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Identifying the Threshold Concept of Learning Nano-Science and Nano-Technology in Material Engineering by Curriculum Map

Tzy-Ling Chen*, Yi-Lin Liu, Hsiu-Ping Yueh**, & Horn-Jiunn Sheen*****

* Graduate Institute of Bio-Industry Management, National Chung Hsing University
** Dept. of Bio-Industry Communication & Development, National Taiwan University
*** Institute of Applied Mechanics, National Taiwan University
Correspondence author email: yueh@ntu.edu.tw

Abstract

The purpose of this study is to introduce new approach to university nano-science/technology curriculum planning based primarily on the threshold concept. Curriculum mapping is employed to explore curricula in the field of nano-related material engineering. Data are derived from 137 course syllabi of twelve Taiwan nano-science/technology undergraduate and graduate programs. In addition, semi-structured interviews with the instructors and program coordinators are conducted. Findings suggested that the “nano-scale” or “small-scale” is pivotal to a better understanding and successful learning of nano-science/technology. In conclusion, the implications of instructional design features as well as exploited threshold concepts for the preparation of nano-science/technology education are discussed.

Keywords **:** curriculum map, threshold concepts, nano science, nano technology, material engineering

INTRODUCTION

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, 2003b). 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 shows there will be openings approximately 5 million by 2015 globally (Roco, 2003a).

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). 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 (Lee, Wu, & Yang, 2002; Roco, 2002, 2003a). 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 (Luckenbill, Hintze, Ramakrishna, & Pizziconi, 1999). What seems lack of in current studies is a thorough analysis of curricula developed for nanotechnology learning. Research on university nano-science/technology curriculum of the present study aims to introduce new approach to curriculum planning based primarily on the threshold concept.

Threshold concepts are defined as concepts that bind a subject together, being fundamental to ways of thinking and practicing in that discipline (Mayer & Land, 2003). Threshold concepts offer potential help to instructors in higher education to tackle two widely reported problems, including students can not apply the knowledge outside the classroom and unable to use the knowledge in conjunction. Once students internalized threshold concepts, they are more able to integrate different aspects of a subject in their analysis of problems, and to see the relevance between related disciplines (Land, Cousin, Mayer, & Davies, 2005; Worsley, Bulmer, & O’Brien, 2008). Besides, threshold concepts also can help instructors manage the ever-growing curriculum. If instructors can identify a relatively small number of threshold concepts within the curriculum, they can make refined decisions about what is fundamental to a grasp of the subject they are teaching. Contrarily, if instructors do not pay attention to introducing these concepts to our students and monitoring their understanding, students may fail to move on, or move on only with surface knowledge of the concept. Therefore, it is a "less is more" approach to curriculum design (Boustedt et al, 2007; Cousin, 2006; Trend, 2009). In the present study, the aim is to explore and identify the threshold concepts of learning nano-science/technology. To achieve this study purpose, curriculum mapping is employed as a tool to explore nano-science/technology curricula in the field of material engineering.

LITERATURE REVIEW

Threshold Concept

The threshold concept was first proposed by Mayer and Land (2003) as a way of characterizing particular concepts that might be used to organize the educational process. A threshold concept can be "considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress." The transformation may be sudden or it may progress over a period of time. Such a transformed view represents how people think in a particular discipline or how they perceive, apprehend, or experience particular phenomena within that discipline. Hence, threshold concepts reveal the relationship between big shifts in thinking in the subject and transformative changes that learners have to experience in their thinking (Davies & Mangan, 2007).

Although the threshold concept is new to instructors, a number of disciplines, including computer science, information science, economics, networked learning, marketing, mathematics, statistics, and geosciences, have begun the process of identifying threshold concepts and investigating how to take advantage of them to improve student learning (Boustedt et al, 2007; Cope & Staehr, 2008; Davies & Mangan, 2007; Dunne, Low, & Ardington, 2003; Khalife, 2006; Kligyte, 2009; Lye, 2006; Rountree & Rountree, 2009; Trend, 2009; Worsley, Bulmer, & O'Brien, 2008).

