Constructing a Holistic Curriculum Map for University Nanotechnology Education in Taiwan

Authors:

Yi-Lin Liu, Doctoral student, Dept. of Bio-Industry Communication & Development, National Taiwan University, Taiwan, r92630006@ntu.edu.tw
Tzy-Ling Chen, Associate Professor, Dept. of Bio-Industry and Urban-Rural Resources Management, National Chung Hsing University, Taiwan, tlchen@nchu.edu.tw
Hsiu-Ping Yueh, Professor, Dept. of Bio-Industry Communication & Development, National Taiwan University, Taiwan, yueh@ntu.edu.tw
Horn-Jiunn Sheen, Professor, Institute of Applied Mechanics, National Taiwan University, Taiwan, sheenh@spring.iam.ntu.edu.tw

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. It is estimated that by 2015, the annual global impact of products and services related to nanotechnology will exceed $1 trillion and the workforce demand of nanotechnology worldwide will be over 2 million (Roco, 2002). One of the key factors determining nanotechnology success lies in training and development of human resources at all levels, which encompass school students from K-12 to higher education, technicians, and postdoctoral fellows, etc. Attributes such as creativity of individual researchers as well as skilled workers with interdisciplinary perspectives are considered necessary for coping with the rapid changes of nanotechnology. In addition, 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. There are also some studies examining the critical skills new graduates should possess while entering nanotechnology industries, and some others focus on instructional design issues of nanotechnology course development. What seems lack of current studies is a thorough analysis of nanotechnology curriculum. Research on university nanotechnology curriculum of the present study aims to introduce new approach to curriculum planning based primarily on outcome-based education as well as competence-based perspectives. To achieve this study purpose, curriculum mapping is employed as a tool to explore nanotechnology curricula in higher education in Taiwan. Curriculum mapping built upon the mapping technique is a useful tool for the development of an integrated curriculum. By definition, a curriculum map as a diagrammatic representation displaying different elements as well as their interrelationships of curriculum can be used to ensure coherence across the integrated curriculum. This paper presents an empirical exploratory study related to the application of curriculum mapping to the design of a holistic university nanotechnology curriculum in Taiwan. Considering the competences of varied nanotechnology professionals expected to develop in higher education as the initial point, the main competences are identified through the content analysis of 536 course syllabi collected from thirteen nanotechnology-related undergraduate and graduate programs in nine leading universities in Taiwan. Next, courses are further analyzed and linked to the identified nanotechnology professional competences 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.

Index Terms — *Curriculum Mapping, Nanotechnology Education, Outcome-based Education.*

BACKGROUND

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 [18]. 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 5 million by 2015 globally [17].

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 [18]. 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 school students from K-

12 to higher education, technicians, and postdoctoral fellows, etc. 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 [11, 16, 17]. A sufficient and well-prepared workforce for research, development and production is required to achieve the potential impact of nanotechnology on our society.

As a result, 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 needed for new graduates before entering nanotechnology industries, many studies also focus on addressing the instructional design concerns related to the development of an effective nanotechnology course [13]. 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 learn [19]. Research findings also suggest that the instructors should avoid curriculum gap between knowledge/skills taught at school and those demanded by the industry [3, 12].

For bridging such a perceived gap between the academic and practice, the present study is designed to conduct a thorough analysis of nanotechnology curriculum of universities in Taiwan, and curriculum mapping is employed as a tool to explore nanotechnology curricula from selected universities. The results of this study aims to introduce a new approach to curriculum planning based primarily on outcome-based education as well as competence-based perspectives.

LITERATURE

Nanotechnology Education in University

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. Nanotechnology research and development investment has increased from $430 million in 1997 to $3 billion in 2003 worldwide [18] (Table 1).

Region	1997	1998	1999	2000	2001	2002	2003
W. Europe	126	151	179	200	~225	~400	~600
Japan	120	135	157	245	~465	~700	~10
USA	116	190	255	270	422	600	774
					(465)**	(697)**	
Others	70	83	96	110	~380	~550	~800
Total	432	559	687	825	1492	2347	2984
(% of 1997)	100%	129%	159%	191%	346%	502%	690%

TABLE 1

Estimated government nanotechnology R&D expenditures (in $ millions/year; survey August 2001).

