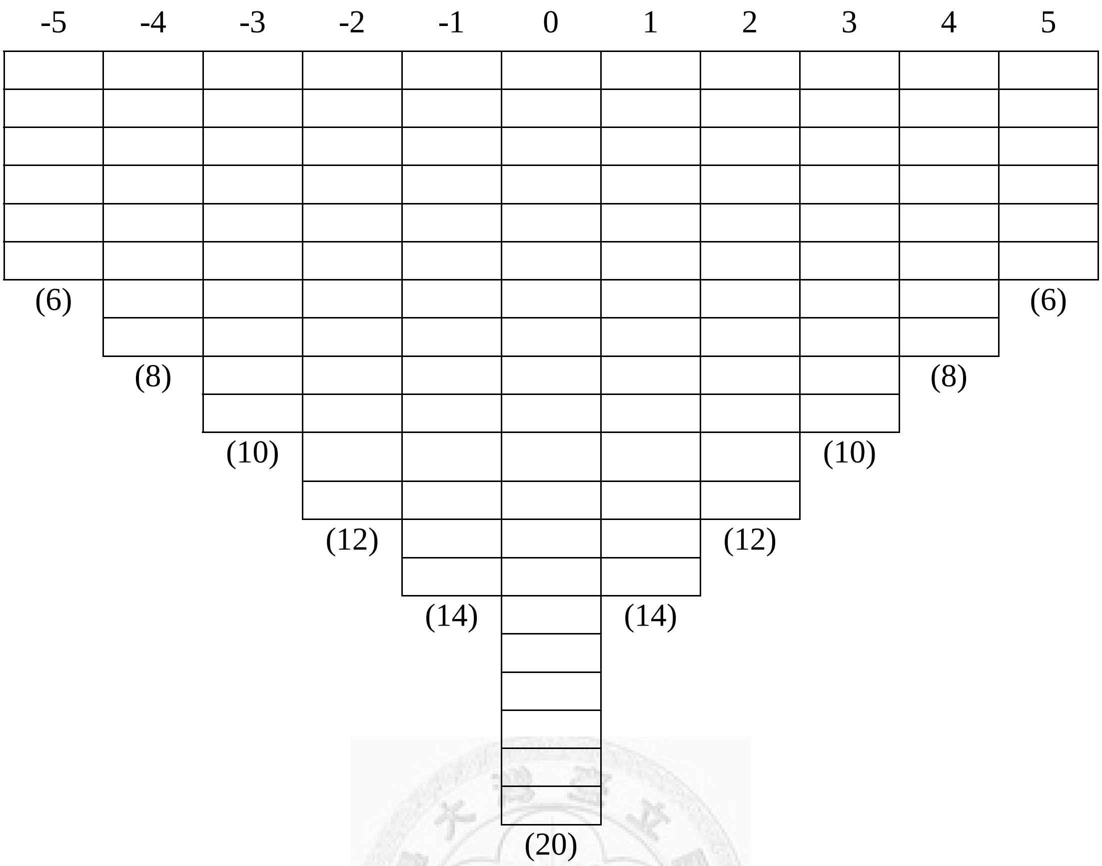

Figure 3.4 Response matrix for pilot Q study

3.2.2.3 Q study

Forty-seven statements (Table 3.4) were applied in the formal Q study. According to the results of curriculum mapping, Appendix 3 shows the summary of statements by detailed competence categories (knowledge, skill, attitude, and other attributes). In order to obtain the valuable and representative viewpoints of different stakeholders, twelve employees in electro-optic company which located in Southern Taiwan Science Park, three professors specialized in nanotechnology employed in National Taiwan University, and eighteen undergraduate and graduate students of National Taiwan University were recruited to be the Q participants. All the participants were selected purposely by the researcher for the representativeness and views they might express on the basis of their unique position.

Table 3.4 Q statements for formal Q study

No.	Statement	No.	Statement
1	Classical physics	25	Nanoelectromechanical system
2	Modern physics	26	Nanoelectronics system
3	Basic chemistry	27	Integrated circuits fabrication
4	Applied chemistry	28	Integrated circuits design
5	Circuit Theory	29	Nanotransport
6	Nanoscience	30	Vacuum technology
7	Nanotechnology	31	Clean room technology
8	Nanomaterial	32	Measurement technique
9	Nanodevice	33	Nanophotonics
10	Plasma engineering	34	Liquid crystal display
11	Electronic equipment	35	Bionanotechnology
12	Electronic manufacturing	36	Nanofood technology
13	Electronic packaging	37	Solar cell
14	Optical packaging	38	Environmental nano technology
15	Nano-optoelectronics	39	Biochip
16	Nano-scale	40	Lab-on-a-chip
17	Nanostructure	41	Microsystem chip
18	Solid structure	42	Innovation
19	Electronic structure	43	Independent thinking ability
20	Nanobiology structure	44	Flexibility
21	Engineering mathematics	45	Understand market trend
22	Nanometrology	46	Solve problem ability
23	Calculus	47	Activeness and aggressiveness
24	Microelectromechanical system		

There are three researchers with instructional design background responsible for executing the Q study. Before the Q study starts, a orientation was convened to explain the purpose of the Q study, the procedures of Q sorting, the standardized and essential questions in postsorting interview, the matters needing attention, and carry out the simulation. During the simulation, researchers pretend to be the Q participant and researcher respectively. Researcher is required to demonstrate the complete procedures from the initial explanation of the Q study to the Q participant, the Q sorting by the participant, and the interview and interaction between them. After the simulation, the confused issues arose and common consensus established among researchers.

The purpose of this stage is to apply Q methodology for exploring the expected nanotechnology-related competences of university graduates. The employees, professors, and students carry out the Q study in May and June, 2011. To help researchers know Q participants' backgrounds and experiences with nanotechnology, Q participants are asked to fill out a questionnaire before the Q sorting. A response matrix from very important (+5) to not important at all (-5) (Figure 3.5) is provided to demonstrate the distribution and number of items that can be assigned to a ranking position. The task for Q participants is to sort all statements according to their relative importance when engaging in nanotechnology careers.

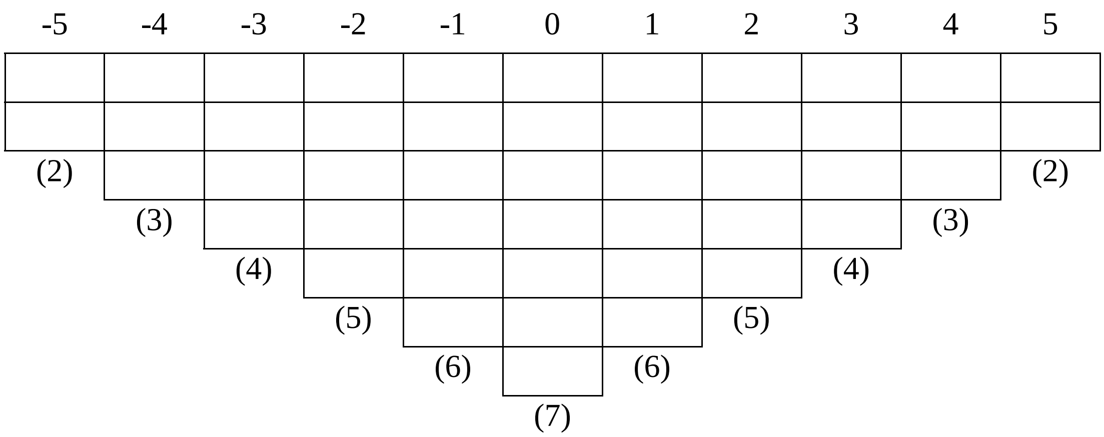

Figure 3.5 Response matrix for Q study

Postsorting interview is conducted to encourage Q participants express their subjective opinions about key issues, such as are there any vague or unclear statement? What are the consideration points when they did sorting? Does the nanotechnology industry exist? Is it necessary to have specific nanotechnology competence description? Furthermore, unique questions are queried to different stakeholders. Employees are asked about the dimensions students need to possess before entering nanotechnology industry from their practical viewpoint, professors provide the insights into the advantages and disadvantages of present university nanotechnology education, and students illustrate the helpfulness of competence definitions to their future career choice and career development. The questions of postsorting interviews for different Q participants are shown in Appendix 4. Finally, the thirty-three Q sorting results analyzed by PQMthod and the discourse analysis of interviews can be compared and show the similarities and differences among different categories.

Chapter Four Curriculum Maps Analysis and Discussion

The results of analysis and interpretation of this research can be divided into two chapters. The chapter four focuses on the content analysis of 600 syllabi. Four curriculum maps of nanotechnology of the university level are constructed and verified using triangulation by three researchers with instructional design backgrounds. In chapter five, configurations of thirty-three Q sorting are analyzed by PQMethod, as well as discourse analysis in postsorting interviews, are integrated and compared to confirm the expected nanotechnology-related competences of university graduates.

4.1 Curriculum Maps Analysis

Table 4.1 represents the summary of research sample. According to the coding standards illustrated in chapter three, all 600 course syllabi are analyzed. Four curriculum maps of nanotechnology of the university level are constructed. Table 4.2 summarizes subject contents in relation to the program levels. Regardless of program levels, courses identified as the nanotechnology related professional course (16.66% and 31.50%, respectively) are the ones being offered the most. However, the continuing order of courses is different between program levels. In undergraduate level, basic course (10.50%) is paid more attention than nanotechnology specific professional course (5.00%) and core course (4.50%). Contrarily, the sequence in graduate level is nanotechnology specific professional course (17.17%), core course (7.50%), and basic course (7.17%).

Table 4.1 Summary of research sample

University	Program	Level	Courses	Total
National Sun Yat-Sen Univ.	Nanotechnology Material Program	Undergraduate	8	14
		Graduate	6	
National Chung Hsin Univ.	Graduate Program for Bio Nanotechnology	Undergraduate	0	20
		Graduate	20	
	Graduate Program for Nanoscience and Nanotechnology	Undergraduate	1	31
		Graduate	30	
National Tsing Hua Univ.	Nanotechnology Program	Undergraduate	20	75
		Graduate	55	
	Nanotechnology and Semiconductor Photonics Industry Program	Undergraduate	25	48
		Graduate	23	
	Institute of NanoEngineering and MicroSystems	Undergraduate	3	69
		Graduate	66	
National Taiwan Univ.	Nano-Technology Curriculum Program	Undergraduate	69	111
		Graduate	42	
National Cheng Kung Univ.	Institute of Nanotechnology and Microsystems Engineering	Undergraduate	0	95
		Graduate	95	
National Chiao Tung Univ.	Degree Program of Nano Science and Engineering	Undergraduate	50	61
		Graduate	11	
	Institute of Nanotechnology	Undergraduate	0	22
		Graduate	22	
National Central Univ.	Nanotechnology Program	Undergraduate	34	40
		Graduate	6	
National Chung Cheng Univ.	Nanotechnology Program	Undergraduate	4	7
		Graduate	3	
National Ilan Univ.	Micro-Nanotechnology Engineering Program	Undergraduate	6	7
		Graduate	1	
Total		Undergraduate	220	600
		Graduate	380	

Source: Summary by the researcher of the study

Table 4.2 Summary of course levels in undergraduate and graduate levels

Level	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Undergraduate level	63 (10.50)	27 (4.50)	30 (5.00)	100 (16.66)	220 (36.66)
Graduate level	43 (7.17)	45 (7.50)	103 (17.17)	189 (31.50)	380 (63.34)
Total (%)	106 (17.67)	72 (12.00)	133 (22.17)	289 (48.16)	600 (100)

The results of curriculm map analyses by level and domain are displayed in Table 4.3 and Table 4.4. In both the undergraduate or graduate levels, near 50% are nanotechnology related professional courses. Next is the group of basic courses (26.12%), nanotechnology specific professional courses (18.37%), and core courses (11.84%) in undergraduate level; and nanotechnology specific professional courses (28.87%), core courses (11.51%), and basic courses (10.09%) in graduate level.

As for the course domains, the courses of basic science research (46.11%) are more emphasized in undergraduate level, followed by material science research (27.35%), advanced technology research (11.02%), and biotechnology research (6.94%). However, the first in terms of course amount in the gradute level is basic science research (37.32%), followed by advanced technology research (22.77%), material science research (16.43%), and biotechnology research (15.02%).

Table 4.3 Analysis of undergraduate curriculum map by level and domain

Level / Domain	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Basic science research	60	20	2	31	113 (46.11)
Material science research	0	4	14	49	67 (27.35)
Advanced technology research	1	0	7	19	27 (11.02)
Resource and environmental science research	0	0	1	0	1 (0.41)
Biotechnology research	2	0	12	3	17 (6.94)
Management research	1	2	5	5	13 (5.31)
Others	0	3	4	0	7 (2.86)
Total (%)	64 (26.12)	29 (11.84)	45 (18.37)	107 (43.67)	245 (100)

Table 4.4 Analysis of graduate curriculum map by level and domain

Level / Domain	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Basic science research	37	27	19	76	159 (37.32)
Material science research	3	4	35	28	70 (16.43)
Advanced technology research	0	6	39	52	97 (22.77)
Resource and environmental science research	0	0	7	14	21 (4.94)
Biotechnology research	3	2	23	36	64 (15.02)
Management research	0	0	0	4	4 (0.94)
Others	0	10	0	1	11 (2.58)
Total (%)	43 (10.09)	49 (11.51)	123 (28.87)	211 (49.53)	426 (100)

Table 4.5 and Table 4.6 show the results of analyses of curriculum maps by level and competence. As seen in Table 4.4, conceptual knowledge (47.77%) and procedural knowledge (29.40%) predominate the learning contents of undergraduate courses. Likewise, conceptual knowledge (42.90%) and procedural knowledge (40.43%) are also the main contents offered in the graduate courses of nanotechnology programs (Table 4.5).

Table 4.5 Analysis of undergraduate curriculum map by level and competence

Level / Competence	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Conceptual knowledge	57	25	23	77	182 (47.77)
Procedural knowledge	18	7	20	67	112 (29.40)
Operational skills	10	2	4	26	42 (11.02)
Other attributes	11	8	8	18	45 (11.81)
Total (%)	96 (25.20)	42 (11.02)	55 (14.44)	188 (49.34)	381 (100)

Table 4.6 Analysis of graduate curriculum map by level and competence

Level / Competence	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Conceptual knowledge	40	42	70	126	278 (42.90)
Procedural knowledge	14	19	87	142	262 (40.43)
Operational skills	7	6	13	44	70 (10.81)
Other attributes	2	7	12	17	38 (5.86)
Total (%)	63 (9.72)	74 (11.42)	182 (28.09)	329 (50.77)	648 (100)

There are only two nanotechnology programs had already established curriculum maps. In order to understand the relationship of different courses and display consistent representation of all the curriculum maps, four course levels are used as the main categories and thirteen curriculum maps of each nanotechnology programs are depicted by this study. Figure 4.1 to Figure 4.13 show the interrelations of basic course, core course, nanotechnology-specific course, and nanotechnology-related course of each program. The solid line means the courses have sequential relationship, and which is usually influenced by the originally established curriculum maps. However, the dashed line represents there is no strict enrollment order among courses. Furthermore, Figure 4.14 depicts the overall and general summary of thirteen nanotechnology programs.