The conceptual framework is different between threshold concepts and learning outcomes (Rountree & Rountree, 2009). Learning outcomes treat education as a set of activities designed to achieve pre-specified outcomes, with success defined in terms of meeting those outcomes. On the other hand, threshold concepts emphasize that students go through a transformation, and after that they begin to "think like a specialist." Similarly, there is common confusion about the difference between core concepts and threshold concepts. All threshold concepts are core concepts, but not all core concepts are threshold concepts (Rountree & Rountree, 2009). A core concept is a conceptual building block that it has to be understood but does not necessarily lead to a qualitatively different view of the subject matter. However, across a range of subject contexts, the general characteristics of threshold concepts are transformative, irreversible, integrative, bounded, and potentially troublesome (Mayer & Land, 2003).

The shift in perspective may lead to a transformation of personal identity, a reconstruction of subjectivity, even shift in values, feelings or attitudes. New understandings are assimilated into our biography, becoming part of what we are, how we see and how we feel. Irreversible means that the change of perspective caused by acquisition of threshold concepts is unlikely to be forgotten, or will be unlearned only by considerable efforts. Learning involves the occupation of a liminal space during the process of mastery of a threshold concept. This space is similar to the one occupied by adolescents who are not yet adults, not quite children. It is an unstable space in which the learner may oscillate between old and emergent understandings, just as adolescents often move between adult – like and child – like responses to their transitional status. Once a learner enters this liminal space, he/she is engaged with the project of mastery. Besides, threshold concepts also expose the previously hidden interrelatedness of something, and helps delimit the boundaries of a subject because it integrates a particular set of concepts, beliefs and theories. The stronger the integration, the sharper the boundaries of a subject; the looser the integration, the more the boundaries of a subject become open to debate (Mayer & Land, 2003). Finally, threshold concepts generally appear to be alien, incoherent, or counter-intuitive for learners. That is, threshold concepts are often fundamental concepts for which learners may express a tacit understanding, yet learners have difficulty applying them to real life, have little evidence for, or have little understanding of the origin of the ideas (Perkins, 1999).

Threshold concept research offers a way of transactional curriculum inquiry in which all the key players, such as subject specialists, academics, students, and educationalists, can work iteratively together to explore the complexity of the subject, generate dialogues among them, as well as allow them to focus on the subject rather than on general education theory (Cousin, 2007, 2010). According to Boustedt et al. (2007) and Kligyte (2009), the threshold concept enables curriculum developers to focus on long-term change, recognize students who are in the liminal space, and create opportunities for them to approach the threshold concepts in iterations. Mayer and Land (2003) also points out that a discipline may have a number of threshold concepts. Similarly, based on Kinchin (2010), the consideration of threshold concepts at different levels of resolution (macro and micro) suggests that students need to cross many threshold concepts of the macro level before making the transition to higher level learning of a particular subject. These macro threshold concepts should form the core of the subject's basic curriculum. Acknowledgement of such a web of threshold concepts may help to establish greater disciplinary continuity for students making the transition from basic to more advanced learning. In this sense, the primary goal of the present study is to solicit the macro level of threshold concepts related to nano-science/technology taking advantage of material engineering as a case.

Curriculum Mapping

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). 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 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 achievements of expected student learning outcomes (Harden, 2001).

All participants involving in curriculum development together identify 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, and the curriculum transparency and accessibility giving stakeholders, including teachers, students, curriculum developers, managers, public and researchers, a broad overview of the curriculum (Harden, 2001; Plaza et al., 2007; Willett, 2008).

Curriculum mapping is an essential tool for the development and implementation of a curriculum in higher education. Mapping not only assists the planning and implementation of a 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 to 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).

By acknowledgment 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. Plaza et al. (2007) employed a descriptive cross-sectional study design based on learning outcome 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). Cottrell, Linger, and Shumway (2004) adopted competence-based framework to map the undergraduate medical school curriculum at West Virginia University.

