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Exploring Competencies of Nanotechnology in Higher Education in Taiwan through Curriculum Mapping*

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The present study aimed to introduce a new approach to curriculum planning for a university nanotechnology curriculum based primarily on outcome-based education according to a competence-based perspective. To achieve this study purpose, curriculum mapping was used to explore nanotechnology curricula in higher education in Taiwan. Considering, as the initial point, the competencies of varied nanotechnology that professionals are expected to develop in higher education, the main competencies were identified through the content analysis of 600 course syllabi collected from thirteen nanotechnology-related undergraduate and graduate programs in nine leading universities in Taiwan. Next, courses were further analyzed and linked to the identified nanotechnology professional competencies, taking advantage of curriculum mapping, and consequently re-organized into a comprehensive curriculum map. Implications of design features in particular and important applications of the developed curriculum map are discussed.

Keywords: curriculum mapping; nanotechnology education; outcome-based education

1. Introduction

Without a doubt, both nanoscience and nanotechnology are fast-growing fields and are known to have significant and exciting future applications in areas such as life science, medicine, and engineering. By 2015, trade in products associated with nanotechnology utilization is projected to exceed $1 trillion worldwide [1]. Accordingly, the demand for a competent workforce to fill the human resource gaps in research and manufacturing in the nanotechnology industry is only expected to grow higher over time. This expected growth implies that the workforce required to suffice and sustain the continuing growth of the nanotechnology industry will be as large as 2 million people by 2015 [1]. As a result, the number of undergraduate and graduate programs in the subject of nanotechnology and nanoscience has increased worldwide since 2000, and investment by government and private organizations has expanded in hope of meeting the needs of the nanotechnology industry.

In addition to the increasing demand for a nanotechnology workforce, other factors determine the success of nanotechnology development. Amid these concerns, the collaborative efforts of government agencies, universities, and industries play key roles in assuring the advance of this newly-emerged technology [1, 2]. Thus, to cope with the complex nature and rapid changes of nanotechnology, there is a widespread call to prepare students and practitioners with interdisciplinary perspectives [3–5]. However, training and preparing a competent workforce for the nanotechnology industry still presents the great challenge for educational institutions and human resource professionals everywhere.

While studies revolving around nanotechnology-related issues are on the increase, the majority of studies unfortunately focus on the scientific matters of nanotechnology, and few explore and address the course design for developing a nanotechnology workforce [6–10]. Many studies suggest that instructors should eliminate curriculum gaps between the knowledge/skills taught in school and those demanded by the industry [11, 12]. Thus, the present study aimed to conduct a thorough analysis of the nanotechnology curriculum available in Taiwan's universities, and to identify the expected

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discrepancies in competency between academia and industry. Curriculum mapping was utilized to explore the nanotechnology curricula from selected universities.

Curriculum mapping is a procedure for presenting a visual representation of a curriculum, based on real time information [13]. A curriculum map is regarded as a roadmap of a curriculum, guiding users through the various elements of the curriculum and their interconnections. Therefore, constructing a curriculum map is a process of considering when, how, and what is taught, as well as the assessment measures utilized to explain the achievement of expected student learning outcomes [14].

To determine the usability of a curriculum map, participants involved in constructing the map review the map to identify the strengths, gaps, and overlaps. Once the review is completed, instructors identify the focus of a given grade level, the patterns across grade levels, and the potential for interdisciplinary collaboration, and they also determine where to add or eliminate contents or strategies, leading to a more streamlined curriculum and integrated program [15, 16]. As a result, the curriculum map is viewed as a useful tool for facilitating the process of curriculum review and evaluation. Another benefit is that curriculum transparency and accessibility give stakeholders, including teachers, students, curriculum developers, managers, the public, and researchers, a broad overview of the curriculum [14, 15, 17].

Competence means the knowledge, skills, and personal attributes that employees need to possess in order to perform specific job tasks effectively. Previous research [18] divided each competence into five main components, namely knowledge, skills, rules or procedures, indicators, context. In terms of academic perspective, the nanotechnology workforce competencies can be identified through learning objectives and learning outcomes since both learning objectives and outcomes depicted by each course clearly point out the desired knowledge and capabilities students have to possess after they finish the course. Research has also shown that learning objectives are valuable references in relation to competencies when conducting curriculum evaluation [19]. Based on the consistent educational and research standpoint, this study applied outcome-based education as the core research approach.