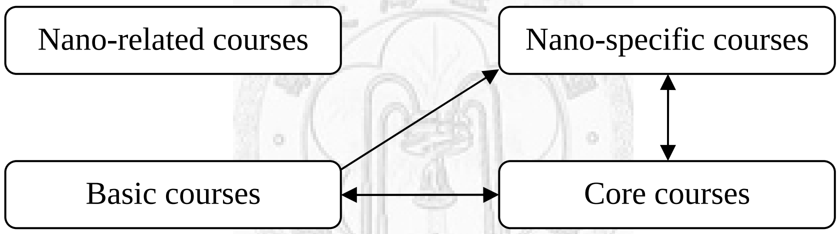

Figure 4.1 Curriculum map of Nanotechnology Material Program, National Sun Yat-Sen University

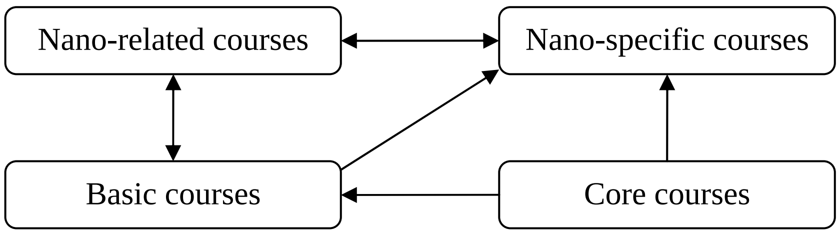

Figure 4.2 Curriculum map of Graduate Program for Bio Nanotechnology, National Chung Hsin University

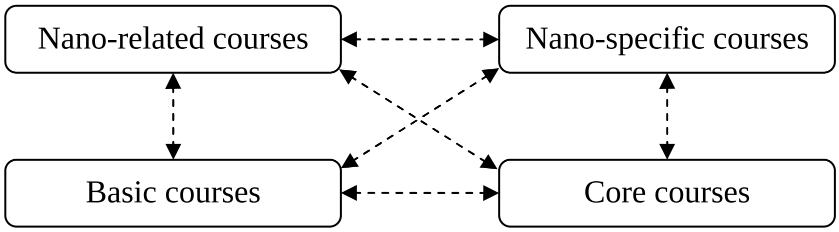

Figure 4.3 Curriculum map of Graduate Program for Nanoscience and Nanotechnology, National Chung Hsin University

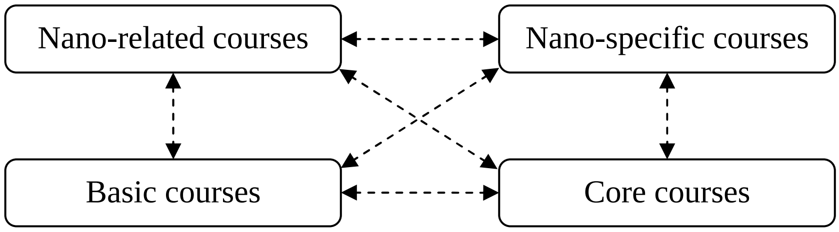

Figure 4.4 Curriculum map of Nanotechnology Program, National Tsing Hua University

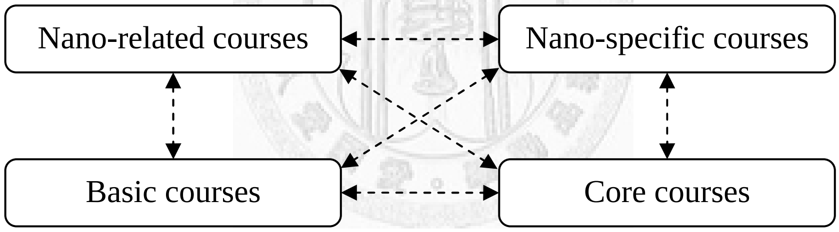

Figure 4.5 Curriculum map of Nanotechnology and Semiconductor Photonics Industry Program, National Tsing Hua University

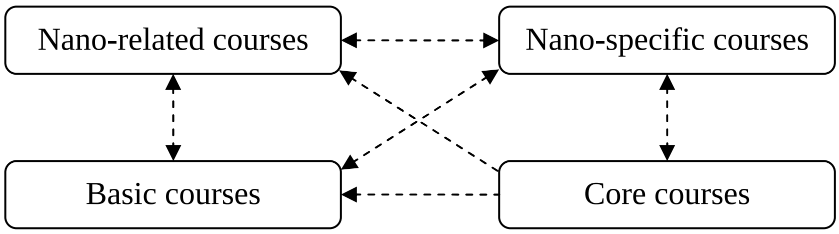

Figure 4.6 Curriculum map of Institute of NanoEngineering and MicroSystems, National Tsing Hua University

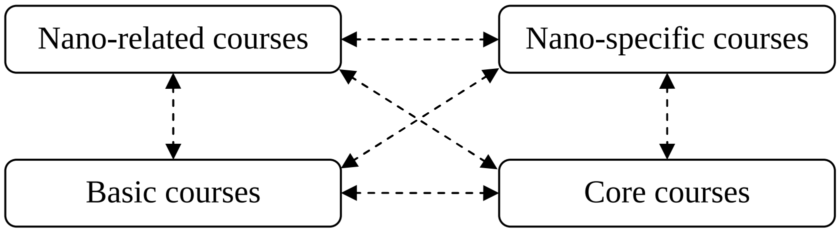

Figure 4.7 Curriculum map of Nano-Technology Curriculum Program, National Taiwan University

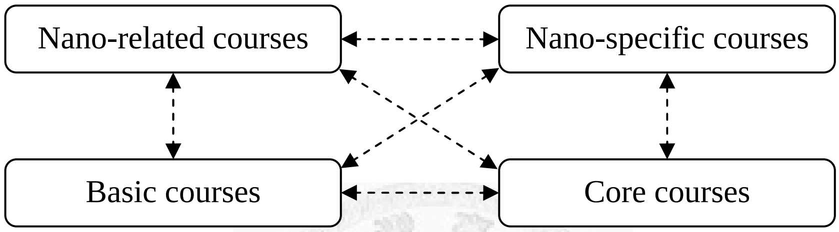

Figure 4.8 Curriculum map of Institute of Nanotechnology and Microsystems Engineering, National Cheng Kung University

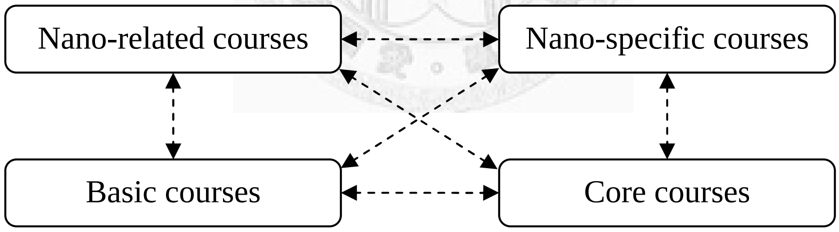

Figure 4.9 Curriculum map of Degree Program of Nano Science and Engineering, National Chiao Tung University

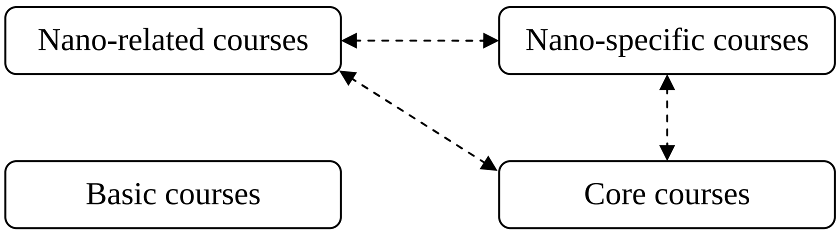

Figure 4.10 Curriculum map of Institute of Nanotechnology, National Chiao Tung University

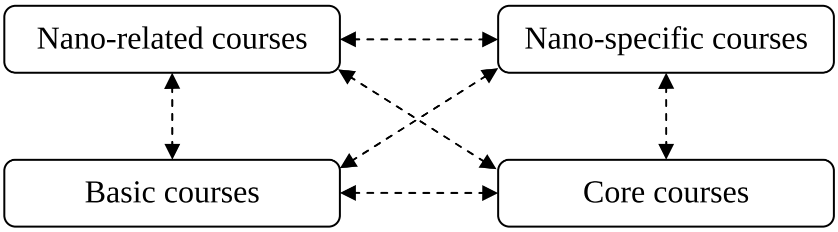

Figure 4.11 Curriculum map of Nanotechnology Program, National Central University

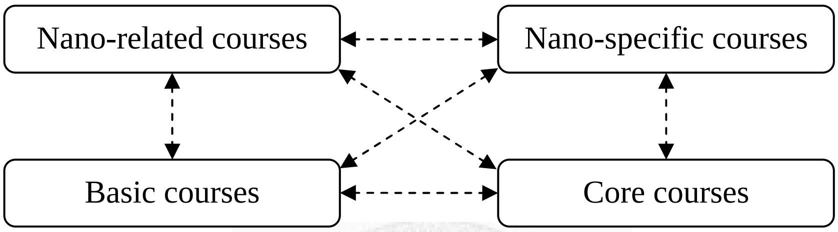

Figure 4.12 Curriculum map of Nanotechnology Program, National Chung Cheng University

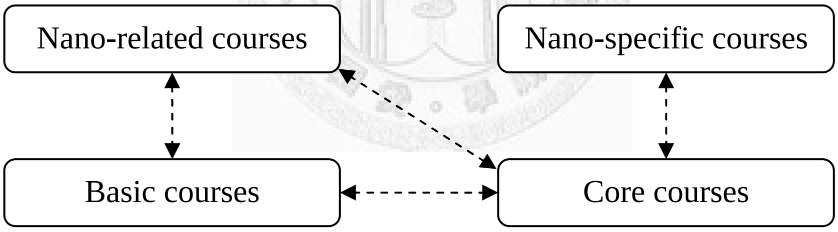

Figure 4.13 Curriculum map of Micro-Nanotechnology Engineering Program, National Ilan University

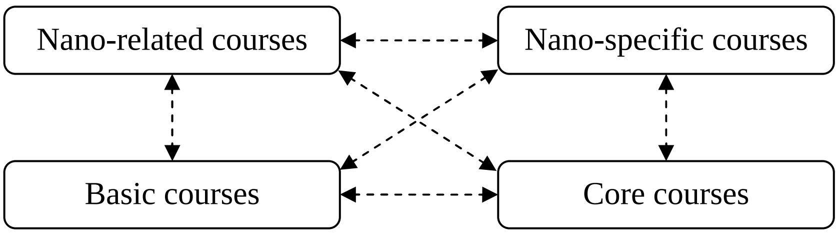

Figure 4.14 Summary of all curriculum maps

4.2 Curriculum Maps Interpretation

This exploratory study utilizes the curriculum mapping as a means to analyze nanotechnology program design in Taiwan's universities with an attempt to introduce new approach to curriculum design and development based on perspectives of outcome-based and competence-based education. The curricum map is considered as an effective means to determine whether the componentents like learning objectives and learning activities that constitute of an educational program are integrated and linked well to further students' learning (Cottrell, Linger, & Shumway, 2004). At present, utilizing curriculum mapping to assist in program design is commonly found in many disciplines, such as medicine (Britton, Letassy, Medina, & Er, 2008; Cottrell et al, 2004; Hege, Siebeck, & Fischer, 2007), education (Sumsion & Goodfellow, 2004; Willett, 2008), and ICT (Toral, Martinez-Torres, Barrero, Gallardo, & Ayala, 2006). Yet, no report is found on the use of a holistic curriculum map in nanotechnology program at the university level.

Based on a review of literature, it suggests that fourteen elements, which are then categorized into four clusters often contribute to a curriculum map (Willett, 2008). For the current study, learning outcomes and specific learning objectives are the foci in correspondence with the competence- and outcome-based perspectives to examine the nanotechnology program design. The finding indicates that the nanotechnology programs in Taiwan place more emphases on nano related professional course. In fact, the percentage of nano related courses available in nanotechnology program is twice more than courses specific related to nanotechnology. It is possible that the nanotechnology represents as a 'small-scale' field of study and is often integrated in almost every engineering professional subject as a specific or advanced section of study. That is, such program is intended to have student first learn from those fundamental and some advanced subjects related to their own field of study and then built upon those learned knowledge link to the field of nanotechnology.

After thoroughly analyzing selected nanotechnology programs, sixty-three foundation courses are generally required for students in hope to further study in nanotechnology. These courses can be further categorized into two foci of study: fostering basic skills, such as conducting and performing various experiments in labs and developing the fundamental science knowledge like physics and chemistry theory. These foundation courses are all considered as core knowledge to develop students' competences for the further professional development. Since there is only one university in Taiwan offers a complete undergraduate program in nanotechnology, most of these foundation courses are offered by different departments as prerequisite courses for students interested in further study in nanotechnology.

Clearly, basic science research, advanced technology research, and material science research are three major areas of study constituting of the nanotechnology curriculum. At both the undergraduate and graduate levels, the curriculum designer and instructors stress more on introducing the basic concepts and theories of physics, biology, chemistry, and mathematics. Considering nanotechnology is an interdisciplinary field in nature, it is no suprise to observe such emphasis. In addition, advanced technology research and material science research are also the key concerns for curriculum planning according to the results of present research. The advanced technology research includes topics, such as devices, engineering, microelectronic mechanical system, and electro-optics, etc., while the topic of semiconductor is the main point of material science research. Accordingly, having various science-related studies enable students to be invovled in studying nanotechnology in order to appropriately apply and integrate learned knowledge to the advacned learning.

Besides, as shown in the study results, the instructors of nanotechnology field provide students with more theoretical knowledge than operational skills in instruction. This may be due to a lack of facility, equipments, and other infrastructures for practicing purpose. While a higher percentage of conceptual knowledge is taught than procedural knowledge at both undergraduate and graduate programs, the difference appears more distinguishable at undergradute level. This finding could be derived from the differences in the design of instructional strategies and curriculum development of the courses offered at undergraduate and graduate levels. Graudate students took several prerequisite courses in conceptual knoweldge before starting the advanced study in nanotechnology. Thus, providing graudate studens with more procedural knowledge would assist in developing their skills and abilitites in solving problems for real life. Furthermore, few competence related to attitude/other attributes were mentioned. The finding is consistent with the general drawback that instructors pay more attention on knowledge/skills development, but overlook the importance of personal attributes. For better preparing students with appropriate attitude and norm towards workplace, instructors should explain and define clearly what personal attributes are necessary for performing well in specified field, and applying different instructional strategies to invoke students' potential capabilities.

From the curriculm maps of each program, it is clearly that most of them lack systematic planning and arrangement for students to enroll in sequentially. Generally, the programs provide definite and required core courses, however, the various kinds of optional courses covered many fields are not well-categorized. On one hand, the indistinct hierarchical relationship among basic, core, nano-related, and nano-specific courses offers flexibility for students to study what they really interested; on the other hand, it also makes students confused about the whole picture of the program, the interrelations between each course, what directions they should go, and the relative importance of each course. The advantages of specific representation of curriculum map also reflected on the higher education course revolutionary project initiated by the Ministry of Education (2007) in Taiwan. The project asked all universities to construct systematic and hierarchical curriculum maps of every departments and programs to assist students planning, organizing, and integrating what they learned or will learn. In other words, the rearrangement of university nanotechnology courses is necessary.

Chapter Five Q Analysis and Interpretation

The purpose of Q study utilized by this research is to discover and confirm the expected competences of university graduates who intend to devote himself/ herself to the nanotechnology-related career. Twelve employees (numbered from s1 to s12), eighteen students (numbered from s13 to s30), and three professors (numbered from s31 to s33) are recruited as the Q participant who can express their subjective opinions in terms of this issue. Q participants are required to go through the procedure of the Q sorting and postsorting interview. The analysis and integration of results embodies that Q study with both qualitative and quantitative advantages. This section presents the demography of Q participants, the Q analysis procedure, and comments come from postsorting interviews will be quoted as well.

5.1 Demographics of Q Participants

The summary of the characteristics of the thirty-three Q participants are showed in Table 5.1. Among the participants, twenty-four are male and nine are female. For employees, most (n=9) of their work experience between 0 to 10 years. However, the work experience range difference is over 10 years for professors. Fourteen graduate students and four undergraduate students involve in this study. There are seventeen students have attended nanotechnology-related laboratories and eleven of them involve in the varied nanotechnology projects. In terms of the degree of familiarization with nanotechnology knowledge, employees (n=7) and students (n=15) are more tended to “average” with nanotechnology, compare with professors are all belonging to the category of “familiarize”. Generally speaking, the sources of nanotechnology knowledge mainly come from workplace training (n=5) and university optional courses (n=4) for employees, and 14 students point out that they learn the knowledge in the laboratory training.

Table 5.1 Demographics of Q participants

	Item	Employee (N=12)	Professor (N=3)	Students (N=18)	Total (N=33)
Gender	Female	2	0	7	9
	Male	10	3	11	21
Work experience	Below 1 year	2	0		2
	1 – 5 years	6	0		6
	6 – 10 years	1	1		2
	11 – 15 years	2	1		3
	16 – 20 years	1	0		1
	Over 20 years	0	1		1
Level	Undergraduate			4	4
	Graduate			14	14
Attend nanotechnology lab	Yes			17	17
	No			1	1
Attend nanotechnology project	Yes			11	11
	No			7	7
Management position	Yes	6			6
	No	6			6
Familiarize with nanotechnology	Familiarize	4	3	3	10
	Average	7	0	15	22
	Unfamiliarize	1	0	0	1
Source of nanotechnology knowledge	Formal education (ex. programs, department)	1		2	3
	University optional courses	4		2	6
	Workplace (lab) training	5		14	19
	Self-learning	2		0	2

5.2 Factors Extraction

PQMthod is the free software which designed especially for Q analysis. First, all the Q sorting results are input in the PQMthod sequentially. Brown (1980) suggested researcher run from a seven-factor to two-factor solution before accepting a final solution. Centroid factor analysis is performed since it is a more simple and economic solution which can produce smaller numbers of factors. Four factors are extracted by centroid factors analysis and rotated by varimax rotation.

Varimax rotation results in higher levels of explained variance and a simple structure which maximizes the similarities within factors and the differences between them (Watts & Stenner, 2005b). Schlinger (1969) proposed that factor with loading of $\pm 2.58/\sqrt{n}$ (n=number of Q statements) will be considered significant and indicative of a meaningful relationship between the Q participant and the factor type. In this research, $2.58/\sqrt{47}=0.376$ is viewed as the judgment criteria. Factor loading greater than 0.376 or smaller than -0.376 will be automatically flagged by bold type and「X」.

Table 5.2 depicts the summary of factor loadings of four factors. Q sorting loads significantly on two factors are suggested to be excluded (Pratrrpko & Chongsuvivatwong, 2009; Watts & Stenner, 2005b). After classification, there are seven Q sorting characterizes factor Ⅰ, seven Q sorting categorizes factor Ⅱ, four Q sorting represents factor Ⅲ, eight Q sorting groups factor Ⅳ, and seven Q sorting be deleted.