Note: “W. Europe” includes countries in EU and Switzerland; the rate of exchange $1 = 1.1 Euro until 2002; $1 = 1 Euro in 2003; Japan rate of exchange $1 = 120 yen in 2002; “Others” include Australia, Canada, China, FSU, Korea, Singapore, Taiwan, 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.

Source: [18]

Currently, the majority of the nanotechnology workforce is semiconductor microelectronics. However, the public has started to realize that nanotechnology is broadly utilized and in fact, is critical to various fields from information storage to biotechnology. But students at the college level don’t often experience a science education or an engineering education with such broaden emphasis. Therefore, to prepare students to handle interdisciplinary knowledge and skills, colleges and universities should not only offer an extensive science and technology courses required by nanotechnology manufacturing, but also provide the state-of-art nanotechnology facilities for students to have hands-on experience [5].

In order to prepare students to gain an appreciation of other professions’ viewpoints and provide them insights in solving traditional problems through novel approaches, [15] 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. Reference [17] argued that educators 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. For graduate-level students, the first nanotechnology doctoral degree program in the United States is established in 2000 at the University of Washington [23]. The Integrative Graduate Education and Research Traineeship (IGERT) funded by the National Science Foundation (NSF) in US in 1999 is a great example, where graduate students receive fellowships for interdisciplinary topics and move under the guidance of professors with various skills and knowledge.

Curriculum mapping

The concept of curriculum mapping was pioneered by Hausman [8], and the role of computers in the process was introduced by Eisenberg [4]. Curriculum mapping is a procedure which promotes the creation of a visual representation of curriculum based on real time information [10]. A curriculum map can be seen as a roadmap of a curriculum, guiding its users 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 [6].

All participants together identifying 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 [4, 14, 22]. 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 [6, 14, 24].

Reference [6] provides a framework to describe what can be included in a curriculum map. Figure 1 represents four key components covered in a curriculum map. In this representation, learning opportunity is placed at the centre, which may include lectures, a session in the community, or an experience in laboratory. What related to learning opportunity includes: (1) the learning outcome to which the learning opportunities contributed, (2) the content in the courses, and (3) the assessment of student competence development. Evidently, the curriculum map provides a broad multidimensional overview of the curriculum and addresses the interrelations of different components involved. The emphasis placed on each of the four components characterizes different educational approaches or philosophical thoughts.

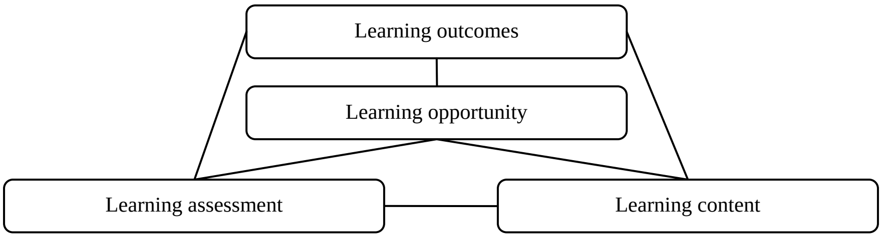

FIGURE 1
Four key areas of a curriculum map. Source: [6]

Within learning outcome dimension, outcome-based education is the main approach. Outcome-based education is an approach to learning in which decisions of designing the curriculum are driven by the outcomes that 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 becoming 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 [7, 25].

METHODOLOGY

Considering the competences of varied nanotechnology professionals expected to develop in higher education as the initial point, the curriculum maps are constructed through the content analysis of 536 course syllabi collected from thirteen nanotechnology-related undergraduate and graduate programs in nine leading universities in Taiwan. The main contents of syllabi, including course title, target learner (undergraduate and/or graduate), course outline, and course description are utilized as data of content analysis to construct the curriculum map. The analysis employs the following classical procedure suggested by the content analysis method: the syllabus contents are first recorded on a standardized form by one of the researchers, items of the form taken into considertion are developed upon perspectives of competence- and outcome-based education, and after completion of coding, several discussions about classification are held to achieve the "interrater agreement."