The outcome-based education approach emphasizes learning outcomes. Outcome-based education is an approach to learning in which decisions on designing the curriculum are driven by the outcomes that students should demonstrate by the end of the course [20]. Outcome-based education provides a powerful and robust framework for creating the curriculum. It helps unify the curriculum and prevents it from becoming fragmented. More importantly, the outcome-based learning approach encourages students to take more responsibility for their own learning [20, 21].

Taking advantage of curriculum mapping and outcome-based education, the results derived from this study may allow educators to bridge the perceived gap between academia and practice in nanotechnology competencies.

2. Methodology

2.1 Data

In 2003, the government of Taiwan launched the National Science and Technology Program for Nanoscience and Nanotechnology. The Advanced Nanotechnology Education Program, one of its sub-programs, aimed to assist universities in developing interdisciplinary nanotechnology programs. Through financial support and the involvement of professional instructors, thirteen nanotechnology-related undergraduate and graduate programs were established at nine leading research universities (i.e., National Taiwan Univ., National Sun Yat-Sen Univ., National Chung Hsin Univ., National Tsing Hua Univ., National Cheng Kung Univ., National Chiao Tung Univ., National Central Univ., National Chung Cheng Univ., and National Ilan Univ.) in Taiwan. The syllabus contents of 600 courses offered by these thirteen programs were collected and analyzed. The contents analyzed included the course title, description of target learners (undergraduates and/or graduates), course outline, and course description. The results were then used to construct the curriculum map.

2.2 Inter-rater reliability

The analysis employed the following classical procedure of the content analysis method: The syllabus contents were first recorded on a standardized form by one of the researchers. Items of the form taken into consideration were developed in accordance with competence- and outcome-based education. After completion of coding, meetings were scheduled to discuss the classification to achieve inter-rater agreement. The quality of the coding was assessed by Cohen's kappa. A value of 0.8 was put forward as an acceptable criterion for inter-rater reliability. The inter-rater agreements among three raters varied from 0.80 to 0.88, and the inter-rater reliability was 0.942, which is a rather reliable level.

2.3 Content analysis

The curricula in nanotechnology programs from different universities were first mapped by course levels and domains based on the analyses of the

contents of the syllabi. Part of the map consisted of four types of subject content: (1) basic courses, (2) core courses, (3) nano-specific professional courses, and (4) nano-related professional courses. Basic courses, such as general physics, chemistry, or biology, are prerequisite or foundation courses generally required for advanced study in such fields as engineering, materials science, medicine, agriculture, and natural science. Core courses provide basic knowledge in nanotechnology, such as introductions to nano-science and technology. Nano-specific professional courses are courses offering advanced knowledge in nanotechnology. Nano-related professional courses, the last type, are commonly built upon basic courses and further linked to the advanced knowledge of other fields.
In addition, basic scientific research, materials science research, advanced technology research, resource and environmental scientific research, biotechnology research, management research, and other types comprise the seven major domains applied to analyses for curriculum mapping.

In addition to the subject contents, curriculum maps were constructed according to course levels and competencies expected to be acquired in the courses. Expected competencies were defined as the capabilities that instructors expected students to possess after they completed the courses. Conceptual knowledge covered introductory, rationale, strategic, and theoretical knowledge that interprets what or why some phenomena occur. Procedural knowledge included information on approaches, laws, principles, and methods of how to operate the instruments and systems. Operational skills were the actual abilities of manipulating experimental equipment or analytical software tools. Finally, attitude/other attributes were related to personal internal characteristics, such as independent thinking, reflection, creativity, or problem-solving abilities.

Any course reviewed could be classified into more than one category because the course contents could span multiple domains and provide different competencies. However, each course was subject only to one specific course level. According to the coding standards illustrated above, all 600 course syllabi were analyzed. Four curriculum maps of nanotechnology of the university level were constructed and verified using triangulation by three researchers with backgrounds in instructional design.