Table 5.2 Factor loading of each Q sorting

Q sorting	Factor			
	Ⅰ	Ⅱ	Ⅲ	Ⅳ
s17	**0.78X**	0.02	0.24	0.16
s21	**0.69X**	0.10	0.10	0.08
s22	**0.68X**	0.14	0.09	0.16
s24	**0.65X**	0.19	0.11	0.37
s26	**0.73X**	0.20	0.06	0.19
s30	**0.44X**	0.20	0.00	0.19
s33	**0.48X**	-0.12	0.31	0.16
s1	0.15	**0.63X**	-0.22	0.06
s2	-0.02	**0.91X**	-0.20	0.12
s4	-0.07	**0.72X**	-0.20	0.19
s6	0.14	**0.42X**	-0.10	0.35
s8	0.16	**0.33X**	-0.15	0.04
s10	0.38	**0.62X**	-0.14	0.36
s29	0.34	**0.54X**	-0.19	0.09
s3	-0.06	0.44	**-0.68X**	-0.05
s12	0.03	-0.33	**0.39X**	0.04
s16	0.47	-0.31	**0.72X**	0.13
s32	0.17	-0.33	**0.63X**	0.38
s9	0.14	0.02	0.24	**0.70X**
s11	0.33	0.36	0.01	**0.60X**
s13	0.38	0.20	0.12	**0.63X**
s14	-0.00	0.19	0.06	**0.64X**
s19	0.21	0.09	0.21	**0.79X**
s20	0.28	-0.11	0.35	**0.50X**
s28	0.36	0.26	0.03	**0.47X**
s31	0.35	0.24	0.10	**0.68X**
s5	0.01	0.50	-0.09	0.51
s7	0.45	0.48	-0.07	0.43
s15	0.29	0.44	-0.06	0.46
s18	0.38	-0.08	0.31	0.39
s23	0.47	0.44	-0.15	0.06
s25	0.43	-0.16	0.41	0.32
s27	0.08	-0.25	0.41	0.37

Note: X indicating a defining sort

5.3 Factors Analysis and Interpretation

Brown, Durning, and Selden (1998) suggested researchers to interpret the results of factors from three dimensions: (1) Point out and illustrate the consensus statement among all factors; (2) Mixed explanation of the extreme statements, such as statements to be assigned to ±5, ±4, and ±3; (3) Compare one factor with the others to display the key differences. Table 5.3 lists Q sort values for statements sorted by consensus versus disagreement. Items at the top of the table are those with the most agreement by the thirty-three participants in this research. Items at the bottom are those with the most disagreement.

Table 5.3 Q sort values for statements sorted by consensus versus disagreement

No.	Statement	Factor			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
27	Integrated circuits fabrication*	-1	1	1	0
37	Solar cell*	-3	-2	0	-1
40	Lab-on-a-chip	0	-3	0	-2
44	Flexibility	1	1	-2	1
34	Liquid crystal display	0	-1	0	-3
19	Electronic structure	-2	0	-1	1
15	Nano-optoelectronics	0	2	2	2
33	Nanophotonics	-1	0	1	2
18	Solid structure	-2	0	0	1
26	Nanoelectronics system	3	-1	1	0
8	Nanomaterial	4	1	4	5
41	Microsystem chip	1	-2	1	-1
10	Plasma engineering	-4	0	-1	-2
28	Integrated circuits design	-1	1	-3	-2
11	Electronic equipment	-3	0	0	-4
12	Electronic manufacturing	-1	2	0	-3
39	Biochip	1	-3	1	-1

No.	Statement	Factor			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
23	Calculus	-5	-1	-4	-2
13	Electronic packaging	-1	1	-2	-4
30	Vacuum technology	-1	2	-3	-4
4	Applied chemistry	0	3	-2	1
9	Nanodevice	2	-1	4	2
1	Classical physics	-3	3	-2	1
24	Microelectromechanical system	3	-2	1	-2
38	Environmental nano technology	-3	-3	2	-1
21	Engineering mathematics	-5	0	-5	-1
32	Measurement technique	0	3	-3	0
14	Optical packaging	-2	2	-3	-3
7	Nanotechnology	2	-1	5	3
6	Nanoscience	2	-1	5	2
29	Nanotransport	0	-4	2	1
17	Nanostructure	2	-2	4	3
45	Understanding market trend	1	1	-5	0
25	Nanoelectromechanical system	4	-2	3	0
20	Nanobiology structure	1	-4	3	0
42	Innovation	4	4	-1	4
22	Nanometrology	-2	-5	2	-1
5	Circuit theory	-4	2	-4	-5
47	Activeness and aggressiveness	3	5	-2	2
2	Modern physics	0	4	-1	5
43	Independent thinking ability	5	5	0	4
31	Clean room technology	3	0	-1	-5
16	Nano-scale	2	-3	3	3
36	Nanofood technology	-4	-5	2	-3
35	Bionanotechnology	1	-4	3	0
46	Solve problem ability	5	4	-1	4
3	Basic chemistry	-2	3	-4	4

Note: * represents the significant consensus statements PQMthod select.

Both the integrated circuits fabrication (27; -1, +1, +1, 0) (the first number in the bracket represents the item number, and the following four numbers represent the scores of four factors) and solar cell (37; -3, -2, 0, -1) are selected by PQMethod as the significant consensus statements. However, the nanomaterial (8; +4, +1, +4, +5) and calculus (23; -5, -1, -4, -2) also show the same positive and negative scores respectively. The Q participants tend to sort the statements according to their learning experience, which is obviously projected by the employees and students. The conceptions and manipulation skills provided by university laboratories will influence the students' perception of importance and attitude towards specialization. To some extent, this situation signifies the professors are the crucial person lead the competences development of individuals, as well as the prospect of nanotechnology industry.

> *"I majored in materials in graduate, which can be applied in varied electronic or electro-optic fields. The learned knowledge is helpful and beneficial to my career." (s6)*
>
> *"I study materials (in the laboratory), for me, the range of 0 to +5 is more important." (s13)*
>
> *"I mainly sort the statements in the light of what I used before. It is impossible for me to use all of these competences, so I sort them according to the techniques that laboratory frequently exercises." (s21)*
>
> *"It depends on the skills our laboratory uses. We (students) deal with mechanism and professor specializes in microelectromechanical system, therefore, our laboratory focuses on the training of materials and clean room techniques." (s22)*

The people who involve in nanotechnology research are mainly those in chemistry and material fields. The specialized knowledge and fabrication techniques of materials are the basic and necessary competences every nanotechnology graduates required to possess in advance, since it is the core capability that can be extensively performed across varied fields. Although the characteristics of nano-meter materials are different from normal materials, the general conceptions and fabrication techniques can be applied mutually in some degree.

> *"If we want to produce solar cells, the point is on the efficiency of material synthesis instead of packaging. The process of packaging influences less." (s13)*
>
> *"I think the nano-scale is important. It is because when nano to be narrowed to smaller scale, the characteristics of materials are different from original one. It is important." (s16)*
>
> *"Subjects like optics, chemistry, or material, are the fundamental knowledge before constituting a big system. It is like the core (subject)." (s19)*
>
> *"I think the key point is on the material fabrication. We have to develop those technologies first, and then related applications can be extended to other industries." (s20)*
>
> *"The fundamental knowledge, such as physics and chemistry, doesn't illustrate clearly about new materials. So employees in nanotechnology industry need to learn more new materials." (s31)*
>
> *"The people who get into nanotechnology (research) are those in chemistry and material fields. Strictly speaking, all the things they do are nanotechnology." (s32)*

The integrated circuits fabrication, solar cell, and calculus are the consensus neutral or negative statements among all participants. From the researchers' observation and responses of the interviews, participants tend to sort the statements they know to the higher scores or lower scores, and the statements which they didn't learn before will be sort easily in the middle of the matrix. In spite of the calculus is the subject every science and engineering freshmen required to enroll in, it is more like a core course across varied fields rather than for specific advanced applications.

5.3.1 Factor Ⅰ: Nano-specific skill and personal attributes oriented

The factor array of factor Ⅰ shows in Figure 5.1. The results reveal that the competences Q participants concerned most are the personal attributes, such as independent thinking ability (43, +5), solve problem ability (46, +5), innovation (42, +4), and activeness and aggressiveness (47, +3). Following items are nanotechnology-specific competences, includes nanomaterial (8, +4), nanoelectromechanical system (25, +4), and nanoelectronics system (26, +3). Nanotechnology-related competences are also emphasized, such as microelectromechanical system (24, +3) and clean room technology (31, +3).

Not important at all ← → Very important

-5	-4	-3	-2	-1	0	1	2	3	4	5
21	5	1	3	12	2	20	6	24	8	43
23	10	11	14	13	4	35	7	26	25	46
(2)	36	37	18	27	15	39	9	31	42	(2)
	(3)	38	19	28	29	41	16	47	(3)	
		(4)	22	30	32	44	17	(4)		
			(5)	33	34	45	(5)			
				(6)	40	(6)				
					(7)					

Figure 5.1 Factor array of pattern Ⅰ

Table 5.4 shows the summary of statements by the detailed competence descriptions of knowledge, skill, attitude, and other attributes extracted from curriculum mapping. From the statements given +3 to +5 scores in factor Ⅰ, it clearly reveals the competences of attitude and other attributes, as well as skills, are the most concerned abilities. Since the Q sorting procedure required the participants to sort the statements according to their relative importance, this study tries to give weighted scores to each statement by the course levels and expected competences for further understanding of the constitution element of each factor. Table 5.5 represents the weighted scores of +3 to +5 statements in factor Ⅰ. The original score participants given to each statement is used as the weighted scores. According to the analysis standard of curriculum mapping, each statement only belongs to one course level. However, the statements related to personal attributes cannot be categorized into any course level. In addition, each statement may provide different competences. The total weighted scores show factor Ⅰ stresses more on the nano-specific capability (weighted scores = 11) and the development of skills and personal attribute (attitude and other attributes).

Table 5.6 displays the distinguishing statements for factor Ⅰ. The three significant statements, include solve problem ability, microelectromechanical system, and clean room technology, also stress the unique importance of personal attributes and skills concerned by factor Ⅰ. In view of the factor array, weighted scores given to different statement, and distinguishing statements, factor Ⅰ is named “Nano-sepcific skill and personal attributes oriented”.

Table 5.4 Summary of detailed competence descriptions of statements in factor Ⅰ

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
43	Independent thinking ability				Thinking ability, independent learning	+5
46	Solve problem ability				Discover and solve problem ability	+5
8	Nanomaterial	Nano materials, material science	Nano fabrication technique, nano characterization technique, nano manipulation technique, nano lithography technique, nano materials fabrication technique, nano materials characterization technique			+4
25	Nanoelectromechanical system		Nano-electromechanical systems (NEMS), nanoenergy and electromechanical systems			+4
42	Innovation			Innovation		+4
24	Microelectromechanical system		Microelectromechanical systems (MEMS) , MEMS packaging technique、MEMS characterization technique, MEMS design			+3
26	Nanoelectronics system		Electronic system, nanoelectronics system			+3
31	Clean room technology		Clean room technology			+3
47	Activeness and aggressiveness			Activeness and aggressiveness		+3

Table 5.5 Weighted scores of statements originally given +3 to +5 in factor Ⅰ

No.	Statement	Level				Expected competence			
		Basic course	Core course	Nano-specific course	Nano-related course	Knowledge	Skill	Attitude	Other attribute
43	Independent thinking ability	0	0	0	0	0	0	0	5
46	Solve problem ability	0	0	0	0	0	0	0	5
8	Nanomaterial	0	0	4	0	4	4	0	0
25	Nanoelectromechanical system	0	0	4	0	0	4	0	0
42	Innovation	0	0	0	0	0	0	4	0
24	Microelectromechanical system	0	0	0	3	0	3	0	0
26	Nanoelectronics system	0	0	3	0	0	3	0	0
31	Clean room technology	0	0	0	3	0	3	0	0
47	Activeness and aggressiveness	0	0	0	0	0	0	3	0
Total		0	0	11	6	4	17	7	10

Table 5.6 Distinguishing statements for factor Ⅰ

No.	Statement	Factor			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
46	Solve problem ability*	5	4	-1	4
24	Microelectromechanical system*	3	-2	1	-2
31	Clean room technology*	3	0	-1	-5
16	Nano-scale	2	-3	3	3
39	Nanotransport	0	-4	2	1
15	Nano-optoelectronics*	0	2	2	2
3	Basic chemistry	-2	3	-4	3

Note: $P < .05$; Asterisk (*) indicates significance at $P < .01$

From the factor array and the salient distinguishing statements, it clearly expresses that the Q participants in factor Ⅰ are more intended to view personal attributes as the basic and required competences no matter in what industry and position. Comparing with other factors, independent thinking ability (43; **+5**, +5, 0, +4) generally equips the graduates to deal with the nanotechnology tasks well. Besides, the score of solve problem ability (46; **+5**, +4, -1, +4) is the highest among all factors implies the focus of the instruction is not purely on the knowledge learning, but on the ability to transform the internalized knowledge into the flexible and applicable ability. Although innovation (42; **+4**, +4, -1, +4) is generally regarded as important attributes among the factors in the competitive environment, it still makes no sense if the innovation cannot solve practical problems. Generally speaking, the phenomenon of development of industry and requirement of workforce competences change rapidly, graduates are forced to possess accurate and appropriate attitude in advance to cope with varied kinds of job challenges.

> "*The reason why I put personal* attributes *ahead (very important) is because technology can be learned. Solving problems ability and innovation*

are the most important. Especially there are many products produced in nano-meter right now, and which make it becomes harder to come out something new. Technology can be learned, however, personal attributes are hard to be trained. " (s17)

"Although the nanotechnology development focuses on the innovation, practical application is still important. Therefore, solving problem ability is the most important competence which every graduate should possess." (s21)

"The knowledge learned at university maybe can't be performed easily at company, hence both problem solving ability and independent thinking ability become important." (s24)

"It is impossible to understand everything when you get into a specific industry. You have to solve varied problems when you face them and which means you need to be very positive. This is the key competence that industry needs." (s26)

"The focus not only relies on the academic knowledge. In my opinion, independent thinking ability and innovation are more crucial than some subjects. …Personal attributes are the key to future success." (s33)

In terms of nanotechnology knowledge and skills which students are encouraged to learn, nanoelectromechanical system (25; **+4**, -2, +3, 0), microelectromechanical system (24; **+3**, -2, +1, -2), nanoelectronics system (26; **+3**, -1, 1, 0), and clean room technology (31; **+3**, 0, -1, -5) are the necessary competences compare with other factors. However, the six statements, include engineering mathematics (21; **-5**, 0, -5, -1), calculus (23; **-5**, -1, -4, -2), plasma engineering (10; **-4**, 0, -1, -2), classical physics (1; **-3**, 3, -2, 1), solar cell (37; **-3**, -2, 0, -1), and environmental nano technology (38; **-3**, -3, 2,

-1), are all not be emphasized. This tendency represents Q participants in factor Ⅰ pay more attention on the competence development of nanotechnology specific operational skills, rather than on the general subjects and application domains.

With respect to the university nanotechnology-related courses in undergraduate level, it seems that the opportunities for students to enroll in the regular courses are relatively rare. In addition, the equipments for nanotechnology usage are not popular which prevents students from experiencing practical manipulation. Specifically, the course contents more focus on the theoretical knowledge rather than on the practical application.

> *"The courses offered by university only introduce what the nanotechnology is and students are unable to learn the skills. If we want to learn more deeply, we need to join the nanotechnology-related laboratories."(s17)*
>
> *"The courses in undergraduate level emphasize fundamental knowledge which covers many fields. I think it is right. But most of the skills required by work are learned in graduate instead of undergraduate. The percentage of nanotechnology-related courses in undergraduate level is not high."(s21)*
>
> *"The practical operation opportunities are lacking in undergraduate level."(s24)*
>
> *"The nanotechnology-related courses are relatively few, and the (nanotechnology) equipments are limited and expensive. In general, students can't use them." (s26)*
>
> *"Some nanotechnology-related courses already open in NTU, it is not complete and impossible to make it complete. The materials provided by university courses include something still unknown, so it is challenging and*

can't cover all the subject matters. Comparing with other universities, there are eleven colleges in NTU which can provide wider, multidimensional, and interdisciplinary nanotechnology courses." (s33)

When talking about the necessity of forming a job titled with nanotechnology and constituted of various competences descriptions, most of the Q participants express their disagreement about this issue. Q participants prefer to put nanotechnology competence definitions and requirements under the existing professional titles.

"It is hard to establish a professional title named nanotechnology engineer. The person needs to learn too many things. If a semiconductor engineer with nanotechnology knowledge, it is feasible." (s17)

"It is possible to put nanotechnology competences under the existing professional titles. I think it will be faster." (s22)

"It is hard to isolate the competences only for nanotechnology engineers. Those competences can be the additional abilities." (s24)

"Nanotechnology is one of the fabrication techniques, and the scope is narrower. It does not need to be displayed on the job title." (s30)

"Nanotechnology is the interdisciplinary field. Semiconductor, electronics, and electro-optic are all nanotechnology-related but they will not be mentioned by nanotechnology specially. It doesn't need to be stand alone." (s33)

5.3.2 Factor Ⅱ: Basic knowledge and personal attributes oriented

The configuration of factor Ⅱ is displayed in Figure 5.2 and the sequence of array is similar to factor Ⅰ. The statements about personal attributes, including independent thinking ability (43, +5), innovation (42, +4), and solve problem ability (46, +4), are also be stressed as in factor Ⅰ. However, activeness and aggressiveness (47, +5) is particularly be highlighted in this factor. The core subjects which contain modern physics (2, +4), classical physics (1, +3), basic chemistry (3, +3), applied chemistry (4, +3), and measurement technique (32, +3) are the main classification basis between factor Ⅰ and Ⅱ.

Not important at all ←→ Very important

-5	-4	-3	-2	-1	0	1	2	3	4	5
22	20	16	17	6	10	8	5	1	2	43
36	29	38	24	7	11	13	12	3	42	47
(2)	35	39	25	9	18	27	14	4	46	(2)
	(3)	40	37	23	19	28	15	32	(3)	
		(4)	41	26	21	44	30	(4)		
			(5)	34	31	45	(5)			
				(6)	33	(6)				
					(7)					

Figure 5.2 Factor array of pattern Ⅱ

Table 5.7 is the summary of statements by the detailed competence descriptions of knowledge, skill, attitude, and other attributes extracted from curriculum mapping. Table 5.8 represents the weighted scores of +3 to +5 statements in factor Ⅱ. The total weighted scores show factor Ⅱ concerned more on the basic capability (weighted scores = 16) and the development of personal attribute (attitude and other attributes).