In addition to identifying the specific competences expected to be developed by the students taught, some researchers focused on identification of generic skills through curriculum mapping. The process of curriculum mapping enables researchers to identify general patterns within the undergraduate education program in relation to the promotion of generic skills, as well as provides faculty members valuable opportunities to reflect on their course and assists them to identify directions for further pursuit (Sumsion & Goodfellow, 2004). Also in this research, curriculum mapping built upon the mapping technique is recognized as a useful tool for elicitation of the threshold concept from an integrated curriculum related to nano-science/technology.

METHODOLOGY

Since there is still no consistent agreement on appropriate methodology to identify threshold concepts among researchers, different strategies are developed. Davies (2006) suggested two methods for recognizing the threshold concept within a discipline. The first approach argues that the threshold concept can be recognized by examining different ways in which two disciplines analyze the same situation. And the second approach focuses on the distinction between people inside and outside the community of practice, specifically, in the differing ways in which students and experts in the discipline analyze the same problem. Even though examining the different ways of which practitioners in related disciplines use to solve similar problems may produce excellent candidates for threshold concepts in each discipline, it opens up a research question concerning whether threshold concepts are shared between disciplines, and whether threshold concepts mutate as they cross between disciplines (Rountree & Rountree, 2009). Additionally, Davies and Mangan (2007) advised that to explore a distinction among basic, discipline, and procedural concepts may be useful in determining a framework for the identification of threshold concepts. Boustedt et al. (2007) and Worsley et al. (2008) utilized interviews, surveys, and course documents to gather data from instructors and/or students for investigation. Cope and Staehr (2008) first identified possible candidates of threshold concepts, then verified them based on an analysis of the general characteristics of threshold concepts proposed in the literature. Cousin (2010) further delineated that the point of threshold concept research is to share an inquiry into the difficulty of their subject *with* the academics and students. It is student-focused but not student-centered in ways that remove the academics from the stage. In other words, it is unlike phenomenographic research centered *on* the students so that once data obtained from students may heighten the risk of the students' experience being interpreted through the researchers' "eyes" or viewpoints.

Taking into consideration the above mentioned and research attempts of this study, content analysis and interview method pertaining to qualitative research is employed for data collection. Data are derived from 137course syllabi of twelve nano-science/technology undergraduate and graduate programs in the field of material engineering from nine leading universities in Taiwan. Items analyzed include course title, description, objective, and outline. Curriculum maps are then constructed based on the results of analyses.

The curriculum was first mapped by course attributes. There are four categories identified based on the course attributs, consisting of the basic course, core course, nano-related professional course, and non nano-related professional course. Basic courses are the fundemental courses realted to surface physics and material science, which does not belong to nano-science/technology field. Core courses provide basic knowledge in nano-science/technology, like introduction to nano-science and technology. Nano-related professional courses are those that offer advanced knowledge in nano-science/technology. And courses built upon basic sciences and integrated with adnanced knowledge in other fields of science and engineering are classfied into the category of non nano-related profesional courses.

Curriculum maps are also constructed by the expected competences to be learned in the courses. By definition, expected competences are capabilities that instructors expect students to possess after they finish the course. Four competence categoires are concluded in this study. Conceptual knowledge is introductory and therotical knowledge, in respond to what or why some phenomenon happened. Procedural knowledge includes the knowledge about theories and methods to operate instruments and systems. Operational skills are the actual capabilities to manipulate an experimental equipment or anytical software. And other ability attributes are something related to personal internal characteristics, such as the abilities of independant thinking, creativity, or problem-solving and so on.

Each course analyzed might be classified into more than one competence category since all the course cross varied domains and provide different competences. However, one course can only belong to one specific course attribute category. After completion of coding, several discussions about coding and classification are held to achieve the "inter-rater agreement." The quality of the coding was assessed by determining Cronbach alpha. A value of 0.8 was put forward as an acceptable criterion for inter-rater reliability. The inter-rater agreements among three raters with instructional design backgrounds varied from 0.80 to 0.88, and the inter-rater reliability, the value of Cronbach alpha was 0.942 which attained a rather high reliable level.