3. Results

3.1 Comparison of course levels and subject contents

Of the 600 course syllabi collected, 220 were identified as undergraduate level and 380 as graduate level. Table 1 summarizes the subject contents in relation to the program levels. Regardless of program level, courses identified as nano-related professional courses (16.66% at undergraduate level and 31.50% at graduate level, respectively) were the ones offered the most. However, the continuing order of courses differed between program levels. In the undergraduate level, basic courses (10.50%) received more attention than nano-specific professional courses (5.00%) and core courses (4.50%). In contrast, the ranking at the graduate level was the reverse: nano-specific professional courses (17.17%), then core courses (7.50%), and finally basic courses (7.17%).

3.2 Comparison of domains and subject contents

The results of curriculm map analyses by domain and subject content are displayed in Table 2 and Table 3. The findings indicate that at both the undergraduate level and the graduate level, the largest portion (close to 50%) was composed of nano-related professional courses. That group was followed by basic courses (26.12%), nano-specific professional courses (18.37%), and core courses (11.84%) at the undergraduate level, and by nano-specific professional courses (28.87%), core courses (11.51%), and basic courses (10.09%) at the graduate level.

As for the course domains, courses in basic scientific research (46.11%) received greater emphasis at the undergraduate level, followed by materials science research (27.35%) and advanced technology research (11.02%). However, greatest in terms of course amount at the gradute level was basic scientific research (37.32%), followed by advanced technology research (22.77%) and materials science research (16.43%).

3.3 Comparison of competencies and subject contents

Table 4 and Table 5 show the results of analyses of curriculum maps by competence and subject content. As seen in Table 4, conceptual knowledge (47.77%) and procedural knowledge (29.40%) pre-

Table 1. Summary of subject contents in undergraduate and graduate levels

Subject content Level	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Undergraduate	63 (10.50)	27 (4.50)	30 (5.00)	100 (16.66)	220 (36.66)
Graduate	43 (7.17)	45 (7.50)	103 (17.17)	189 (31.50)	380 (63.34)

Table 2. Analysis of undergraduate curriculum map by domain and subject content

Subject content Domain	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Basic science	60	20	2	31	113 (46.11)
Material science	0	4	14	49	67 (27.35)
Advanced technology	1	0	7	19	27 (11.02)
Resource and environmental science	0	0	1	0	1 (0.41)
Biotechnology	2	0	12	3	17 (6.94)
Management	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 3. Analysis of graduate curriculum map by domain and subject content

Subject content Domain	Basic course	Core course	Nano specific professional course	Nano related professional course	Total (%)
Basic science	37	27	19	76	159 (37.32)
Material science	3	4	35	28	70 (16.43)
Advanced technology	0	6	39	52	97 (22.77)
Resource and environmental science	0	0	7	14	21 (4.94)
Biotechnology	3	2	23	36	64 (15.02)
Management	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)

dominate in undergraduate courses. Likewise, conceptual knowledge (42.90%) and procedural knowledge (40.43%) are the main contents of graduate courses in nanotechnology programs (Table 5).

4. Discussions

A review of the literature suggested that fourteen elements, which were then categorized into four clusters, including often contribute to a curriculum map [17]. For the current study, learning outcomes and specific learning objectives were the foci, consistent with the competence- and outcome-based perspectives, to examine the nanotechnology program design. The finding indicates that nanotechnology programs in Taiwan place greater emphasis on nano-related professional courses. In fact, the percentage of nano-related courses available in nanotechnology programs was twice that of courses specifically related to nanotechnology. It is possible that nanotechnology represents a 'small-scale' field of study and is integrated into almost every engineering professional subject as a specific or advanced section of study. That is, such a program

Table 4. Analysis of undergraduate curriculum map by competence and subject content

Subject content 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)
Attitude/ 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 5. Analysis of graduate curriculum map by competence and subject content

Subject content 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)
Attitude/ other attributes	2	7	12	17	38 (5.86)
Total (%)	63 (9.72)	74 (11.42)	182 (28.09)	329 (50.77)	648 (100)

may be designed such that students first learn fundamental and some advanced subjects related to their own field of study before extending those knowledge links to the field of nanotechnology.

Selected nanotechnology programs were analyzed, and it was found that sixty-three foundation courses were generally required for students to study further in nanotechnology. These courses were further categorized into two foci of study: fostering basic skills, such as conducting and performing various experiments in labs, and developing fundamentals of scientific knowledge; e.g., physics and chemistry theory. These foundation courses are all considered to provide core knowledge that develops students' competencies for further professional development. Since 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 pursuing further studies in nanotechnology.