The nanotechnology curricula of different universities are first mapped by course levels and domains based on the content analysis of syllabi. Part of the map consisits of four course levels of the basic course, core course, nanotechnology-related professional course, and professional course not related to nanotechnology. Basic courses are those preliminary or foundation courses generally required for further course taking in field of enginerring, material science, medicine, or agriculture and natural science, etc., such as general physics, chemitry, or biology. Core courses provide basic knowledge in nanotechnology, like introduction to nano-science and technology and so on. Nanotechnology-related professional courses are courses offering advanced knowledge in nanotechnology. The courses commonly built upon basic courses and further linked to the advanced knowledge in other fields are classfied in the profesional courses not related to nanotechnology. 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 analyses for curriculum mapping.

Moreover, curriculum maps are constructed by course levels and competences expected to learn in the courses. Expected competences are capabilities that instructors expect students to possess after they accomplish the courses. Conceptual knowledge covers those of introductory, rationale, strategic and therotical 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 capabilities to manipulate experimental equipments or anytical software tools. Last, the other attributes are related to personal internal characteristics, such as independant thinking ability, creativity, or problem solving ability.

Each course under review is possibly recorded and classified into more than one category since its content may cover multiple domains and provide different competences. However, one course can only belong to one specific course level. According to the coding standards illustrated above, all 536 course syllabi are analyzed. In consequence, four curriculum maps of nanotechnology of the university level are constructed and verifieded using triangulation by three researchers with instructional design backgrounds.

RESULTS

Among 536 course syllabi collected, 390 of them belong to the graduate level and 366 syllabi are the undergraduate level. The results of curriclm map analyses by level and domain are displayed in Table 2 and Table 3. The findings show that in both the undergraduate or graduate levels, more (over 50%) are professional courses not directly related to nanotechnology. Next is the group of nanotechnology-related professional courses (about 30%), core courses (8.42%), and basic courses accordingly. As for the course domains, the courses of advanced technology research are more emphasized in both the undergraduate (36.05%) and graduate (41.69%) levels. The second in terms of course amount in the undergradute level is basic science research (31.05%), followed by material science research (21.05%). In the graduate level, courses of basic science research (23.13%), biotechnology research (15.66%) and material science research (14.46%) are also mainly focused.

level / domain	basic course	core course	nanotechnology-related professional course	professional course not related to nanotechnology	total (%)
basic science research	11	4	13	90	118 (31.05)
material science research	0	5	27	48	80 (21.05)
advanced technology research	0	22	48	67	137 (36.05)
resource and environmental science research	0	0	5	5	10 (2.63)
biotechnology research	1	1	18	9	29 (7.63)
management research	0	0	0	5	5 (1.33)
Others	0	0	1	0	1 (0.26)
total (%)	12 (3.16)	32 (8.42)	112 (29.47)	224 (58.95)	380 (100)

TABLE 2
Undergraduate curriculum map by level and domain

level domain	basic course	core course	nanotechnology-related professional course	professional course not related to nanotechnology	total (%)
basic science research	0	4	11	81	96 (23.13)
material science research	0	3	25	32	60 (14.46)
advanced technology research	0	24	59	90	173 (41.69)
resource and environmental science research	0	0	5	7	12 (2.89)
biotechnology research	0	2	32	31	65 (15.66)
management research	0	0	0	5	5 (1.20)
Others	0	2	1	1	4 (0.97)
total (%)	0 (0.00)	35 (8.43)	133 (32.05)	247 (59.52)	415 (100)

TABLE 3

Graduate curriculum map by level and domain

Table 4 and Table 5 reveal the results of analyses of curriculum maps by level and competence. As seen in Table 4, procedural knowledge (43.89%) and conceptual knowledge (43.32%) predominate the learning contents of undergraduate courses. Likewise, procedural knowledge (47.43%) and conceptual knowledge (37.70%) are also the main contents offered in the graduate courses of nanotechnology programs.

level competence	basic course	core course	nanotechnology-related professional course	professional course not related to nanotechnology	total (%)
conceptual knowledge	6	22	59	140	227 (43.32)
procedural knowledge	8	17	73	132	230 (43.89)
Operational skills	6	5	11	39	61 (11.64)
other attributes	2	0	0	4	6 (1.15)
total (%)	22 (4.20)	44 (8.40)	143 (27.29)	315 (60.11)	524 (100)