There are twenty-four statements distinguish factor Ⅱ from the other factor, and

Table 5.9 shows the statements and the scores assigned to each factor. It is clearly that the three significant and positive statements, such as activeness and aggressiveness, measurement technique, and applied chemistry, are also related to personal attributes and basic capabilities. The results of factor array, weighted scores, and distinguishing statements all emphasize and form the source of the name of this factor "Basic knowledge and personal attributes oriented".

Table 5.7 Summary of detailed competence descriptions of statements in factor Ⅱ

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
43	Independent thinking ability				Thinking ability, independent learning	+5
47	Activeness and aggressiveness			Activeness and aggressiveness		+5
2	Modern physics	Modern physics, solid state physics, nanoscale physics, quantum physics, condensed matter physic, wave physics, surface physics, soft condensed matter physics, strong correlation physics, statistical physics, plasma physics, low-dimensional physics, biomedical physics, nano statistical mechanics, nanomechanics, nanomechanics materials, quantum electrodynamics, computational nanomechanics, electronics, nano electronics, bioelectronics, nano bioelectronics, spintronics, molecular electronics, solid-state electronics, organic electronics, optical electronics, electron-phonon interactions, nanomagnetism, band theory, nano heat transfer, wave propagation in elastic solids, solid state science, lasers, nanophotonics,	Laser technique and system			+4

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
		biomedical optics, solid state optics, nonlinear optics, modern physical optics, integrated optics, wave optics, spectroscopy, liquid crystal optics, engineering optics, microstructures				
42	Innovation			Innovation		+4
46	Solve problem ability				Discover and solve problem ability	+4
1	Classical physics	Physics, mechanics, micromechanics, statistical mechanics, thermodynamics, thermodynamics of materials, classical mechanics, molecular mechanics, powder mechanics, fluid mechanics, solid mechanics, biomechanics, elastic mechanics, dynamics, chemical kinetics, molecular dynamics, electrodynamics, magnetism, biomagnetism, electricity theory, electromagnetics, electromagnetic waves, nonlinear dynamics and chaos, optics	mechanics measurement, molecular dynamics simulation, dynamic system			+3
3	Basic chemistry	Chemistry, solid state chemistry, computational chemistry, quantum chemistry, plasma chemistry, surface chemistry, organic chemistry, inorganic chemistry, biochemistry, physical	bioanalytical chemistry, gel technique, electrochemistry technique and			+3

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
		chemistry, physical biochemistry, surface and colloid chemistry, electrochemistry	system			
4	Applied chemistry	environmental chemistry, nano chemistry, materials chemistry, nanomaterials chemistry, nano biochemistry				+3
32	Measurement technique		Radio frequency measurement technique, measurement technique			+3

Table 5.8 Weighted scores of statements originally given +3 to +5 in factor Ⅱ

No.	Statement	Level				Expected competence			
		Basic course	Core course	Nano-specific course	Nano-related course	Knowledge	Skill	Attitude	Other attribute
43	Independent thinking ability	0	0	0	0	0	0	0	5
47	Activeness and aggressiveness	0	0	0	0	0	0	5	0
2	Modern physics	4	0	0	0	4	4	0	0
42	Innovation	0	0	0	0	0	0	4	0
46	Solve problem ability	0	0	0	0	0	0	0	4
1	Classical physics	3	0	0	0	3	3	0	0
3	Basic chemistry	3	0	0	0	3	3	0	0
4	Applied chemistry	3	0	0	0	3	0	0	0
32	Measurement technique	3	0	0	0	0	3	0	0
Total		16	0	0	0	13	13	9	9

Table 5.9 Distinguishing statements for factor Ⅱ

No.	Statement	Factor			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
47	Activeness and aggressiveness*	3	5	-2	2
32	Measurement technique*	0	3	-3	0
4	Applied chemistry*	0	3	-2	1
1	Classical physics	-3	4	-2	1
14	Optical packaging*	-2	2	-3	-3
5	Circuit theory*	-4	2	-4	-5
30	Vacuum technology*	-1	2	-3	-4
8	Nanomaterial*	4	1	4	5
28	Integrated circuits design*	-1	1	-3	-2
13	Electronic packaging	-1	1	-2	-4
21	Engineering mathematics	-5	0	-5	-1
10	Plasma engineering	-4	0	-1	-2
6	Nanoscience*	2	-1	5	2
7	Nanotechnology*	2	-1	5	3
9	Nanodevice*	2	-1	4	2
17	Nanostructure*	2	-2	4	3
25	Nanoelectromechanical system*	4	-2	3	0
39	Biochip	1	-3	1	-1
16	Nano-scale*	2	-3	3	3
29	Nanotransport*	0	-4	2	1
20	Nanobiology structure*	1	-4	3	0
35	Bionanotechnology*	1	-4	3	0
22	Nanometrology*	-2	-5	2	-1
36	Nanofood technology	-4	-5	2	-3

Note: $P < .05$; Asterisk (*) indicates significance at $P < .01$

Obviously, independent thinking ability (43; +5, **+5**, 0, +4) is important competence that participants in both factor Ⅰ and factor Ⅱ agree. Innovation (42; +4, **+4**, -1, +4) and solve problem ability (46; +5, **+4**, -1, +4) are widely accepted by more participants. Nevertheless, activeness and aggressiveness (47; +3, **+5**, -2, 2) is statistically crucial for factor Ⅱ and which can be viewed as the main indicator of requirement of personal attribute.

> *"Solving problem ability is the most important competence in industry. If the question asks me about in academic environment, the answer will be different. I had a job in Industrial Technology Research Institute of Taiwan before, (at that time) maybe I will put innovation at the right (most important). Depends on the circumstance, there exists difference." (s1)*
>
> *"No matter in what industries, solving problem ability and* activeness *and aggressiveness are helpful to deal with jobs. Others are the technical skills which can be learned. Skills can be trained comparing with personal attributes. It is hard to change personal attributes." (s4)*
>
> *"In industry, we put more emphasis on the attitude and thinking way of new employee." (s6)*
>
> *"Engineering students can do many varied jobs not be restricted to engineering-related jobs. However, the competences which all the jobs need are innovation, independent thinking ability, and autonomy. I think these competences are more important for job, rather than what you really learned." (s10)*

The fundamental subjects are the remarkable focal point for factor Ⅱ. The general and required core courses for all the science and engineering students, such as classical physics (1; +3, **+3**, -2, +1) and applied chemistry (4; 0, **+3**, -2, +1), are statistically selected by PQMthod to be the distinguished competences. In addition, modern physics (2; 0, **+4**, -1, +5) and basic chemistry (3; -2, **+3**, -4, +3) are the common competences factor Ⅱ and factor Ⅳ valued. The essential ability of nanotechnology graduates is to understand how to measure the nano-meter and which reflects on the importance given to measurement technique (32; 0, **+3**, -3, 0). The results reveal the graduates are suggested to be proficient in fundamental knowledge and skills which is replicable and can be applied across disciplines. The advantages of changeless, the base of concepts development, and the extensibility constitute the necessity and indispensable feature of fundamental theories. In other words, the mastery of core subjects is beneficial for advanced and extended application, and which is more important than learn something new. The reference is consistent with the low importance given to nanotechnology-related competences, include nanofood technology (36; -4, **-5**, +2, -3), nanometrology (22; -2, **-5**, +2, -1), bionanotechnology (35; +1, **-4**, +3, 0), nanotransport (29; 0, **-4**, +2, +1), nanobiology structure (20; +1, **-4**, +3, 0), lab-on-a-chip (40; 0, -3, 0, -2), biochip (39; +1, **-3**, +1, -1), environmental nano technology (38; -3, **-3**, 2, -1), and nano-scale (16; +2, **-3**, +3, +3), are all at left of the factor array.

> "*Modern physic and basic chemistry are the basic and required competences. The application field needs to base on these foundations to further develop. What you learned at school maybe different from you use at job, but the basic concepts are same.*" *(s2)*

> "*Basic skills, like many academic knowledge are replicated, it is the foundation for your learning and utilization at job in the future. Primary subjects and theories have high priorities when I sort. If (those subjects) learned well, other applications and subjects will be comprehended faster.*" *(s6)*

> "*I put the physics and chemistry at the most important positions. Because I think if you understand these contents, you can learn or infer*

newer theories based on these (concepts). Besides the importance of independent thinking ability and attitude, the basic knowledge is more important than newer one." (s10)

When talking about their observations of university nanotechnology-related courses provided to students, most of the participants point out the lack of appropriate course design to help students learn accurate soft skills. The over emphasis on the instruction and learning of theoretical knowledge, as well as the ignorance of the practical achievement and personality development, that result in the shortage of workforce really fit in with the requirement of workplace.

"I think the biggest problem is on the quality of higher level workforce. Now, every university has many opportunities to know LCD or LED development, and many exhibitions, I don't worry about that. Even when graduates get into the workplace, it is not a problem for them to learn these technologies. However, the independent thinking ability, solving problem ability, and attitude, are the university education lacks." (s1)

"The universities should stress the development of personal attributes when training students. Knowledge can be learned generally, therefore, course design ought to highlight the personality development." (s4)

"Besides the basic theories, the courses should take the applications into account." (s6)

"Of course the theories are needed. Basically, you can find and learn the knowledge of theories from many channels, even on the google. But, the application methods maybe can not be found on the internet. Even the information you learn in academic fields is just theoretical values, no practical values." (s8)

In terms of nanotechnology competence definition, participants express their common viewpoints that the scope and applicability of nanotechnology are too extensive, and which prevent the specific definition from clarifying. This implies the proper way to define competences is to allow stakeholders who interested in nanotechnology development to communicate the general meaning and range in order to reach an agreement at the first stage. Then the specific descriptions of each competence for nanotechnology-related jobs will emerge and be extracted more easily. Otherwise, the obscure definition of nanotechnology may confuse the public, as well as the employees who involve in the related jobs.

> *"The term of nano is to be misused, so it is hard for government to define nanotechnology. I think we should have a common consensus about nano first, and then to define the competences." (s1)*
>
> *"There is no specific definition for nanotechnology since it can be used in many fields. Many products can be produced by nanotechnology, such as the stool, so it is an extensive technology. Every industry has the opportunities to use this technology, that's why it is difficult to give it a definite description." (s4)*
>
> *"I think it is too extensive. Even the semiconductor industry may include nanotechnology…. Like electronics and semiconductor, every product is connected to nano as long as the scale is narrowed. It is covered in every product." (s10)*

5.3.3 Factor Ⅲ: Nano core and specific knowledge oriented

The emphasis be put on the nanotechnology-centered aspects constitute the source of the name given to Factor Ⅲ. The factor array of factor Ⅲ is showed in Figure 5.3. It is obvious that the personal attributes are all assigned the scores equal or below 0, and which represents the apparent difference between factor Ⅲ and the other three factors.

What participants be categorized into factor Ⅲ concerned most is about core and preliminary knowledge of nanotechnology, includes nanoscience (6, +5) and nanotechnology (7, +5). Following by advanced and specific subjects such as nanomaterial (8, +4), nanodevice (9, +4), and nanostructure (17, +4). The extended application in technique and biology aspects explain the importance given to nano-scale (16, +3), nanobiology structure (20, +3), nanoelectromechanical system (25, +3), and bionanotechnology (35, +3).

Not important at all ← → Very important

-5	-4	-3	-2	-1	0	1	2	3	4	5
21	3	14	1	2	11	24	15	16	8	6
45	5	28	4	10	12	26	22	20	9	7
(2)	23	30	13	19	18	27	29	25	17	(2)
	(3)	32	44	31	34	33	36	35	(3)	
		(4)	47	42	37	39	38	(4)		
			(5)	46	40	41	(5)			
				(6)	43	(6)				
					(7)					

Figure 5.3 Factor array of pattern Ⅲ

Table 5.10 represents the summary of statements by the detailed competence descriptions of knowledge, skill, attitude, and other attributes extracted from curriculum mapping, and Table 5.11 shows the weighted scores of +3 to +5 statements in factor Ⅲ. From the total weighted scores, factor Ⅲ concerned more on the nano core capability (weighted scores = 25) and knowledge learning (weighted scores = 27). This tendency is similar to factor Ⅳ that both factors consider the mastery of nano core knowledge is crucial. However, factor Ⅲ also thinks nano advanced applications is beneficial for career development. The results is consistently reflected on the significant distinguishing statements show in Table 5.12 that nanoscience, nanotechnology, bionanotechnology, and nanobiology structure are more emphasized in factor Ⅲ. This tendency constitutes the naming foundation of this factor “Nano core and specific knowledge oriented”.

Table 5.10 Summary of detailed competence descriptions of statements in factor Ⅲ

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
6	Nanoscience	Nanoscience				+5
7	Nanotechnology	Nanotechnology				+5
8	Nanomaterial	Nano materials, material science	Nano fabrication technique, nano characterization technique, nano manipulation technique, nano lithography technique, nano materials fabrication technique, nano materials characterization technique			+4
9	Nanodevice		Nanodevice, nano devices manufacturing technique, nano devices characterization technique, nano devices design, nano devices sensing technique			+4
17	Nanostructure	Assembling of atoms and molecules, nanostructures				+4
16	Nano-scale	Micro scale, nano scale				+3
20	Nanobiology structure	Biostructure, nanobiology structure				+3
25	Nanoelectromechanical system		Nano-electromechanical systems (NEMS), nanoenergy and electromechanical systems			+3
35	Bionanotechnology	Nanobiology、bionanotechnology	Nanobiology manufacturing technique, nanobiology inspection technique, nanobiology lithography technique			+3

Table 5.11 Weighted scores of statements originally given +3 to +5 in factor Ⅲ

No.	Statement	Level				Expected competence			
		Basic course	Core course	Nano-specific course	Nano-related course	Knowledge	Skill	Attitude	Other attribute
6	Nanoscience	0	5	0	0	5	0	0	0
7	Nanotechnology	0	5	0	0	5	0	0	0
8	Nanomaterial	0	4	0	0	4	4	0	0
9	Nanodevice	0	4	0	0	0	4	0	0
17	Nanostructure	0	4	0	0	4	0	0	0
16	Nano-scale	0	3	0	0	3	0	0	0
20	Nanobiology structure	0	0	3	0	3	0	0	0
25	Nanoelectromechanical system	0	0	3	0	0	3	0	0
35	Bionanotechnology	0	0	3	0	3	3	0	0
Total		0	25	9	0	27	14	0	0

Table 5.12 Distinguishing statements for factor Ⅲ

No.	Statement	Factor			
		I	II	Ⅲ	Ⅳ
6	Nanoscience*	2	-1	5	2
7	Nanotechnology*	2	-1	5	3
35	Bionanotechnology*	1	-4	3	0
20	Nanobiology structure*	1	-4	3	0
38	Environmental nano technology*	-3	-3	2	-1
22	Nanometrology*	-2	-5	2	-1
36	Nanofood technology*	-4	-5	2	-3
24	Microelectromechanical system*	3	-2	1	-2
43	Independent thinking ability*	5	5	0	4
42	Innovation*	4	4	-1	4
46	Solve problem ability*	5	4	-1	4
44	Flexibility*	1	1	-2	1
47	Activeness and aggressiveness*	3	5	-2	2
32	Measurement technique*	0	3	-3	0
3	Basic chemistry	-2	3	-4	3
45	Understanding market trend*	1	1	-5	0

Note: P < .05 ; Asterisk (*) indicates significance at P < .01

The statistically significant distinguishing statements showed in Table 5.12 prove the reference that all the personal attributes, comprise understanding market trend (45; +1, +1, **-5**, 0), activeness and aggressiveness (47; +3, +5, **-2**, +2), flexibility (44; +1, +1, **-2**, +1), solve problem ability (46; +5, +4, **-1**, +4), innovation (42; +4, +4, **-1**, +4), and independent thinking ability (43; +5, +5, **0**, +4), are not correlate closely with nanotechnology and which are categorized as the unimportant competences for nanotechnology workforce. However, the sequence of crucial competences appears to abide by the order of fundamental, advanced, and application framework. Especially comparing with other factors, the statements given scores above 3 are the relatively key competences employees need to possess. This result may reflect the factor is more specific work or domain oriented, and qualification of workforce is not on the general ability but on the professional skills.

"The personal attributes are not related to nanotechnology. I prefer to put the statements titled nano in the more important positions." (s12)

"I select and sort the statements with nano first. I think the most important (competences) are those science and technology with wide scope and has no limitation. Then sort (statements) according to my feeling and relevance to my field….Actually in nano-meter, many theories are not used. We don't know how these (theories) to be connected with nano. Maybe in the nano-level, we have to learn its phenomenon again. So, it is better to directly learn nanotechnology-related knowledge." (s16)

"I sort the statements base on the sequence from basic nanotechnology competence, basic science, to extended nanotechnology applications." (s32)

The participants point out the difficulty in designing courses which can equip students with necessary and sufficient abilities. Although the detailed competence definitions are beneficial for students to plan their future career and learning path, it still has the consideration that competence descriptions will lead students to put more efforts on those subjects and ignore the basic one.

"The competence definition will influence our learning planning and how we improve our abilities. If the competence descriptions exist, such as the preliminary and advanced knowledge, it becomes the rule and guidance. But it will bring out a problem that every student learns that (professional) knowledge instead of general concepts." (s16)

"You have to study some subjects before to help you solve practical

problems. There is no single course can cover all the subjects, which means we need to provide a set of courses to prepare students have the integration ability….Maybe the competences which industry suggested are based on the principle that if you have work experience, you are supposed to have these competences. However, the basic principles and operation procedure of equipments are different by every facilities….This is not one course can handle. " (s32)

According to the comments from Q participants, the scope of nanotechnology industry is still unclear. Generally speaking, it can be used across many fields. Such as electronics, IC fabrication, and semiconductor industries, all can be covered in the nanotechnology-related research and development. Nevertheless, the importance and essentiality of nanotechnology industry existence is not obvious. This viewpoint represents the nanotechnology can be viewed as a supplemental technique for other industries and related competence definitions are suggested to be put on the detailed items under other job titles.