In addition, several semi-structured interviews with the instructors and one program coordinator of nano-science/technology are conducted. Interviews carried out in the current study are mixed with the semi-structured and informal aiming at clarification and elaboration of the results of content analysis and curriculum maps. Strategies of triangulation using multiple viewpoints, member checks as well as peer debriefing of three co-researchers are applied to the establishment of trustworthiness of this research.

RESULTS

Among 137 course syllabi analyzed, 67 of them belong to the undergraduate level and 70 syllabi are the graduate level. Table 1 shows the summary of course attribute identified in the analyzed courses by undergraduate and graduate levels. As revealed, more than half the courses (56.20%) in the curriculum of nano-science/technology in field of material engineering are none nano-related professional courses, following by nanotechnology-related professional courses (35.77%) and core courses (5.84%).

Results of further analyses of two curriculum maps by course attribute and expected competence are displayed in Table 2 and Table 3. For the courses offered in undergraduate level, conceptual knowledge (47.14%) is more emphasized than procedual knowledge (35.77%), operational skills (8.94%), and other attributes (8.13%). However, the conceptual knowledge (47.96%) and procedual knowledge (43.90%) are both concered in graduate courses, and operational skills (4.07%) and other attributes (4.07%) are less mentioned.

Further exploration of the conception of nano-science/technology using both semi-structured and informal interviews and comparative analyses is proceeded. Initial findings based on the analyses of curriculum maps and interviews are concluded in Table 4. Four typologies of conception are viewed critical to transformative learning of nano-science/technology according to the results of comparative analyses. Interpretations of the conception of fundamental, science, technology, and application are also illuminated by the description of its essence and by representation of aspect of variation based on iterative comparisons among different layers of coded themes. Additionally, the curriculum maps are included for analysis. Over half of the courses of nano-material engineering regardless of the basics or operation are considered pertaining to the fundamental and application unrelated to property change, 31.16% and 22.79%, respectively. And 46.05% of courses linked to property change.

Table 1: Summary of course attribute by undergraduate and graduate levels.

Level Course	Undergraduate level	Graduate level	Total (%)
Basic	0	3	3 (2.19)
Core	4	4	8 (5.84)
Nano-related	14	35	49 (35.77)
Non nano-related	49	28	77 (56.20)
Total (%)	67 (48.91)	70 (51.09)	137 (100)

Table 2: Undergraduate curriculum map by course attribute and expected competence.

Competence Course	Conceptual knowledge	Procedural knowledge	Operational Skill	Other attributes	Total (%)
Basic	0	0	0	0	0 (0.00)
Core	4	2	0	1	7 (5.69)
Nano-related	12	12	1	1	26 (21.14)
Non nano-related	42	30	10	8	90 (73.17)
Total (%)	58 (47.14)	44 (35.77)	11 (8.94)	10 (8.13)	123 (100)

Table 3: Graduate curriculum map by course attribute and expected competence.

Competence Course	Conceptual Knowledge	Procedural knowledge	Operational Skill	Other attributes	Total (%)
Basic	3	1	0	0	4 (3.25)
Core	3	4	2	0	9 (7.32)
Nano-related	31	31	3	3	68 (55.28)
Non nano-related	22	18	0	2	42 (34.15)
Total (%)	59 (47.96)	54 (43.90)	5 (4.07)	5 (4.07)	123 (100)

Table 4：Typology of conception of nano-science/tech.

Type of conception	Fundamental	Science	Technology	Application
Course frequency	67 (31.16%)	50 (23.26%)	49 (22.79%)	49 (22.79%)
Description	Interpreted as the basics unrelated to property change	Interpreted as the basics related to property change	Interpreted as the operation related to property change	Interpreted as the operation unrelated to property change
Aspect of variation		Related to property change		
	Basics		Operation	

DISCUSSION

The results showed that the numbers of nanotechnology professional courses are nearly triple than nanotechnology-related professional courses in undergraduate level. However, the amount of nanotechnology-related professional courses is more in graduate level. This may be reasonable since nanotechnology is an interdisciplinary profession in which the concept of nano can be utilized across varied engineering fields. It is better for students to have the prerequisite backgrounds and become specialized in their undergraduate majors to further integrate what have been learned with nano-related knowledge for extended applications in graduate level of studies. Besides, the results also indicate relatively few core courses are offered in the curriculum of nano-material engineering, and in fact, not every university investigated offers the core course. This evokes the doubt of what exactly nano-science/technology consists in the sense of epistemology.

