Mei-Hung Chiu *Editor*

# Science Education Research and Practices in Taiwan

## Challenges and Opportunities

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# Preface

## The Goals of This Book

The aim of this book is not only to present the efforts and research that science educators in Taiwan have accomplished in the past but also to positively influence science education researchers, educational practitioners, and even policy makers to ponder how to implement the outcomes of research in practice, and how science education research can influence students' learning and teachers' teaching in the context of science and to educate our next generation with high quality of scientific literacy to leave them well-equipped to face the twenty-first century.

Finally, I hope this book ignites people's interest in conducting science education research and then putting it into practice to change the climate in school science teaching and learning. I also hope policy makers take evidence-based research into account when they make decisions about science educational reforms for the sake of motivating students' interest in learning sciences, facilitating teachers' instruction, and helping people enjoy the wonderful journey of learning sciences, as well as for the public to gain a positive perception of science and to appreciate science enterprise globally. I intend this volume to be a comprehensive first step in addressing the role of Taiwan in science education research in the past, present, and future.

M.-H. Chiu

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I thank all of the authors who committed to contribute to this work. It has been a privilege to collaborate with all the authors on this book. Without their contributions, we could not have presented this book to you in its current format. I would also like to extend my appreciation to Springer Publishers, who have been supportive to make this book possible. Of course, the long term financial support for science education researchers to conduct research in Taiwan coming from Department of International Collaboration and Science Education of Ministry of Science and Technology (formally as Department of Science Education of National Science Council) in Taiwan is highly appreciated.

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# Chapter 1
# Introduction: Science Education Research and Practice in Taiwan: A Little Giant!

**Mei-Hung Chiu**

**Abstract** This chapter describes the structure of this book and its four main sections: Overview of Science Education in Taiwan, Science Learning and Assessment, Innovative Technology for Science Learning and Instruction, and Curriculum and Teacher Professional Development. Also, this chapter highlights the scope of this work and the specific goals it sets out to meet for the readers.

## 1.1 Background of Taiwan

The Republic of China (ROC) was established in China in 1912. Due to a long history of political issues and civil war, its government relocated to Taiwan in 1949 and its territory confined to the island of Taiwan and a few small islands surrounding the main island. Taiwan has an area of about 36,000 $km^2$, which is close to the size of the Netherlands in Europe or slightly larger than Maryland in the USA. When the Portuguese sailed past it in the seventeenth century (1642), they exclaimed "ilha formosa!," or "beautiful island," a name most Westerners used till the end of World War II. After the war, Taiwan underwent rapid economic and industrial growth. According to *The Global Competitiveness Report 2013–2014*, Taiwan was ranked 13th out of 144 countries on the global competitiveness index (GCI) for 2012–2013 and 12th out of 148 countries for 2013–2014 (Schwab 2013). Its performance has been very stable and consistently strong over the past 5 years (Schwab 2013). Notable strengths include the capacity of Taiwanese businesses to innovate (8th), its highly efficient goods markets (7th), and its world-class primary education (9th) and higher education (11th). This growth also spurred research and development.

Currently, Taiwan has a population of about 23 million people, including majority of Han Chinese ethnicity and few indigenous people (2 %), which is divided into 14 major groups. Mandarin is the official national language and spoken by majority of the population in Taiwan. The written language comprises complex Chinese characters. The philosophy of Taiwan has been influenced by the long history of Confucianism and newly developed neo-Confucianism that aim for guiding people

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for goodness and moral perfection, as well as pursuing harmony and peace of the society, different cultures, and the universe. In the past decades, feminism, constructivism, postmodernism, human rights, educational reforms, and environmental issues also influenced our society in various ways.

As for education, Taiwan launched 9-year compulsory education in 1968 and will be 12-year compulsory education in 2015. The compulsory educational system in Taiwan consists of three levels: elementary (grades 1–6, aged 6–12), junior high (grades 7–9, aged 13–15), and senior high school (grades 10–12, aged 16–18). The number of students attending elementary school and number of teachers have been decreasing in the past few years. This phenomenon will become apparent within the upcoming 10 years. In particular, the imbalance between the need for and the supply of teachers has been an issue for teacher education programs (Chiu 2010).

In 1979, Science Education Advisory Committee was established and it was mandatory to provide guidance for the directions of science education policies by the Ministry of Education. However, most of the reforms were mainly emphasized on development of curriculum standards (Cheng 2005). Curriculum standards are designed to guide school instructions, textbook designs, assessment, learning outcomes, and more importantly, they act as the guidelines for high-stakes entrance examinations, which are influential to assess students' academic performance and to screen them for entering high schools and universities within the educational system. In Chinese culture, academic performance is very important to many families and people, therefore, providing standards (or so called as guidelines for curriculum) to ensure the equity and quality of education becomes a major effort for educational reform.

In 2002, the first national conference on science education was held to discuss the reform for science education and the White Paper on Science Education (Ministry of Education 2003) was released to highlight the value and effort for promoting science education research and practice and also several related issues raised to fulfill the societal needs. In the past years, several related issues (such as evaluation standards for science education, establishment of center for development of teaching materials, and promoting public understanding of science).