"I don't think there has an independent nanotechnology industry. It can be applied in many fields, and which is not obvious that any industry only focuses on it. The nanotechnology is regarded as a technique or supplement. For me, I don't know what the competences nano-engineers should possess, so I suggest to put the competences under the other job titles." (s16)

"It is hard to say whether the nanotechnology industry exist or not. The appearance of nanotechnology only 10 years, and is too early to force it become an industry. It still has the developmental potential." (s32)

5.3.4 Factor Ⅳ: Nano core knowledge oriented

From the factor array of pattern Ⅳ showed in Figure 5.4, the participants tended to be the mixed type which the basic science, nanotechnology fundamental theories, and personal attributes are all categorized as the important competences for workforce. Particularly, the attention paid on the nanomaterial (8, +5), nanotechnology (7, +3), nano-scale (16, +3), nanostructure (17, +3), as well as the importance given to modern physics (2, +5) and basic chemistry (3, +3), compose the factor development of nanotechnology fundamental ability oriented.

Not important at all ← → Very important

-5	-4	-3	-2	-1	0	1	2	3	4	5
5	11	12	10	21	20	1	6	3	42	2
31	13	14	23	22	25	4	9	7	43	8
(2)	30	34	24	37	26	18	15	16	46	(2)
	(3)	36	28	38	27	19	33	17	(3)	
		(4)	40	39	32	29	47	(4)		
			(5)	41	35	44	(5)			
				(6)	45	(6)				
					(7)					

Figure 5.4 Factor array of pattern Ⅳ

Table 5.13 shows the summary of statements by the detailed competence descriptions of knowledge, skill, attitude, and other attributes extracted from curriculum mapping. Table 5.14 represents the weighted scores of +3 to +5 statements in factor Ⅳ. The total weighted scores show factor Ⅳ concerned more on the nano core knowledge (weighted scores for nano core and knowledge are 14 and 22, respectively). The emphasis put on the learning of nano fundamental theories forming the source of the name of this factor “Nano core knowledge oriented”.

Table 5.13 Summary of detailed competence descriptions of statements in factor Ⅳ

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
2	Modern physics	Modern physics, solid state physics, nanoscale physics, quantum physics, condensed matter physic, wave physics, surface physics, soft condensed matter physics, strong correlation physics, statistical physics, plasma physics, low-dimensional physics, biomedical physics, nano statistical mechanics, nanomechanics, nanomechanics materials, quantum electrodynamics, computational nanomechanics, electronics, nano electronics, bioelectronics, nano bioelectronics, spintronics, molecular electronics, solid-state electronics, organic electronics, optical electronics, electron-phonon interactions, nanomagnetism, band theory, nano heat transfer, wave propagation in elastic solids, solid state science, lasers, nanophotonics, biomedical optics, solid state optics, nonlinear optics, modern physical optics, integrated optics, wave optics, spectroscopy, liquid crystal optics, engineering optics, microstructures	Laser technique and system			+5
8	Nanomaterial	Nano materials, material science	Nano fabrication technique, nano characterization technique, nano			+5

No.	Statement	Knowledge	Skill	Attitude	Other attributes	Scores
			manipulation technique, nano lithography technique, nano materials fabrication technique, nano materials characterization technique			
42	Innovation			Innovation		+4
43	Independent thinking ability				Thinking ability, independent learning	+4
46	Solve problem ability				Discover and solve problem ability	+4
3	Basic chemistry	Chemistry, solid state chemistry, computational chemistry, quantum chemistry, plasma chemistry, surface chemistry, organic chemistry, inorganic chemistry, biochemistry, physical chemistry, physical biochemistry, surface and colloid chemistry, electrochemistry	Bioanalytical chemistry, gel technique, electrochemistry technique and system			+3
7	Nanotechnology	Nanotechnology				+3
16	Nano-scale	Micro scale, nano scale				+3
17	Nanostructure	Assembling of atoms and molecules, nanostructures				+3

Table 5.14 Weighted scores of statements originally given +3 to +5 in factor Ⅳ

No.	Statement	Level				Expected competence			
		Basic course	Core course	Nano-specific course	Nano-related course	Knowledge	Skill	Attitude	Other attribute
2	Modern physics	5	0	0	0	5	5	0	0
8	Nanomaterial	0	5	0	0	5	5	0	0
42	Innovation	0	0	0	0	0	0	4	0
43	Independent thinking ability	0	0	0	0	0	0	0	4
46	Solve problem ability	0	0	0	0	0	0	0	4
3	Basic chemistry	3	0	0	0	3	3	0	0
7	Nanotechnology	0	3	0	0	3	0	0	0
16	Nano-scale	0	3	0	0	3	0	0	0
17	Nanostructure	0	3	0	0	3	0	0	0
Total		8	14	0	0	22	13	4	8

Eight distinguishing statements for factor Ⅳ displayed in Table 5.15. Although the personal attributes are not statistically significant to differentiate factor Ⅳ from the others, innovation (42; +4, +4, -1, **+4**), independent thinking ability (43; +5, +5, 0, **+4**), and solve problem ability (46; +5, +4, -1, **+4**) still have high priority. The value of appropriate attitude reflects on the mass experiment operations in the closed laboratory, on the driving force of innovation and thinking ability to personal professional development, and on the potential to apply internalized knowledge.

> *"Innovation and independent thinking are most important. When you learned those technologies, you can innovate and thinking by yourself. Have a new start. Those two features are the driving forces." (s9)*
>
> *"The reason why I think attitude is important resulted from the experience when I conducted experimentations before. So I give high priority to the statements about attitude." (s13)*
>
> *"I think the most important (competence) is the basic science and the personal attributes that is helpful to learn and apply those knowledge." (s14)*

No matter in basic science or nano fields, the core concept relates to the fundamental knowledge underpinned the domain. The focal point is not on how well employees can utilized those capabilities to varied fields, on the contrary, is on the degree of familiarity with general but core concepts. This explanation also implies the shortages of crucial competences will serious influence the regular execution of work.

> *"I decide the degree of importance based on the basic concepts. Basic science is the standard. Most of the academic statements are assigned to important positions, followed by applied fields. That's my sorting process,*

especially for nanotechnologies." (s9)

"(The sorting procedure) Depends on what the basic science (knowledge) I really use right now, and I will search what kind of knowledge when meet the problems. The starting point is on how to solving problems. Now, the science already in the stable stage and it has to return to the basics to make the breakthrough. Most of the statements I choose and put on the important side are academic theories." (s11)

"I think the basic science is more important, and then the personal attributes that can learn and apply those knowledge. Basic (statements) get higher scores, and application aspects get lower. Totally, the classification standard is from basic to application." (s14)

"I think the more fundamental subjects, such as modern physics or quantum physics, are the basic knowledge you need to learn before constituting a big system. It looks more like a core. Others are more belonging to industrial-related capabilities. If you possess the basics, those (industrial application knowledge) will be learned more easily." (s19)

"The most important (competences) are the basic knowledge, followed by the personal attributes if you want to work smoothly in the industry. I will prefer the knowledge rather than technical part. If the competences are about applications in varied fields, it will be emphasized less. That's because those competences can be learned rapidly in industry." (s31)

Table 5.15 Distinguishing statements for factor Ⅳ

No.	Statement	Factor			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
1	Classical physics	-3	3	-2	1
25	Nanoelectromechanical system*	4	-2	3	0
21	Engineering mathematics	-5	0	-5	-1
39	Biochip	1	-3	1	-1
12	Electronic manufacturing	-1	2	0	-3
34	Liquid crystal display*	0	-1	0	-3
13	Electronic packaging	-1	1	-2	-4
31	Clean room technology*	3	0	-1	-5

Note: P < .05 ; Asterisk (*) indicates significance at P < .01

The instructional strategy of nanotechnology courses is suggested to develop learning activities which is beneficial for the development of solving problem ability. Generally, the universities already offer sufficient nanotechnology-related courses to students. The critical and often be ignored point is on the degree of connection between course materials and practical applications. The students prefer the knowledge and technologies they learned at university can smoothly be utilized at workplace. In other words, it needs further adjustment of the whole course planning and arrangement in order to suit the actual needs of students and underline the importance of specific subjects.

"(The courses) Need to provide training for the development of solving problem abilities. It is better to know how to solve problems rather the teach you and give you. The books are dead, it is more important to know how to find problems and directions." (s11)

"I think the university provides enough nanotechnology courses. It is because the courses don't cover many detailed parts, and which make nano

become one small part of those (other) industries. Actually, neither courses nor students need to teach or learn those detailed industrial knowledge." (s14)

"Although the university provides many courses in undergraduate level, but after finishing those courses, students still don't know how to use them at work, (the reason is) it covers more theories. You have to enroll in graduate school if you want to get in touch with industry. But at that time, it is too late. The courses can cover practical operations to let students have the feeling of it. It can be not too complicated, but require basic opportunities (for students) to touch." (s19)

"The problem is on the system instead of courses themselves. Actually, there already exist many courses. The reason why many new introduction courses are opened is because they (instructors) want the title of nano. I think it's enough. If we want to improve the nanotechnology courses, some courses should be emphasized their importance particularly. In programs, those are required courses." (s31)

Generally speaking, participants think the nanotechnology industry doesn't exist yet. The indistinct and over-extended applications, as well as the lack of mass production of nanotechnology-related products, result in the position of nanotechnology to be integrated under other industries. That is the reason participants suggest the competence definitions should be one of the detailed descriptions of other work titles.

"There is no specific industry only to conduct nanotechnology, and the division of labor is not clear. … It is not so many products can be mass produced, and if we want to differentiate (nanotechnology) competences

from others, it needs to be mass produced. Taiwan has no (nanotechnology) industry, so it will not have competence classifications." (s13)

"Nanotechnology should be covered by other industries, rather than independent industry. For example, nanotechnology capabilities ought to be put in the detailed items in the engineer title, instead of pointing out what nanotechnology engineer need. So I give the higher scores to the basic knowledge." (s14)

"It is better to add the nanotechnology competences in the detailed items since there is no nanotechnology engineer in the industries. We don't understand what the job nanotechnology engineers really do, so it not needs to add the title purposely. Everybody knows the work of fabrication engineers, for example, the competence of nano electronics can be added under that title." (s19)

"The applicants will think there is a department or new equipment which is especially for nano-scale if the job title includes nanotechnology. So it is different between these two types. But if the nanotechnology is covered in the competence items, the graduates of electronic and fabrication fields all can be recruited. The expected applicants or degree is different." (s20)

"(Nanotechnology) Is one branch of the engineering field and can't be viewed as the independent industry. It is just the difference of scale size, so I think it can't stand alone. Possibly, maybe the worker is fabrication engineer who learns more professional nanotechnology knowledge and quip that ability into self's competences." (s28)

"The definition of industry comes from its economic activities, such as

finance and distribution, it will be isolate. But the nanotechnology just looks like one technique of every industry. The competences of nanotechnology can be one small item instead of the specific title of nanotechnology engineer." (s31)

The viewpoint of the helpfulness of competence definitions varies. Some participants think the definitions are too formal and meaningless that is not consistent with what employees really do in company. However, the others consider the definitions are beneficial as a reference for what industry really needs, what competences need to be strengthened, or what courses require to be emphasized.

"I think those competences are too formal that is different from reality when enter the company. You have to get in touch with the employees who really involve in that job and see what they do to know the actual situation. Otherwise, it is hard to reflect the real situations due to the huge difference of every company." (s13)

"I think the competence definitions have some help to me. If the information to be opened to students, they will know which aspects need to be learned better." (s14)

"The competence definition may helpful to the career development. If you decide to involve in specific industry, you will know what aspects need to be strengthened and can use it as a reference." (s28)

"I think it is necessary to develop competence definitions. Although most of the courses in engineering department are studied, the most required courses are not stressed. For example, if a student wants to engage in the development of nanotechnology, he enrolled in some courses but he

doesn't know that course is important for his career, so he will not put much attention on that course. Some courses need to be emphasized instead of every course has equivalent value." (s31)

By the distribution of crucial statements assigned in four factors, it generally reveals participants concerned more about nano core knowledge and personal attributes, following by basic knowledge and nano-specific knowledge/skill. This phenomenon shows the inconsistent result that the university nanotechnology program put more emphasis on the nano-related courses; however, the usefulness and importance of those abilities are not as important as they anticipated in practical nano-related career development. Moreover, participants think knowledge acquisition, as well as personal attributes development, is beneficial for their career development. On the one hand, the result is consistent with curriculum mapping that knowledge instruction is essential and should be given more attention; on the other hand, the importance of personal attributes is not reflected on the nanotechnology curriculum planning. The comparison between curriculum mapping and depicted above represents

5.3.5 Comparison among Q participants

The Q participants' distribution is displayed in Table 5.16. The results show employees (n=6) are more tended to the type of factor Ⅱ, students mainly belong to factor Ⅰ (n=6) and Ⅳ (n=5), however, there is no specific tendency of professors.

The significant and consistent viewpoint expressions of employees, including the emphasis on the development of personal attributes and the enrichment of pure science understanding, reflect the actual competences requirement of nanotechnology-related workforce. Nanotechnology is an interdisciplinary field and can be integrated in varied industries, the breath of its applicability implies it is hard, or even not necessary, to give specific competence definitions for nanotechnology-focused jobs. In other words, the importance given to general attitude and capabilities reflect the employees consider the basic abilities are the more valuable asset which helps them to achieve work requirement. This is not to say the professional knowledge is unimportant, on the contrary, the proficient of core theories supplement with proper attitude are favorable for the mastery of specific practical knowledge and long-term career development.

Table 5.16 Distribution of Q participants

Q Participants	Factor				Delete	Total
	Ⅰ	Ⅱ	Ⅲ	Ⅳ		
Employee	0	6	2	2	2	12
Student	6	1	1	5	5	18
Professor	1	0	1	1	0	3
Total	7	7	4	8	7	33

In recent years, the public and education system fully promote the development and respect of soft skills. This concept also influences the cognition of students who are more willing to devote themselves in the enhancement of various personal internalized abilities. Nevertheless, the courses provided by universities can't fit in with the needs yet. Due to the engineering materials' nature and the traditional instruction strategies focused on the one-way knowledge instruction, the design of learning activities are relatively inflexible and not attractive. Besides, the interaction opportunities between instructor and students, or among students, are insufficient. The phenomenon obviously prevents students from learning by examples.

Comparing with widespread applications of nanotechnology, students consider the nanotechnology fundamental capabilities deserve more attention. This viewpoint comes from the reality that the essential knowledge and skills engineering students equipped can generally be utilized across fields. The nanotechnology is generally be viewed as an emerging technique which is supplemental to those originals, and for students who plan to engage in the nano-related fields, the mastery of nano core concepts coupled with engineering backgrounds is sufficient and flexible for the multilateral career development.

In addition to the inconsistence between students' expectation and actual reality about learning activities arrangement, the connection between academic and practical application are also comparably weak. The students are willing to assimilate the experiences from someone who really involve in that job and have the opportunities to be the trainee of interested company. From the present situation, the instructors understand the urgent need and try hard to provide various channels for students to obtain up-to-date knowledge and practical experience. However, the problem arises on the provision of channels but without any further explanation about the correlation between academic knowledge and industrial application. This phenomenon will not only make students feel confused and unsatisfied about the course particular arrangement, but the incorrect perception and inappropriate attitude of students will also potentially damage the collaboration relationship between institutions and universities. The pivotal results of whole Q interpretations summarized in Table 5.17.

Table 5.17 Summary of Q interpretations

Total

(1) Consensus statements

- Positive: nanomaterial
- Neutral: integrated circuits fabrication
- Negative: solar cell, calculus

(2) Nanomaterial is the core competences of nanotechnology graduates.

(3) Professors are the key person who potentially influences the individual professional perceptions and competence development.

Factor Ⅰ: Nano-sepcific skill and personal attributes oriented

(1) Personal attributes are the most crucial competences, follows by nano-specific operational competences.

(2) Personal attributes, especially independent thinking ability, solve problem ability, and innovation, are the core and necessary competences across different industries and positions.

(3) There are few nano-related courses provided in undergraduate level, the experimentation equipments are rare, and materials excessively focus on the theories.

(4) The nanotechnology competence definitions can be one of the competence requirements in other professional job titles.

Factor Ⅱ: Basic knowledge and personal attributes oriented

(1) Fundamental sciences are the unique point which constitutes the factor.

(2) Personal attributes, especially activeness and aggressiveness, are the indicative competences factor Ⅱ concerned.

(3) University nano-related courses pay little attention on the development of soft skills and practical applications.

(4) The initial step is to establish a consensus about the nanotechnology definition, and then the competences will emerge easily.

Factor Ⅲ: Nano core and specific knowledge oriented
(1) Comparing with the other three factors, factor Ⅲ considers personal attributes are not much important. (2) Nanotechnology professional competences are more stressed than general skills. (3) Competence definitions are helpful for learning development and career planning, however, the proper leading of accurate cognition is important. (4) Nanotechnology-related competences are supplemental and one part under other engineering job titles.
Factor Ⅳ: Nano core knowledge oriented
(1) Although personal attributes and basic science are emphasized, the nanotechnology fundamental competences are crucial for professional development. (2) No matter in pure science or applied field, the general but core concepts are concerned most. (3) The courses need to be rearranged to make the connection between academic and practical more clear, and some specific courses need to be emphasized its particular importance. (4) Nanotechnology can be covered by other industries and which means the competences are suggested to be included by other titles.
Employees' viewpoint
(1) Emphasize the development of personal attributes and the enrichment of pure science understanding. (2) The basic abilities are the more valuable asset which helps employees to achieve work requirement.
Students' viewpoint
(1) Personal attributes and nanotechnology fundamental capabilities are crucial. (2) The focal point of students' expectation about learning activities design is not satisfied. (3) Nanotechnology is a supplemental technique. (4) The relationship between courses and industrial applications need to be clearly illustrated and emphasized.