Clearly, basic scientific research, advanced technology research, and materials science research are the three major areas of study constituting the nanotechnology curriculum. At both the undergraduate level and the graduate level, the curriculum designers and instructors focus on introducing the basic concepts and theories of physics, biology, chemistry, and mathematics. Considering that nanotechnology is, by nature, an interdisciplinary field, it is no suprise to find such a focus. In addition, advanced technology research and materials science research are also key concerns for curriculum planning, according to the results of the present research. Advanced technology research includes many topics, such as devices, engineering, microelectronic mechanical systems, and electro-optics, while the main topic of materials science research is semiconductors. Accordingly, having various science-related studies enables students to be involved in studying nanotechnology in order to appropriately apply and integrate learned knowledge to advanced learning.

In addition, as shown in the study results, the instructors in the nanotechnology field provide students with more theoretical knowledge than operational skills. This may be due to a lack of facilities, equipment, and other infrastructure for practice. While more conceptual knowledge than procedural knowledge is taught in both undergraduate and graduate programs, the difference appears greater at the undergradute level. This finding could be explained by the differences in the design of instructional strategies and curriculum development of the courses offered at undergraduate and graduate levels. Graduate students take several prerequisite courses in conceptual knoweldge before beginning advanced studies in nanotechnology. Thus, providing graduate studens with more procedural knowledge would assist in developing their skills and abilities in problem-solving for real life.

Furthermore, few competencies related to attitude/other attributes were found. This finding is consistent with the general drawback that instructors pay more attention to the development of knowledge/skills and tend to overlook the importance of personal attributes, and it echoes the arguments of [22] that engineering education still focuses on the development of observable skills and the knowledge dimension. However, over half of competences required by the Accreditation Board for Engineering and Technology belonged to the category of attitude/other attributes [23]. The interviews conducted by [24] to examine the postgraduate researchers' experiences of researching in nanotechnology field showed that creative thinking skill is an essential competence to explore different ideas in practical work. And the international survey conducted by [25] and [26] also revealed that employers expect engineering graduates to acquire more humanistic and generic skills, rather than focusing on the application of science and mathematics. Although the results of [27] who adopted active learning methodologies in an engineering course showed that the improvement of students' time management competence was not as significant as teamwork competence, it was still a valuable example showing that instructors gradually emphasize the development of other professional attributes. To better prepare students with appropriate attitudes and mindsets toward the workplace, instructors should explain and define clearly what personal attributes are necessary for performing well in a specified field, and apply different instructional strategies to develop students' capabilities.

5. Conclusions

This exploratory study utilized curriculum mapping as a means to analyze the nanotechnology program design in Taiwan's universities in an attempt to introduce a new approach to curriculum design and development consistent with outcome-based and competence-based education. A thorough examination of nanotechnology-related undergraduate and graduate programs showed that most professional courses offered by these programs did not directly address nanotechnology. The courses for basic scientific research, materials science research, and advanced technology research are often emphasized more than others at both the undergraduate and graduate levels. In addition, instructors in the nanotechnology field tend to provide students with more knowledge than operational skills, and to de-emphsaize the competencies related to attitude/other attributes.

The development of personal attributes and the enrichment of pure science understanding are recognized in this study, from the industrial perspective, as important competencies in the nanotechnology field. Considering the competence deficiencies in the current curriculum planning of the thirteen nanotechnology programs in Taiwan, it is suggested that the balance between knowledge- and skill-oriented course contents be adjusted. Similarly, to meet employer's expectations of nanotechnology graduates, it is necessary for university courses to give greater weight to the development of personal attributes. Universities with nanotechnology programs are encouraged to establish a cross-university resource center to provide instructors with total solutions for curriculum development. Such a center would also facilitate consultations on improving nanotechnology education by offering innovative instructional strategies, integrated teaching and learning resources, and advances and benchmarking of practical experience in engineering education.

Curriculum mapping is an ongoing and dynamic process. This technique provides a mechanism for visually representing what competencies are covered, as well as areas that are potentially not sufficiently covered. It is recommended that future studies include faculty interviews to ensure the trustworthiness of the curriculum map constructed. In addition, it is necessary to conduct research on verification of nanotechnology curriculums in terms of their effects and practical outcomes.

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