TABLE 4

Undergraduate curriculum map by level and competence

level competence	basic course	core course	nanotechnology-related professional course	professional course not related to nanotechnology	total (%)
conceptual knowledge	0	21	63	129	213 (37.70)
procedural knowledge	0	20	87	161	268 (47.43)
operational skills	0	7	15	59	81 (14.34)
other attributes	0	0	0	3	3 (0.53)
total (%)	0 (0.00)	48 (8.50)	165 (29.20)	352 (62.30)	565 (100)

TABLE 5

Graduate curriculum map by level and competence

DISCUSSION & CONCLUSION

This exploratory study aims to introduce new approach to curriculum development based on perspectives of outcome-based as well as competence-based education. To achieve the study purposes, curriculum mapping is employed as a tool to explore nanotechnology curricula in higher education in Taiwan. The curriculum map is viewed as beneficial to determining whether the components of an educational program, such as learning objectives and learning approaches, are well-designed and linked to further students' learning [2]. Although there are some studies employing curriculum mapping in different fields of medicine [1, 2, 9], education [20, 24], and ICT [21], it is still lack of a holistic curriculum map of nanotechnology in the university level. Besides, prior research on curriculum mapping has suggested 14 elements to be included in curriculum maps, and these 14 elements are further categorized into 4 clusters [24]. Among these identified 14 elements, this study merely focuses on learning outcomes and specific learning objectives, in correspondence with the competence- and outcomes-based perspectives.

From the results of this study, we find that the nanotechnology programs in Taiwan put more emphasis on professional courses not directly related to nanotechnology. The fact is the percentage of courses irrelevant to nanotechnology is nearly twice than nanotechnology-related professional courses. The reason may be that the concept of nanotechnology represents 'small-scale' and is widely employed in every engineering profession, so it is better for students to understand the advanced professional knowledge of their own fields first and then transfer what is learned into the nanotechnology field.

It is obvious that the courses of advanced technology research, basic science research, material science research, and biotechnology research are four major fields contributing to the nanotechnology curriculum. The field of advanced technology research includes varied course topics, such as devices, semiconductor engineering, microelectronic mechanical system, and electro-optics, etc.. In addition, the instructors of this field provide students with more knowledge than actual operational skills in the courses. This result may be primarily due to a lack of sufficient experimental equipments and resources for all in the nanotechnology programs. Also it is clear that the percentage of procedural knowledge taught is higher than conceptual knowledge in the graduate courses. This is reasonable since instructional strategies and curriculum are supposed to be different between the courses of undergraduate and graduate levels. As a result, when graduate students have learnt lots of preliminary conceptual knowledge in the undergraduate study, more procedural knowledge is offered as a basis for them to solve the real world problems.

Curriculum mapping is an ongoing and dynamic process. This technique provides a mechanism for visually representing what the competences are covered as well as areas that are potentially not sufficiently covered. Future study is recommended to include faculty interviews for ensuring trustworthiness of the curriculum map constructed. In addition, research on verification of nanotechnology curriculum in terms of its effects and outcomes in a practical sense is necessary.

ACKNOWLEDGEMENT

The authors would like to thank Taiwan National Science Council (NSC 98-2120-S-002-002-NM) for their grants support to this study.

REFERENCES

[1] Britton, A., Letassy, N., Medina, M. S., & Er, N., "A curriculum review and mapping process supported by an electronic database system", *American Journal of Pharmaceutical Education,* Vol 72, No5., 2008, pp1-6.

[2] Cottrell, S., Linger, B., & Shumway, J., "Using information contained in the curriculum management tool (CurrMIT) to capture opportunities for student learning and development", *Medical Teacher,* Vol 26, No 5., 2004, pp423-427.

[3] Couger, J. D., Davis, G. B., Dologite, D. G., Feinstein, D. L., & Gorgone, J. T. et al., "IS'95: Guideline for undergraduate IS curriculum", *MIS Quarterly,* Vol 19, No 3., 1995, pp341-359.

[4] Eisenberg, M., "Microcomputer-based curriculum mapping: A data management approach", Paper Presented at the Mid-Year Meeting of the American Society for Information Science. Bloomington, IN. 1984.

[5] Fonash, S. J., "Education and training of the nanotechnology workforce", *Journal of Nanoparticle Research,* Vol 3, 2001, pp79-82.