Chapter Six Conclusion and Suggestion

Nanotechnology changes the world and the way we live, creating new scientific applications that are smaller, faster, safer and more reliable. For its unique small-scale feature, the conception of nano-scale is transformative and irreversible since it involves an ontological as well as a conceptual shift. When it is truly comprehended, the concept of nano-scale can be viewed as the integrative and bounded force for connecting interdisciplinary knowledge and skills which are unapparent previously in medicine, energy, material, communication, and mechanical components, etc.. The integration is not only limited in engineering-related professions, but also in biology, basic science, computer science, public health, life science, medicine, and so on. The comprehensive integration of varied fields makes the nanotechnology research boundaries sharper.

The workforce competences demand of nanotechnology changes rapidly as the development of industrial trend and applications scope. In order to investigate the fundamental but core competences across varied nanotechnology-related careers, curriculum mapping and Q methodology are utilized sequentially. From the results of this research, both methodologies are proved as beneficial and helpful tools to construct and extract focal viewpoints toward nanotechnology competences of stakeholders. The integrated conclusions contain findings of curriculum mapping and Q methodology, as well as the research and practical suggestions, are presented below.

6.1 Conclusion

The purpose of this research is to identify what the expected nanotechnology core competences of university graduate really are. Both the findings of curriculum mapping and Q analysis agree material science research is major area of study constituting of the nanotechnology competence. The materials are the foundation of all things, and the development of emerging technologies needs to operate in coordination with new-type materials (Lin, 2011). A nanometer is one-billionth of a meter. By definition, dimensions between approximately 1 and 100 nanometers are known as the nano-scale. Physical, chemical, and biological properties become unusual and appear on materials at the nano-scale. These properties may differ in important ways from the properties of bulk materials to single atoms or molecules (NNI, 2001). Thus, the conception of nano-scale utilized in material and the varied applications of nanomaterial may be crucial for graduates who anticipate engaging in related jobs.

Although principle or professional knowledge and skills are important for students to learn, the person with proper personal attributes is considered more crucial in future workplace. The personal characteristics, such as independent thinking ability, solving problem ability, and innovation are pivotal nanotechnology workforce competences. The result is consistent with Zaharim et al. (2009a) that engineering curricula should stress more on the humanistic aspects. However, there are few competence related to attitude were mentioned in course syllabi. The great difference of importance given to the personal attributes reveals what the stakeholders look forward and what the university courses provide are inconsistent. It is also corresponding to the industrial viewpoint in Japan that the preparation of university education graduates and requirement of industry workforce is disconnected (Kao, 2006). Although the personal attributes are not easy to alter in nature, it can be changed and influenced unobtrusively and imperceptibly through proper instructional design and strategies.

According to curriculum mapping, most competences expected to be learned in such curriculum are linked to conceptual knowledge and procedural knowledge. The result is consistent with the common phenomenon seen that university instructors put much more emphases on teaching advanced theories but ignore the importance of practical applications in engineering education (Lo, 2008). Similar to what former president of National Chi Nan University, professor Li once said, “now students in engineering fields even have no feeling with practice” (Chiu, 2008). The finding also corresponds to the comments from postsorting interviews that practical operation opportunities are provided relatively rare at school which prevent students from experiencing and manipulating the advanced equipments. This kind of courses planning may potentially influence students’ learning enthusiasm and cognition of practice. Roco (2003a) predicted that job market and related careers in nanotechnology will reach approximately 5 million by 2015 globally, which means the demand of practical and skilled workforce are getting urgent. Although the gap between what have been taught at schools and what is in need in industry can be understood by the shortage of resources and expensive experimental equipments allocated for each university, it is suggested that governments should put more concerns, efforts and budgets in preparing future nanotechnology workforce.

In terms of the arrangement and presentation of nanotechnology workforce competences, most of the participants think it is more suitable to integrate them into the existing engineering-related jobs. It is possible that the nanotechnology represents as a small-scale field of study and is often integrated in almost every engineering professional subject as a specific or advanced section of study. The viewpoint also responds to the opinion that the formation of nanotechnology industry in Taiwan is still on-going.

Nanomaterial, independent thinking ability, solving problem ability, and innovation are confirmed as the four core competences for nanotechnology workforce. Especially nanomaterial is believed the most important competence that determines whether the graduates eligible or not. Even though the participants of four factors have their own and dissimiliar conecrned standpoints, the long-term development of those competnecs are suggested to be given the high priorities. Specifically, the required core competence of general nanotechnology graduates suggested by this research includes:

- K (Knowledge): Understanding and familiar with the nanomaterial science, the properties of varied materials, and the theories of material dynamics.
- S (Skill): Familiar with the principles and operation process of nanomaterial-related fabrication techniques, including nanomaterial manufacturing techniques, nanomaterial examination techniques, nanomaterial controlling technique, and nanomaterial lithography technique.
- A (Attitude): Innovation.
- O (other attributes): Independent thinking ability and solving problem ability.

6.2 Suggestion

6.2.1 Future research

No matter is what industries or fields, the focal point of competence research is on the discovery of practical capability requirements for employees qualified to deal with the jobs. From the results of this research, the ambiguous cognition of nanotechnology result in the difficulty achieving the common consensus among stakeholders toward expected nanotechnology competences. Especially, the nano-scale is not only limited to the pure science field, but also be applied in extensive engineering fields, and which make it more difficult to establish mutual agreement. This phenomenon points out the future research which intend to investigate emerging technology workforce competence need to clarify the definition centered on the application aspect initially. The well-defined illustration is the fundamental but essential step for conducting further research.

Generally, the competence definition constituted by four elements, such as knowledge, skill, attitude, and other attributes. The Q statements utilized in this research also include those aspects. On the one hand, the mixed usage is advantageous for researchers to understand the relative importance of varied competences. However, it is somehow confused the participants to make the decision in the different levels. In virtue of the attitude or other attributes are the important aspects of competences, it is suggested to allow Q participants conduct Q sorting twice that separate the knowledge and skill from personal characteristics.

The general competences extracted from this research focus on the fundamental and required core capabilities. As mentioned before, nanotechnology is covered under extensive application fields, which means not only the difference of industrial circumstance result in the various workforce demands, but the job positions also influence the competence requirements. The continuing research is encouraged to focus on the discovery of the advanced nanotechnology competences for specific domains. The integration of core and advance competences is more valuable for practical reference.

In comparison with questionnaire-type survey, Q methodology gives consideration to both qualitative and quantitative advantages. The viewpoints expressed by Q participants represent the subjective opinions of specific group, and which may be different from the general public essentially. The follow-up questionnaire survey is advised to conduct in order to understand and contrast the same and dissimilar competences requirement, as well as the reference for the establishment of competence map.

6.2.2 Practical application

Instructors are encouraged to apply varied instructional strategies to offering students the opportunities to exercise these unique personal capabilities. Project-based learning (PBL) is suggested as an appropriate instructional approach which allows students to acquire new knowledge and skills through designing, planning and producing a product on their own (Simkins, 1999). Students in PBL need to form a learning group to solve complex real-world problems and learn how to communicate and work collaboratively with team members. No doubt integrating a PBL strategy into interdisciplinary learning is helpful to increasing personal creativity, team performances, presentation skills, learning involvement, communication skills, and project practicality for nanotechnology students.

To solve the limitation of budgets or resources required, one of the e-learning technologies - virtual reality (VR) - is another appealing alternative for application to engineering education. VR is an artificial communication environment which is able to convey meaning, transfer knowledge, and generate experience (Pares & Pares, 2006). VR can immerse people in an environment that would normally be unavailable due to cost, safety, or perception restrictions. VR has been applied as an instructional support mechanism in varied fields, such as biology (Lu et al., 2006) and surgery (Klapan et al, 2007), and VR-based job training, which is proved beneficial to training beginner or intermediate level workers by enabling them to virtually experience the workflow beforehand (Watanuki, 2008). Based on the advantages confirmed, VR may be suitable for providing nanotechnology students with realistic-like experiences and helping them possess operation skills.

Besides the mastery of knowledge and skills, the importance on the personal features to long-term career development is obviously well-known. However, it exists the gap that even the instructors perceive the needs of personal characteristic preparation, they don’t know how and where to obtain resources which is helpful for them to integrate varied and efficient instructional strategies into original courses. For preparing the instructors who are eager to adopt new instructional strategies in the engineering courses, universities with nanotechnology-related programs are encouraged to establish a cross-universities professional team. The mission of this team is to provide total solutions to the instructors about the lead-in process of innovative instructional strategies, the integrated application of multi-resources, and the sharing of engineering education knowledge and outstanding practical experiences. The specialized team acts as a nanotechnology education resource center to comprehensively cooperate with universities, institutions, and industries all over the world.

Nanotechnology is covered by different aspect of fields and which means the students have the opportunities to enroll in extensive courses. To some extent, the course openness is beneficial for students to get in touch with varied professional knowledge. Nevertheless, it is also risky that students feel confused for not accurately be aware of what courses they should enroll for specific field. The re-arrangement and more emphasis given to specific courses are needed. Diverse courses are suggested to be categorized by level.

Comparing with the original curriculum map showed in Figure 4.14, Figure 6.1 depicts the concept and re-arrangement of university nanotechnology courses suggested by this research. The concept of basic courses are same between original and revised curriculum map that are those courses science and engineering freshmen required to learn, such as general physic, general chemistry, and calculus. Nanotechnology fundamental courses are those categorized into core courses originally, and which include nanotechnology and nanoscience that students who desire to understand general nano knowledge. Besides, the focal finding of this research that nanomaterial is crucial for nanotechnology-related careers results in the unique position and forms the nanotechnology core course. Finally, the original nanotechnology-specific and nanotechnology-related courses are together categorized into nanotechnology professional courses. Each engineering domain integrated with nanotechnology is requested to develop hierarchical nanotechnology professional courses respectively, and the courses are further divided into required, compulsory elective, and elective levels.

<table>
<tr><td rowspan="9">Core personal attributes development
Independent thinking ability, Solve problem ability, Innovation</td><td colspan="3">Nanotechnology professional course</td></tr>
<tr><td>Biology domain</td><td>Electro-optical domain</td><td>…</td></tr>
<tr><td>(ex.) Nano biomedical and fluidic systems (elective)</td><td>(ex.) Nano-scale optical lithography technology (elective)</td><td>…</td></tr>
<tr><td>(ex.) Nano engineering in biomedicine (compulsory elective)</td><td>(ex.) Nano-scale optical metrology and applications (compulsory elective)</td><td>…</td></tr>
<tr><td>(ex.) Introduction to bionano (required)</td><td>(ex.) Introduction to nanoelectronics (required)</td><td>…</td></tr>
<tr><td colspan="3">Nanotechnology core course (required)</td></tr>
<tr><td colspan="3">(ex.) Nanomaterial</td></tr>
<tr><td colspan="3">Nanotechnology fundamental course (required)</td></tr>
<tr><td colspan="3">(ex.) Nanotechnology, Nanoscience</td></tr>
<tr><td colspan="4">Basic course (required)</td></tr>
<tr><td colspan="4">(ex.) General physic, General chemistry, Calculus</td></tr>
</table>

Provided by nanotechnology program/ department

Provided by each department

Figure 6.1 Suggested rearrangements of university nanotechnology courses

6.3 Research Limitation

Although the Q participants recruited by this research represent the subjective viewpoints toward the nanotechnology competences of the main stakeholders, the sources are limited to one specific university and institution. In addition, all the employees come from the electro-optic industry who may not well-understand the job requirements of other industries. This situation possibly causes the analysis results focus on the particular direction.

The Q statements were extracted from thirteen nanotechnology-related programs in Taiwan. It is impossible for Q participants to learn and understand all the contents of different levels of courses and domains, and which make them doubt the appropriateness of Q sorting results. In this research, the focal point is on the discovery of general nanotechnology competences across fields and the unfamiliarity with certain professional knowledge is acceptable.

As a first exploratory research concerned on the aspect of nanotechnology competences in Taiwan, it is hard for researchers to refer and compare the findings of this research to existing references. Although the research results may represent specific viewpoint of small group and need to be verified by further research, it also invokes the attentions on the transformation demand of university nanotechnology courses, as well as the professional competence development of emerging technology.

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Appendix 1: Summary of courses by level

1. Courses for undergraduate students

- Basic courses

Item	Course	University	No.
1	Physical chemistry	National Chiao Tung Univ.	1
		National Central Univ.	4
		National Chung Cheng Univ.	1
2	Modern physics	National Taiwan Univ.	3
		National Chiao Tung Univ.	1
		National Chung Cheng Univ.	1
		National Ilan Univ.	1
3	Introduction to solid state physics	National Chiao Tung Univ.	1
		National Central Univ.	2
4	Solid state electronics	National Taiwan Univ.	2
		National Central Univ.	1
5	Quantum physics	National Central Univ.	2
		National Chung Cheng Univ.	1
6	Solid state physics (II)	National Taiwan Univ.	1
		National Chiao Tung Univ.	1
7	Quantum mechanics	National Taiwan Univ.	1
		National Central Univ.	1
8	Solid state chemistry	National Chung Hsin Univ.	1
9	Introduction to semiconductor industry	National Tsing Hua Univ.	1
10	Introduction to plasma physics I		1
11	Special topics in analytical chemistry (I)	National Taiwan Univ.	1
12	Introduction to biotechnology (I)		1
13	Fundamental of electro-optics		1
14	Special topics on physical chemistry		1
15	Computational optoelectronics		1
16	Fundamental of optics		1
17	Principles and application of quantum physics		1
18	Introduction to computational modeling at microscopic scale		1
19	Introduction to electromagnetic waves		1
20	Electricity and magnetism		1
21	Introduction to precision machine design		1
22	Applied electrochemistry		1
23	Catalysis chemistry		1

Item	Course	University	No.
24	Chemistry (I)	National Chiao Tung Univ.	1
25	Chemistry (II)		1
26	Chemistry lab.		1
27	Organic chemistry (I)		1
28	Organic chemistry (II)		1
29	Solid state physics (I)		1
30	Physics (I)		1
31	Physics (II)		1
32	Physics labs. (I)		1
33	Physics labs. (II)		1
34	Cell biology (I)		1
35	Cell biology (II)		1
36	General biology lab.		1
37	General biology		1
38	Differential equations		1
39	Microbiology		1
40	Calculus (I)		1
41	Calculus (II)		1
42	Thermal physics		1
43	Applied Maths. (I) (Linear algebra, vector analysis)		1
44	Optical properties of solids	National Central Univ.	1
45	Electronics (I)		1
		Total	63

- Core courses

Item	Course	University	No.
1	Introduction to nanotechnology	National Sun Yat-Sen Univ.	2
		National Taiwan Univ.	1
		National Chiao Tung Univ.	1
2	Introduction to nanoelectronic devices	National Tsing Hua Univ.	2
3	Introduction to nanomaterials	National Ilan Univ.	1
		National Central Univ.	1
4	Introduction to nano-semiconductors	National Sun Yat-Sen Univ.	1
5	Quantum physics and the physical properties of nanostructures		1
6	Introduction to semiconductor industry and manufacturing	National Tsing Hua Univ.	1
7	Introduction to nanostructure science and technology		1
8	Introduction to nano tech and photonic		1

Item	Course	University	No.
	semiconductor industry		
9	Introduction to nanoscale physics		1
10	Introduction to nanoscale physics II		1
11	Nanotechnology and modern sciences and technology		1
12	Nanotechnology and its applications		1
13	Introduction to nanotechnology	National Taiwan Univ.	1
14	Nano-photonics		1
15	Nanoscience lab (I)		1
16	Nanoscience lab (II)		1
17	Nano and life	National Chiao Tung Univ.	1
18	Nano and career planning		1
19	Research (I)		1
20	Introduction to nano electronic and optical devices	National Central Univ.	1
21	Nano electronics		1
22	Introduction to material chemistry	National Chung Cheng Univ.	1
		Total	27

- Nanotechnology-specific professional course

Item	Course	University	No.
1	Nanobiotechnology	National Taiwan Univ.	2
2	General topics in nanobiotechnology	National Tsing Hua Univ.	2
3	Manufacturing technology of semiconductor for nano device	National Sun Yat-Sen Univ.	1
4	Licenses and experiments for nanotechnology		1
5	Fabrication of nanobulk materials and composites		1
6	Electrochemistry of nanomaterials		1
7	Semiconductor and nanotechnology processing experiments	National Tsing Hua Univ.	1
8	Nanobiotechnology industry and patents		1
9	Nanobiotechnology and new material development		1
10	NanoBio new materials and products		1
11	Bio-business and nano-convergency		1
12	Introduction to nanostructured materials and technology		1
13	Launching a nano-startup		1
14	Synthesis of nanoparticles		1

Item	Course	University	No.
15	Introduction to nanoelectronics		1
16	Principles of nano and micro systems engineering		1
17	Non-silicon based micro and nano fabrication technology		1
18	Nanobiotech companies and patents		1
19	Nanoimprinting processes and its applications with polymer		1
20	Introduction to plasma engineering		1
21	Molecular and nanoscale material spectroscopy	National Taiwan Univ.	1
22	Submicron devices		1
23	Introduction to nanomechanics materials		1
24	Nanoscale materials and devices and biosensors		1
25	Introduction of nanobio science and technology		1
26	Nano/micro processing theory and experiments	National Central Univ.	1
27	Bionanotechnology		1
28	Nano-materials		1
		Total	30