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. 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). 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.

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.

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 innovation, activeness and aggressiveness, flexibility, and understanding of market trends are pivotal nanotechnology workforce competences (Liu, Chen, Yueh, & Sheen, 2010). Instructors are encouraged to apply varied instructional strategies to offering students the opportunities to exercise these unique 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.

Based on the findings of this study, although concepts, such as surface area, surface force, surface energy, small scale, and nano scale, etc. elicited remain vague to some extents, what is clear is the phenomenological essence underlying the conception of nano-science/technology seems related to property change. Built upon such reasoning mechanism, the threshold concept of “nano-scale” or “small-scale” is particularly suggested as pivotal to a better understanding and critical to students’ successful learning of nano-science/technology as to the field of material engineering.

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). Even the concept of nano-scale was first brought up in 1959 by Feynman, its promotion and research investment by National Science Foundation in US actually started in 1997 (Roco, 2004). Also most of its research is application-oriented; thus, the conception of nano-scale may be troublesome for students to learn since it remains somehow alien.

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.

In practice, when integrating any threshold concept in curriculum development, it requires use of different application strategies since what is a threshold concept for one person, may not be for another (Rountree & Rountree, 2009). Due to the level of resolution or transformative characteristics of threshold concepts (Boustedt et al, 2007; Davies & Mangan, 2007), for a better fit in multiple courses, it is necessary to revisit the same threshold concepts incorporated in the instruction from time to time because the concept itself may subsequently be transformed through the acquisition of further threshold concepts.

CONCLUSION

The application of curriculum map in the present study is considered beneficial and successful. An interview probing based on what is presented in the curriculum map also turns out appropriate, but the most critical of all is that iterative nature of continuous dialogues and reflexivity allows us to further unveil the academic conceptions simultaneously eliciting the threshold concepts based on experienced experts’ points of view. However, it is necessary to also be alert, as advised by

Dunne et al. (2003) that an essential element of threshold concepts is defined mainly by the subjective experience in acquiring it instead of an objective analytical process. In this sense, the findings of the present case study of material engineering field still need to be confirmed. Further research involving varied student groups for investigation is recommended.

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AUTHORS

Tzy-Ling Chen received the B.S. degree in Agricultural Extension from National Taiwan University in 1994, M.S. and Ph.D. degrees in Adult Education from Pennsylvania State University in 1997 and 1999, respectively. She started as an Assistant Professor at the National Chung Hsing University in 2000, was promoted to Associate Professor in 2006.

Yi-Lin Liu received the B. S. degree and M.S. degree in Agricultural Extension from National Taiwan University in 2003 and 2005, respectively. She started her doctoral study in 2006, and currently is a Ph.D. candidate at Department of Bio-Industry Communication & Development, College of Bio-Resource & Agriculture, National Taiwan University.

Hsiu-Ping Yueh received the B.S. degree in Psychology from National Taiwan University in 1992, M.Ed. degree in Instructional Systems and M.S. degree in Educational Psychology from Pennsylvania State University in 1994 and 1996, respectively. In 1997, she received her Ph.D. degree in Instructional Systems from Pennsylvania State University. She started as an Assistant Professor in 1997, Associate Professor in 2001, and was promoted to Professor in 2009 at the National Taiwan University. Currently, she is the Professor and Chair of Department of Bio-Industry Communication & Development, College of Bio-Resource & Agriculture, National Taiwan University.

Horn-Jiunn Sheen received the B.S. degree in Power Mechanical Engineering from National Tsing-Hua University, Taiwan in 1978, M.S. and Ph.D. degrees in Mechanical Engineering from State University of New York, Stony Brook, in 1983 and 1987, respectively. He started as an Associate Professor in 1987, and was promoted to Professor in 1998 at the Institute of Applied Mechanics, National Taiwan University.