[6] Harden, R. M., "AMEE guide no.21: Curriculum mapping: A tool for transparent and authentic teaching and learning", *Medical Teacher,* Vol 23, No 2., 2001, pp123-137.

[7] Harden. R. M., Crosby, J. R., & Davis, M. H., "AMEE guide no.14: Outcome-based education: Part 1 – An introduction to outcome-based education", *Medical Teacher,* Vol 21, No 1., 1999, pp7-14.

[8] Hausman, J. J., "Mapping as an approach to curriculum planning", *Curriculum Theory Network,* Vol 4, No 2/3., 1974, pp192-198.

[9] Hege, I., Siebeck, M., & Fischer, M. R., "An online learning objectives database to map a curriculum", *Medical Education,* Vol 41, *No* 11., 2007, pp1095-1096.

[10] Jacobs, H. H., "Mapping the big picture: Integrating curriculum and assessment K-12", Alexandria, VA: Association for Supervision and Curriculum Development. 1997.

[11] Lee, C. K., Wu, M. K., & Yang, J. C., "A catalyst to change everything: MEMS/NEMS – a paradigm of Taiwan's nanotechnology program", *Journal of Nanoparticle Research,* Vol 4, No 5., 2002, pp377-386.

[12] Lee, D., Trauth, M. S., & Farewell, D., "Critical skills and knowledge requirements of IS professionals: A joint academic/industry investigation", *MIS Quarterly*, Vol 19, *No* 3., 1995, pp313-340.

[13] Luckenbill, L., Hintze, K., Ramakrishna, B. L., & Pizziconi, V., "Interactive nano-visualization in science and engineering education: Conforming technology to transform education", *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning,* Vol 1, No 2., 1999. Retrieved April 13, 2010, from http://imej.wfu.edu/articles/1999/2/09/index.asp

[14] Plaza, C. M., Draugalis, J. R., Slack, M. K., Skrepnek, G. H., & Sauer, K. A., "Curriculum mapping in program assessment and evaluation", *American Journal of Pharmaceutical Education,* Vol 71, No 2., 2007, pp1-8.

[15] Porter, L. A., "Chemical nanotechnology: A liberal arts approach to a basic course in emerging interdisciplinary science and technology", *Journal of Chemical Education,* Vol 84, No 2, 2007, pp259-264.

[16] Roco, M. C., "Nanotechnology – a frontier for engineering education", *International Journal of Engineering Education,* Vol 18, No 5, 2002, pp1-15.

[17] Roco, M. C., "Converging science and technology at the nanoscale: Opportunities for education and training", *Nature Biotechnology,* Vol 21, No 10, 2003a, pp1247-1249.

[18] Roco, M. C., "Broader societal issues of nanotechnology", *Journal of Nanoparticle Research,* Vol 5, No 3/4., 2003b, pp1818-189.

[19] Stoof, A., Martens, R. L., Merrienboer, J. J. G., & Bastiaens, T. J., "The boundary approach of competence: A constructivist aid for understanding and using the concept of competence", *Human Resource Development Review,* Vol 1, *No* 3., 2002, pp345-365.

[20] Sumsion, J. & Goodfellow, J., "Identifying generic skills through curriculum mapping: A critical evaluation", *Higher Education Research & Development,* Vol 23, No 3., 2004, pp329-346.

[21] Toral, S. L., Martinez-Torres, M. R., Barrero, F., Gallardo, S., & Ayala, E. V., "Planning a master's level curriculum according to career space recommendations using concept mapping techniques", *International Journal of Technology and Design Education,* Vol 16, No 3., 2006, pp237-252.

[22] Uchiyama, K. P., & Radin, J. L., "Curriculum mapping in higher education: A vehicle for collaboration", *Innovative Higher Education,* Vol 33, No 4., 2009, pp271-280.

[23] University of Washington, "Education", 2010. Retrieved January 18, 2010, from http://www.nano.washington.edu/education/index.html

[24] Willett, T. G., "Current status of curriculum mapping in Canada and the UK", *Medical Education,* Vol 42, No 8., 2008, pp786-793.

[25] Willett, T. G., Marshall, K. C., Broudo, M., & Clarke, M., "TIME as a generic index for outcome-based medical education", *Medical teacher, Vol 29*, No 7., 2007, pp655-659.