- Nanotechnology-related professional course

Item	Course	University	No.
1	Electronic materials	National Chiao Tung Univ.	1
		National Tsing Hua Univ.	1
		National Taiwan Univ.	1
2	Semiconductor engineering	National Chiao Tung Univ.	1
		National Taiwan Univ.	1
3	Physic of semiconductor devices	National Chiao Tung Univ.	1
		National Taiwan Univ.	1
4	Material science	National Taiwan Univ.	1
		National Central Univ.	1
5	Solid state electronic devices	National Tsing Hua Univ.	1
		National Central Univ.	1
6	Microelectronic mechanical system	National Taiwan Univ.	1
		National Tsing Hua Univ.	1
7	Semiconductor optics	National Taiwan Univ.	2
8	Principles of semiconductor lasers		2
9	Optical electronics		2

Item	Course	University	No.
10	Compound semiconductor technology		2
11	Material physics	National Central Univ.	2
12	Inorganic and materials chemistry		2
13	Catalysis chemistry		2
14	Control systems	National Tsing Hua Univ.	2
15	Thin film engineering		2
16	Introduction to quantum mechanics	National Chiao Tung Univ.	2
17	Production planning and control (I)	National Tsing Hua Univ.	1
18	Opto-electronic devices		1
19	Automatic machinery		1
20	The physical properties of materials		1
21	Laboratories of materials III		1
22	Introduction to solid-state electronic devices		1
23	Solid-state electronics experiments		1
24	Solid-state electronics laboratory - Semiconductor processing		1
25	Quality control		1
26	Facilities planning		1
27	Measurements lab.		1
28	Principles in microsystem engineering		1
29	Electronic manufacturing processes		1
30	Introduction to precision machine		1
31	Statistical semiconductor process control and optimization	National Taiwan Univ.	1
32	Semiconductor processing and packaging		1
33	Introduction to semiconductor processing		1
34	Parallel computing		1
35	Biotechnology		1
36	Introduction to biomaterials		1
37	Photonic crystals		1
38	Materials analysis		1
39	Materials chemistry		1
40	Introduction to materials (I)		1
41	Introduction to materials (II)		1
42	Solid state devices		1
43	Solid state physics (I)		1
44	Fundamental finite element method		1
45	Liquid crystal optics		1
46	Introduction to statistical contro; and optimization		1

Item	Course	University	No.
47	Microbiological engineering		1
48	Lab on e-beam technology		1
49	Electronic ceramics		1
50	Electronic and optoelectronics polymers		1
51	Application of transmission electron microscopy (TEM) in chemistry		1
52	Electrochemical engineering		1
53	Integrated optics		1
54	Thin-film technology and surface		1
55	Biochemistry (I)	National Chiao Tung Univ.	1
56	Biochemistry (II)		1
57	Introduction to optics (I)		1
58	Introduction to optics (II)		1
59	Introduction to materials science and engineering		1
60	Microstructural characterization of materials		1
61	Thermodynamics of materials (I)		1
62	Thermodynamics of materials (II)		1
63	Metal materials		1
64	Polymer materials science		1
65	Ceramics materials		1
66	Introduction to quantum mechanics (II)		1
67	Electrical engineering lab.		1
68	Electronic (I)		1
69	Electronic (II)		1
70	Electromagnetism (I)		1
71	Electromagnetism (II)		1
72	Introduction to materials science, materials engineering and chemical engineering (I)	National Central Univ.	1
73	Introduction to materials science, materials engineering and chemical engineering (II)		1
74	Advanced materials		1
75	Advanced material processing		1
76	Low temperature physics		1
77	Physical metallurgy		1
78	Electronic and ceramic materials		1
79	Precision machine design (I)		1
80	Semiconductor materials	National Ilan Univ.	1

Item	Course	University	No.
81	Spectral chemical analysis		1
82	Microfabrication techniques		1
83	MEMS		1
		Total	100

2. Courses for graduate students

- Basic courses

Item	Course	University	No.
1	Solid state physics	National Central Univ.	2
		National Cheng Kung Univ.	1
		National Chiao Tung Univ.	1
2	Surface physics	National Tsing Hua Univ.	1
		National Central Univ.	1
		National Chung Hsin Univ.	1
3	Quantum mechanics	National Tsing Hua Univ.	1
		National Taiwan Univ.	1
4	Condensed matter physics	National Chung Hsin Univ.	2
5	Basic molecular biology	National Sun Yat-Sen Univ.	1
6	Mathematical modeling for engineering science	National Chung Hsin Univ.	1
7	Functional proteomics		1
8	Surface science and technology (II)		1
9	Special topics in surface/colloid chemistry		1
10	Special topics on tissue engineering		1
11	Protein structure and function		1
12	Proteomics laboratory		1
13	Stem cell biology		1
14	Surface and colloid chemistry		1
15	Applied quantum mechanics (I)		1
16	Molecular dynamics simulations	National Tsing Hua Univ.	1
17	Introduction to biosensor technologies		1
18	Photonics I		1
19	Nature color and animal vision		1
20	Microscopic properties of solids		1
21	Special topics in semiconducting polymers		1
22	Applied electro-chemistry		1
23	Theory of phonon dynamics		1
24	Thin film materials science		1

Item	Course	University	No.
25	Mesoscopic and low-dimensional physics	National Taiwan Univ.	1
26	Introduction to spintronics		1
27	Polymer physics I: In solid state		1
28	Introduction to quantum computation and information		1
29	Introduction to biomechanics	National Cheng Kung Univ.	1
30	Cell mechanics		1
31	Quantum computation		1
32	Quantum information		1
33	Stem cell biology		1
34	Special topics on microfluidic devices		1
35	Special topics on electrochemistry analysis		1
36	Solid state chemistry	National Central Univ.	1
		Total	43

- Core courses

Item	Course	University	No.
1	Introduction to nanotechnology	National Cheng Kung Univ.	1
		National Chung Hsin Univ.	1
		National Tsing Hua Univ.	1
		National Chiao Tung Univ.	1
2	Seminar	National Cheng Kung Univ.	2
		National Tsing Hua Univ.	1
		National Chiao Tung Univ.	1
3	Introduction to micro and nano-scale science and technology	National Tsing Hua Univ.	2
		National Cheng Kung Univ.	1
4	Chemistry in nanotechnology	National Tsing Hua Univ.	2
5	Special topic on nanophysics		2
6	Nanofabrication and characterization	National Chiao Tung Univ.	2
7	Advanced introduction to nanoscience and nanotechnology	National Chung Hsin Univ.	2
8	Introduction to numerical simulation method in nano-scale	National Sun Yat-Sen Univ.	1
9	Characterization of nano-structured materials		1
10	Fabrication of nanomaterials: Assembling of atoms/ molecules and beyond		1
11	Special topics on nanopolymers	National Chung Hsin Univ.	1

Item	Course	University	No.
12	Fabrication and characterization of nano devices		1
13	Introduction to nanotechnology		1
14	Introduction to modern physics and nano technology		1
15	Computational nanomechanics		1
16	Nanoengineering		1
17	Introduction to applications of nanotechnology	National Tsing Hua Univ.	1
18	Computational physics for nano sciences and nano technologies		1
19	Nanodevice physics		1
20	Introduction to nano technology		1
21	Nano technology experiment		1
22	Knowledge system science		1
23	Writing of scientific papers and research methods	National Cheng Kung Univ.	1
24	Seminar (II)		1
25	Seminar (III)		1
26	Seminar (IV)		1
27	Creativity and innovation in nano technology		1
28	Quantum transport of nano-heterostructures		1
29	Silicon nanometer devices and physics	National Chiao Tung Univ.	1
30	Surface and intermolecular forces - Principle and applications		1
31	Nano science	National Central Univ.	1
32	Nano fabrication and characterization experiment	National Chung Cheng Univ.	1
33	Nanometrology	National Ilan Univ.	1
		Total	45

- Nanotechnology-specific professional course

Item	Course	University	No.
1	Nano-materials	National Cheng Kung Univ.	2
		National Chung Hsin Univ.	1
2	Nanometer scale characterization techniques	National Tsing Hua Univ.	2
		National Chung Hsin Univ.	1
3	Biomedical nano-electromechanical systems	National Chiao Tung Univ.	2
4	Introduction to bioMEMS and bionanotechnology	National Tsing Hua Univ.	2
5	Introduction to nanobiotechnology		2
6	Nanophotonic devices		2
7	Nano-scale optical lithography technology		2
8	Nanomaterials chemistry		2
9	Nano polymer composites		2
10	Nanotechnology in the environment		2
11	Analysis techniques of nano-scale thin films		2
12	Fabrication and characterization of nanowires and nanodots		2
13	Polymer micro/nano system technology		2
14	Micro/nano system engineering for bio-molecular diagnosis		2
15	Sensing and actuation in miniaturized systems		2
16	Micro and nano technology		2
17	Micro and nano fabrication technology		2
18	Micro/nano materials	National Sun Yat-Sen Univ.	1
19	Nano-imprint technique		1
20	Interface between supramolecules, macromolecules, and nanomaterials	National Chung Hsin Univ.	1
21	Biomedical molecular imaging		1
22	Bio microelectromechanical systems		1
23	Nano fabrication technology		1
24	Nanobiomaterials		1
25	Nanotechnology and environment		1
26	Nano scanning probe microscopy		1
27	Fabrication characterization techniques of nanoscience & nanotechnolog		1
28	Processing of nanomaterials		1
29	Nano technology and measurement		1

Item	Course	University	No.
30	Hands on fabrication and characterization of nano devices		1
31	Nanobiotechnology		1
32	Application of nanotechnology on biomedical detections		1
33	Environmental nanotechnology		1
34	Neutron and x-ray small angle scattering	National Tsing Hua Univ.	1
35	Semiconductor optics, photonic and nano photonic devices		1
36	Bionanomaterials		1
37	Multidisciplinaty theory for nano/micro-applications		1
38	Low-dimensional nanomaterials		1
39	Nanobiotechnology		1
40	Practical nanobiotechnology		1
41	Nano-scale optical metrology and applications		1
42	Science and engineering of nanomaterials		1
43	Nanomaterials processing and analysis		1
44	Applicaiton of environmental nanomaterials		1
45	Physics of nanoscale CMOS devices		1
46	Nano-scale measurement and design		1
47	Atomistic-continuum mechanics		1
48	Nanostructures : Fabrication, measurement, and application		1
49	Nano transducers and applications		1
50	Nanoelectronics		1
51	Nanoelectronics and quantum transport		1
52	Carbon nanotubes		1
53	Epitary-materials science in its nano regime		1
54	Nano mechanical property evaluation		1
55	Measurements of nano and micro devices		1
56	Nano/micro biomedical and fluidic systems		1
57	Nano/micro electromechanical systems		1
58	Nano and micro system characterization experiment		1
59	Special topics and case study on HARMST (High aspect ratio micro/nano		1

Item	Course	University	No.
	structure technology)		
60	Electronic biomedical sensors and the application of nanotechnology		1
61	Fabrication and application of magnetic nano devices		1
62	Fabrication of magnetic microstructures		1
63	Environmetal nanomaterials chemistry		1
64	Environmental nano-science		1
65	Nanobioscience	National Taiwan Univ.	1
66	Nano/micro engineering in biomedicine		1
67	Nanomaterials		1
68	Biosensor in molecular medicine	National Cheng Kung Univ.	1
69	Synthesis of nanomaterials and nanotechnologies		1
70	The science and technology in nano materials		1
71	Interface of nano technology		1
72	Carbon nanomaterials		1
73	Nanoimprint and device fabrication		1
74	Microsystem analysis		1
75	Micro-nano scale heat transfer		1
76	Micro/nano-fluidics technology		1
77	Micro/nano statistical mechanics		1
78	Introduction to physics of semiconductor nanostructures	National Chiao Tung Univ.	1
79	Biochemical and sensing technology		1
80	Materials science and nanotechnologies		1
81	Nanodevices, measurement and analysis		1
82	Introduction to nanostructured materials		1
83	Nanomanipulation		1
84	Nanophotonics	National Chung Cheng Univ.	1
		Total	103

- Nanotechnology-related professional course

Item	Course	University	No.
1	Introduction to molecular dynamics simulation	National Tsing Hua Univ.	3
2	Semiconductor devices physics	National Tsing Hua Univ.	1
		National Chiao Tung Univ.	1
3	Microelectromechanical systems (MEMS) design	National Tsing Hua Univ.	1
4		National Cheng Kung Univ.	1
5	Molecular biology	National Chiao Tung Univ.	2
6	Surface analysis		2
7	Biochip technology (I)	National Chung Hsin Univ.	2
8	Medical biotechnology (I)		2
9	Finite element method	National Taiwan Univ.	2
10	Microelectronic engineering	National Tsing Hua Univ.	2
11	Mechanics fundamentals for electronic packaging		2
12	Introduction to micro-electro-mechanical system (MEMS)	National Cheng Kung Univ.	2
13	MEMS fabrication technology		2
14	Methods in molecular biology	National Chung Hsin Univ.	1
15	Laboratory for biotechnology		1
16	Biochip technology (II)		1
17	Material chemistry		1
18	Transgenic techniques		1
19	Laboratory for genomics		1
20	Advanced VLSI manufacturing technologies		1
21	Analytical electrochemistry		1
22	Medical biotechnology (II)		1
23	Fundamental analog circuits for MEMS	National Tsing Hua Univ.	1
24	Methods of small angle scattering in polymer science		1
25	Semiconductor production management		1
26	Semiconductor material and device characterization		1
27	Semiconductor microwave devices		1
28	Semiconductor processing		1
29	Transport phenomena in semiconductor manufacturing process		1
30	Introduction of biomedical technology		1
31	Biomedical engineering		1
32	Fundamentals of biophotonics		1

Item	Course	University	No.
33	Biomimetics and mcirosystem: Principle and laboratory		1
34	Opto-mechatronics for instrumentation		1
35	System dynamics analysis		1
36	Nonlinear nynamics and chaos		1
37	Quality engineering		1
38	RF MEMS components and applications		1
39	Semiconducting polymers and related devices		1
40	Polymer micro systems technology		1
41	Polymers in microelectronics		1
42	Advanced CMOS MEMS design		1
43	Cellular neuroscience		1
44	Flexible electronics and systems		1
45	Soft condensed matter		1
46	Ultratrace analytical chemistry		1
47	Micro-optical elements and systems		1
48	Microscale heat transfer		1
49	Microsystem technology and experiment		1
50	Materials for microsystems		1
51	Microsystems packaging design and experiment		1
52	Micro system design		1
53	Microfluidic systems		1
54	Special topics on microarray biomedical engineering		1
55	Trace analysis		1
56	Microsensor and microinstrument system		1
57	Microelectronic engineering laboratory		1
58	Micromechanical system technology		1
59	MEMS packaging and eeliability		1
60	Microscopic energy transport		1
61	Theory of electric double layer		1
62	Electronic material and device characterization		1
63	Cooling systems for electronic equipment		1
64	Electronic packaging		1
65	Electronic cooling		1
66	Electromagnetic MEMS components and applications		1

Item	Course	University	No.
67	Plasma engingeering and applications		1
68	Principles of plasma applications in materials processing		1
69	Plasma laboratory and experiment design methods		1
70	Microscopic theories of magnetism		1
71	Integrated photonic devices		1
72	Integrated optics		1
73	Device electronics for I.C.		1
74	Thin film physics and technologies		1
75	Theory and practice of atmospheric diffusion	National Taiwan Univ.	1
76	Softoare system and design for engineering application		1
77	Molecular simulation		1
78	Fundamentals of water pollution and control		1
79	Parallel computing and its engineering applications		1
80	Physics for medicine and biology		1
81	Opto-electronic and piezoelectric systems		1
82	Optical microscopy		1
83	Control of gaseous air pollutants		1
84	Kinetics of materials		1
85	Air pollution chemistry		1
86	Fundamentals of air		1
87	Computational flow dynamics		1
88	Dislocation theory		1
89	Powder metallurgy		1
90	Properties of particulate matter		1
91	Polymer syntheses		1
92	Advanced electrochemistry		1
93	Physical and chemical treatment processes		1
94	Crystal structure		1
95	Special topics in micro-optomechatronic systems		1
96	Fabrication and design in optical MEMS		1
97	Application of MEMS for cell and tissue physiology		1
98	Colloid and interfacial phenomena		1

Item	Course	University	No.
99	Special topics on mass transfer		1
100	Environmental chemistry		1
101	Environmental organic chemistry		1
102	Environmental toxicology and risk assessment		1
103	Environmental fluid mechanics		1
104	Environmental dispersion process		1
105	Medical microsensor		1
106	Drug delivery system		1
107	CMOS/MEMS microsystem chip design		1
108	Engineering optics		1
109	Engineering Quantum mechanics (I)		1
110	Engineering electromagnetics		1
111	Molecular genetics		1
112	Analytical dynamics		1
113	Special topics on solar cell technology		1
114	Physics of semiconductor materials and devices		1
115	Semiconductor and optoelectronic devices		1
116	Bioanalytical chemistry		1
117	Biomaterial chemistry		1
118	Biomechanics of living tissues and cells		1
119	Application of high-resolution microscopy and single-cell-based biochip	National Cheng Kung Univ.	1
120	Biomechanics of microstructures		1
121	Special topics in bioMEMS		1
122	Bioelectrochemistry		1
123	Biomechamical engineering		1
124	Fundamental of biomedical optics		1
125	Multi-scale simulation of biomedical system		1
126	Introduction to CMOS Biotechnology		1
127	Biosensor		1
128	Taguchi quality engineering		1
129	Precision measurements by optical methods		1
130	Optical sensing technology		1
131	Analysis of materials		1
132	Wave optics		1
133	Micro-fabrication techniques for		1

Item	Course	University	No.
	polymeric materials		
134	Advanced engineering mathematics		1
135	Advanced applied mathematics		1
136	High-resolution transmission electric microscopy		1
137	Special topics on physics in strong correlation physics		1
138	Optimal control theory		1
139	Advanced MEMS device fabrication: Experiment		1
140	Control of quantum systems		1
141	Quantum information		1
142	Quantum electrodynamics		1
143	Microsensor design		1
144	Advanced topics in microfabrication techniques		1
145	MEMS device fabrication: Experiment		1
146	MEMS material		1
147	Integartion of MEMS technology		1
148	Micro/nano tribology issues		1
149	Micro-tribology		1
150	Micromechanics		1
151	Excimer laser in microfabrication		1
152	Laboratory experiments on electronic devices (I)		1
153	Plasma chemistry		1
154	Digital signal processing		1
155	Adaptive control		1
156	Field theories in condensed matter physics		1
157	Piezoelectric materials and acoustical electronic devices		1
158	Wave propagation in elastic solids		1
159	Special topics of acoustic and electric-optical devices		1
160	Thin film engineering		1
161	Thin film physics		1
162	Testing and analyses of thin films		1
163	Ferroelectric and devices		1
164	Molecular electronics	National Chiao Tung Univ.	1
165	Chemical techniques for semiconductors		1

Item	Course	University	No.
166	Special topics in chemical engineering		1
167	Biochip and analysis		1
168	Applications of bioinformatics		1
169	Optical electronics		1
170	Physical biochemistry		1
171	Surface science		1
172	Protein structure		1
173	Quantum mechanics		1
174	Miniaturization engineering		1
175	Introduction to laser		1
176	Solgel science and application	National Central Univ.	1
177	Material science	National Chung Cheng Univ.	1
		Total	189

Appendix 2: Competences utilized in this study

No.	Competence	No.	Competence
1	physics	39	low-dimensional physics
2	mechanics	40	biomedical physics
3	micromechanics	41	nano statistical mechanics
4	statistical mechanics	42	nanomechanics
5	thermodynamics	43	nanomechanics materials
6	thermodynamics of materials	44	quantum electrodynamics
7	classical mechanics	45	computational nanomechanics
8	molecular mechanics	46	electronics
9	powder mechanics	47	nano electronics
10	fluid mechanics	48	bioelectronics
11	solid mechanics	49	nano bioelectronics
12	biomechanics	50	spintronics
13	elastic mechanics	51	molecular electronics
14	mechanics measurements	52	solid-state electronics
15	dynamics	53	organic electronics
16	chemical kinetics	54	optical electronics
17	molecular dynamics	55	electron-phonon interactions
18	molecular dynamics simulations	56	nanomagnetism
19	electrodynamics	57	band theory
20	dynamic system	58	nano heat transfer
21	magnetism	59	wave propagation in elastic solids
22	biomagnetism	60	solid state science
23	electricity theory	61	lasers
24	electromagnetics	62	laser techniques and systems
25	electromagnetic waves	63	nanophotonics
26	nonlinear dynamics and chaos	64	biomedical optics
27	optics	65	solid state optics
28	modern physics	66	nonlinear optics
29	solid state physics	67	modern physical optics
30	nanoscale physics	68	integrated optics
31	quantum physics	69	wave optics
32	condensed matter physic	70	spectroscopy
33	wave physics	71	liquid crystal optics
34	surface physics	72	engineering optics
35	soft condensed matter physics	73	microstructures
36	strong correlation physics	74	chemistry
37	statistical physics	75	solid state chemistry
38	plasma physics	76	computational chemistry

No.	Competence	No.	Competence
77	quantum chemistry	115	solid-state material
78	plasma chemistry	116	magetic material
79	surface chemistry	117	electric material
80	organic chemistry	118	optoelectronic material
81	inorganic chemistry	119	piezoelectric material
82	biochemistry	120	electrogen
83	physical chemistry	121	molecular material
84	physical biochemistry	122	nano molecular material
85	bioanalytical chemistry	123	biomimetic nanomaterial
86	surface and colloid chemistry	124	optical materials
87	gel techniques	125	thim material
88	electrochemistry	126	microsystem material
89	electrochemistry techniques and systems	127	insulation
90	environmental chemistry	128	catalysis
91	nano chemistry	129	quantum dot
92	materials chemistry	130	porous material
93	nanomaterials chemistry	131	crystal material
94	nano biochemistry	132	heat treatment
95	powder	133	piexoelectrics
96	nano powder	134	electronic transducer
97	nano materials	135	powder technology
98	low dimensional nanomaterial	136	material fabrication technoques
99	inorganic nanopowders	137	material synthesis techniques
100	semiconductor	138	material processing techniques
101	nano semiconductor	139	nanomaterial techniques
102	biomaterial	140	materials fabrication techniques
103	nano biomaterial	141	nanomaterial synthesis techniques
104	carbon nanotube	142	optical thin film
105	nanoparticle	143	printing technologies
106	nanowire	144	materials characterization techniques
107	bulk nanomaterials	145	material analysis techniques
108	nanofilm	146	nanomaterials characterization techniques
109	nanocrystal	147	nanomaterial analysis techniques
110	nanoribbons	148	biology
111	nanoflakes	149	genomics
112	carbonaceous materials	150	cytology
113	metal material	151	bionics
114	ceramics material	152	protein

No.	Competence	No.	Competence
153	microarray	190	optical manufacturing technique
154	protein microarray	191	nano optical lithography technique
155	plasmid	192	nano optical inspection technique
156	tissue engineering	193	nano optical manufacturing technique
157	bioinformatics	194	biophotonics
158	biostructure	195	nanophotonics
159	nanobiology structure	196	nano biophotonics
160	bioreactor	197	nano optoelectrionics and magnetic system
161	biochip	198	optical system design
162	nanobiology	199	solid structure
163	biology technology	200	crystal structure
164	bionanotechnology	201	photonic crystals
165	biomedical system	202	crystal fabrication
166	biomedical sensing and optical system	203	nano device
167	nanobiology system	204	nano sensing device
168	biology manufacturing technique	205	nano actuating device
169	nanobiology manufacturing technique	206	nano photonics device
170	biology inspection technique	207	nano electric device
171	nanobiology inspection technique	208	nano magnetic device
172	biology lithography technique	209	nano bionic device
173	computational materials science	210	photonic device
174	tribology	211	photovoltaic device
175	nanoscale surface	212	electric device
176	surface analysis	213	molecular electric device
177	surface and molecule interaction	214	photonics device
178	kinetic process of materials	215	acoustic wave devices
179	material science	216	acousto-optic device
180	surface science	217	solid-state device
181	material surface science	218	semiconductor device
182	production management	219	high capacity device
183	quality control	220	MEMS device
184	statistical control	221	microsystem device
185	equipment planning	222	microfluidic device
186	spectral analysis	223	waveguide device
187	optical sensing technique	224	optical waveguide
188	optical technique	225	optical resonators
189	optical inspection technique	226	optical detector

No.	Competence	No.	Competence
227	optical amplifier	262	solar cell
228	nano sensing	263	radio frequency identification system
229	sensor	264	small angle X-ray scattering
230	nano sensor	265	multidisciplinaty theory
231	biology sensor	266	system dynamics approach
232	electrostatic actuation	267	nanofluid
233	actuator	268	nanofluid techniques
234	nano actuator	269	bio-micro nanofluid
235	nano transducer	270	microfluidic
236	micromechanical resonator	271	optofluidic
237	accelerator	272	fluidic system
238	device design	273	nanotechnology
239	nano device design	274	nanoscience
240	sensor design	275	nanometrology
241	actuator design	276	nanofood techniques
242	sensing techniques	277	assembling of atoms and molecules
243	nano devices manufacturing techniques	278	nanostructures
244	devices manufacturing techniques	279	transport phenomena
245	device processing techniques	280	Nanotransport
246	optical waveguide manufacturing techniques	281	drug delivery system
247	microscale thermal-fluids	282	electron beam techniques
248	nano device measuring techniques	283	nano lithography techniques
249	devices characterization techniques	284	lithography optics
250	micro scale	285	electronic system
251	nano scale	286	nanoelectronics system
252	engineering mathematics	287	micromanufacturing techniques
253	advanced applied mathematics	288	nano fabrication techniques
254	finite element method	289	nano processing techniques
255	machinery	290	micromachining
256	automatic machinery	291	nano manipulation techniques
257	precision machinery	292	nano-electromechanical systems (NEMS)
258	nano machinery	292	nano-electromechanical systems (NEMS)
259	biomachinery	293	nanoenergy and electromechanical systems
260	parallel computing technique	294	nano analysis techniques
261	optical packaging	295	nano characterization techniques

No.	Competence	No.	Competence
296	nearfield optical	332	circuit design
297	quantum system control	333	plasma engineering
298	radio frequency measurement techniques	334	calculus
299	measurement technique	335	computational modeling at microscopic scale
300	micro motor	336	mathematics
301	microsystem chip	337	statistic
302	microanalysis	338	linear algebra
303	optical system	339	knowledge system science
304	optomechatronic system	340	dislocation theory
305	processing techniques	341	vacuum technology
306	Microelectromechanical systems (MEMS)	342	neuroscience
307	microsystem	343	powder metallurgy
308	microsystem packaging	344	energy transport
309	MEMS packaging techniques	345	information display
310	chip scale packaging	346	digital signal processing
311	grid array	347	chip design
312	device packaging	348	clean room technology
313	MEMS design	349	lab-on-a-chip
314	microsystem design	350	magnetic structure
315	microsysytem characterization techniques	351	magnetic structure manufacturing
316	integrated circuits design	352	water purification techniques
317	integrated circuits packaging	353	water pollution
318	integrated circuits fabrication	354	air pollution
319	random access memory	355	dispersion
320	electronic packaging	356	air quality
321	electronic structure	357	poisonous gas control
322	electronic equipment	358	natural color
323	electronic manufacturing	359	physical treatment
324	electric analysis techniques	360	environmental toxicology
325	computer science	361	environmental naotechnology
326	computer programming	362	nanotechnology in the environment
327	computer simulation techniques	363	photonic theory
328	computer integrated manufacturing	364	diffusion theory
329	information transmission	365	field theory
330	engineering software analysis and design	366	logic chip
331	circuit theory	367	cooling system

No.	Competence	No.	Competence
368	control system	390	start a nano enterprise
369	liquid crystal display	391	understand industry needs
370	mass transfer	392	understand future trends
371	adaptive control	393	integrate theories and applictions
372	optimal control theory	394	express ability
373	language ability	395	communication ability
374	humanities concern	396	solving problem ability
375	social responsibility	397	information literacy
376	write paper ability	398	interdisciplinary research ability
377	report paper ability	399	teamwork
378	research ability	400	negotiation ability
379	group research ability	401	practical skills
380	read paper ability	402	professional qualification
381	analysis ability	403	leading ability
382	exploration ability	404	flexibility
383	international viewpoint	405	good attitude
384	patent	406	enthusiasm
385	professional ethics	407	thinking ability
386	organizational ability	408	independent learning ability
387	innovation	409	lifelong learning ability
388	willing to challenge	410	pressure management ability
389	discover new fields		

Appendix 3: Summary of statements by competences

No.	Statement	Knowledge	Skill	Attitude	Other attributes
1	Classical physics	Physics, mechanics, micromechanics, statistical mechanics, thermodynamics, thermodynamics of materials, classical mechanics, molecular mechanics, powder mechanics, fluid mechanics, solid mechanics, biomechanics, elastic mechanics, dynamics, chemical kinetics, molecular dynamics, electrodynamics, magnetism, biomagnetism, electricity theory, electromagnetics, electromagnetic waves, nonlinear dynamics and chaos, optics	mechanics measurement, molecular dynamics simulation, dynamic system		
2	Modern physics	Modern physics, solid state physics, nanoscale physics, quantum physics, condensed matter physic, wave physics, surface physics, soft condensed matter physics, strong correlation physics, statistical physics, plasma physics, low-dimensional physics, biomedical physics, nano statistical mechanics, nanomechanics, nanomechanics materials, quantum electrodynamics, computational	Laser technique and system		

No.	Statement	Knowledge	Skill	Attitude	Other attributes
		nanomechanics, electronics, nano electronics, bioelectronics, nano bioelectronics, spintronics, molecular electronics, solid-state electronics, organic electronics, optical electronics, electron-phonon interactions, nanomagnetism, band theory, nano heat transfer, wave propagation in elastic solids, solid state science, lasers, nanophotonics, biomedical optics, solid state optics, nonlinear optics, modern physical optics, integrated optics, wave optics, spectroscopy, liquid crystal optics, engineering optics, microstructures			
3	Basic chemistry	Chemistry, solid state chemistry, computational chemistry, quantum chemistry, plasma chemistry, surface chemistry, organic chemistry, inorganic chemistry, biochemistry, physical chemistry, physical biochemistry, surface and colloid chemistry, electrochemistry	Bioanalytical chemistry, gel technique, electrochemistry technique and system		
4	Applied chemistry	environmental chemistry, nano chemistry, materials chemistry, nanomaterials chemistry, nano biochemistry			

No.	Statement	Knowledge	Skill	Attitude	Other attributes
5	Circuit Theory	Circuit theory	Circuit design		
6	Nanoscience	Nanoscience			
7	Nanotechnology	Nanotechnology			
8	Nanomaterial	Nano materials, material science	Nano fabrication technique, nano characterization technique, nano manipulation technique, nano lithography technique, nano materials fabrication technique, nano materials characterization technique		
9	Nanodevice		Nanodevice, nano devices manufacturing technique, nano devices characterization technique, nano devices design, nano devices sensing technique		
10	Plasma engineering		Plasma engineering		
11	Electronic equipment		Electronic equipment		
12	Electronic manufacturing		Electronic manufacturing		
13	Electronic packaging		Electronic packaging		
14	Optical packaging		Optical packaging		
15	Nano-optoelectronics	Biophotonics, nanophotonics, nano biophotonics	Nano optoelectrionics and magnetic system, optical		

No.	Statement	Knowledge	Skill	Attitude	Other attributes
			system design		
16	Nano-scale	Micro scale, nano scale			
17	Nanostructure	Assembling of atoms and molecules, nanostructures			
18	Solid structure	Solid structure, crystal structure, photonic crystals	Crystal fabrication		
19	Electronic structure	Electronic structure			
20	Nanobiology structure	Biostructure, nanobiology structure			
21	Engineering mathematics	Engineering mathematics, advanced applied mathematics, finite element method			
22	Nanometrology		Nanometrology		
23	Calculus		Calculus		
24	Microelectromechanical system		Microelectromechanical systems (MEMS) , MEMS packaging technique、MEMS characterization technique, MEMS design		
25	Nanoelectromechanical system		Nano-electromechanical systems (NEMS), nanoenergy and electromechanical systems		
26	Nanoelectronics system		Electronic system、		

No.	Statement	Knowledge	Skill	Attitude	Other attributes
			nanoelectronics system		
27	Integrated circuits fabrication		Integrated circuits packaging, integrated circuits fabrication		
28	Integrated circuits design		Integrated circuits design		
29	Nanotransport	Transport phenomena, nanotransport	Drug delivery system		
30	Vacuum technology		Vacuum technology		
31	Clean room technology		Clean room technology		
32	Measurement technique		Radio frequency measurement technique, measurement technique		
33	Nanophotonics		Spectral analysis, optical sensing technique, optical technique, optical inspection technique、optical manufacturing technique, nano optical lithography technique, nano optical inspection technique, nano optical manufacturing technique		
34	Liquid crystal display		Liquid crystal display		
35	Bionanotechnology	Nanobiology、bionanotechnology	Nanobiology manufacturing technique, nanobiology inspection technique,		

No.	Statement	Knowledge	Skill	Attitude	Other attributes
			nanobiology lithography technique		
36	Nanofood technology		Nanofood technology		
37	Solar cell		Solar cell		
38	Environmental nano technology	Nanotechnology in the environment	Environmental nano technology		
39	Biochip	Biochip	Biochip technology, CMOS biotechnology		
40	Lab-on-a-chip	Lab-on-a-chip			
41	Microsystem chip	Microsystem chip			
42	Innovation			Innovation	
43	Independent thinking ability				Thinking ability, independent learning
44	Flexibility				Flexibility
45	Understand market trend				Understand industry development , needs, and trend
46	Solve problem ability				Discover and solve problem

No.	Statement	Knowledge	Skill	Attitude	Other attributes
					ability
47	Activeness and aggressiveness			Activeness and aggressiveness	

Appendix 4: Questions for postsorting interviews

1. For employees

- Are there any competences you haven't heard it before?
- What are the consideration points when you did sorting?
- Do you think there exist a good connection between what you learned at school and apply in the workplace?
- What capabilities do you think the schools need to pay more attention when preparing workforce who will involve in nanotechnology careers?
- What reasons do you think result in the lack of nanotechnology competences so far?

2. For professors

- Are there any competences you haven't heard it before?
- What are the consideration points when you did sorting?
- What are the advantages and weakness of present nanotechnology-related programs in Taiwan?
- Does the nanotechnology industry exist?
- Do you think the competence definition be helpful?

3. For students

- Are there any competences you haven't heard it before?
- What are the consideration points when you did sorting?
- Do you intend to involve in nanotechnology-related careers in the future?
- What reasons do you think result in the lack of nanotechnology competences so far?
- Does the specific competence definition be helpful to your future career choice and care development?