While it is no longer a secret that Asian countries outperform other countries on the TIMSS and PISA international assessments (e.g., Anderson et al. 2010; Anderson et al. 2007; Yore et al. 2010), Taiwan (Chinese Taipei) was not an exception in these international studies (ranking 4th in 2006, 12th in 2009, and 13th in 2012 on PISA science). In general, Taiwan demonstrates high mean performance and high self-efficacy in science. Also, it was reported that statistically, the relationship between performance and socioeconomic background in Taiwan was not significantly different from the OECD average. However, Taiwan had a high total between-school and within-school variance compared to the OECD average. Moreover, from the analysis of index of general interest in science in Taiwan, it is reported that students were either close to the OECD average or below average (OECD 2007a, b). Similar negative results were found in self-concept in science. Therefore, school science curricula appear to emphasize domain-specific subjects rather than scientific competencies that are related to inquiry, nature of science, and problem-solving. Expectations from teachers, parents, and society in Taiwan might reflect different educational goals compared to Western countries.

Based upon a series of content analysis of publication in selected journals, Taiwan was ranked as one of the top ten countries in research publications since 1999 (Tsai and Wen 2005; Lee et al. 2009) and even acquired third position in the world in 2005 and 2007 (Lee et al. 2009). What did science education researchers in Taiwan accomplish and what contribution did they make to enlighten researchers and practitioners in science education? With this retrospective and reflective manner as a guide, a series of selected topics in science education were chosen for this edited book that might shed light to our understanding of science education research in this context and factors influencing the research. Hopefully, the chapters of this book could also present global concerns on science education enterprise.

## 1.2 The Structure of the Book

The authors invited to contribute to this book were asked to orient their chapter around a particular aspect of science education in Taiwan such as the development of science education research, cognitive learning and assessment in science education, innovative technology in science learning, and teacher professional development. As a consequence, we have 21 very different chapters organized into five sections that show the development and progress of science education in Taiwan. Also, four experienced and well-known international science education scholars commented on clusters of chapters within a section to provide their professional opinions on a specific research area presented. These commentaries intended to provide comments on the existing research conducted by scholars in Taiwan in the past from a perspective of mutual interest in science education, and to pinpoint some possible visions from their professional expertise as global researchers. In addition, there is a chapter prepared by the science education editors of *International Journal of Science and Mathematics Education* (IJSME) sponsored by Ministry of Science and Technology in Taiwan (previously known as the National Science Council) that was launched in 2003. IJSME received its first SSCI impact factor (IF) in 2012 in the Social Sciences Citation Index (Thomson Reuters) with IF of 0.460 in 2012 and 0.636 in 2013. Their experiences and reflections of working as senior editors of IJSME and with local scholars tell part of the story of science education in Taiwan. Finally, a collection of reflections from scholars who have been to Taiwan were presented to depict their thoughts and experiences working with scholars and students in Taiwan which I am grateful for their contribution.

### *1.2.1 Section One: Overview of Science Education in Taiwan*

The development of science education research was highly influenced by the country's growing societal and economic status, which allowed for the capacity of institutes to be expanded. Taiwan was fortunate to have experienced an economic boom in the late 1980s. Science education research has benefited from this rapid economic growth. Guo and Chiu (Chap. 2) reviewed governmental documents and academic reports on science education during 1982–2012 and provided historical points of view on the progress of science education research in Taiwan. They argued that the findings and successes from the research of the last 30 years were attributed to factors such as government financial support, local scholars' deep involvement, a formal evaluation system of researchers' academic contributions, and interaction with international scholars. The retrospective reviews allow readers to look back at the history of science education in Taiwan as well as look forward into the possible impacts and challenges of international and local publications.

Chiu, Tam, and Yen (Chap. 3) analyzed 394 articles published in *Chinese Journal of Science Education* (CJSE), the official journal of the Chinese Association for Science Education in Taiwan, from 1993 to 2012. The findings revealed that a majority of articles were empirical studies, and among them, 34.5 % were related to learning. In contrast, relatively low percentages of studies were in the areas of informal learning (1.8 %) and text and textbook analysis (1.0 %). The major trend of science education research in CJSE was aligned with estabhlished international research trends. The authors point out that the most challenging tasks might be to have science education research contribute both to local and international journals and put research outcomes into practice.

Finally, Duit (Chap. 4) commented on the two chapters and highlighted the challenges of the role of English as lingua franca for many non-English speakers. He further pinpointed the influential elements of the development of science education research as well as challenged the future direction of science education to be developed in Taiwan.

### *1.2.2 Section Two: Science Learning and Assessment*

Science learning and assessment has been one of the research emphases of science education research (Driver et al. 1994; Gabel 1994). Over the past three decades, research on students' learning has moved from behaviorism, to constructivism, to social constructivism (Duit and Treagust 1998). These changes also influenced the sub-domain of students' learning, namely conceptual change, which has moved from epistemological aspects dominated by Posner et al. (1982) and motivational aspects by Pintrich et al. (e.g., Pintrich et al. 1993; Sinatra and Pintrich 2003) to multidimensional aspects by Duit and Treagust (2003) and Treagust and Duit (2008). Chiu, Lin, and Chou (Chap. 5) analyzed 383 articles that appeared in the four major science education journals and 86 articles from CJSE (discussed in Chap. 3 in this book). The analyses showed that there were more publications on developing and implementing pedagogical instruction in school practice than on exploring or empowering theoretical frameworks for research in the science learning processes and products in both international journals and CJSE. Approximately, about 30 % of the studies on conceptual change were in physics education, followed by biology and chemistry in the international journals. Meanwhile, in CJSE, about one third of the research was in the area of physics, followed by earth science, chemistry, and biology. Taiwan, a non-English speaking country, was ranked third as a contributing country by first or correspondence authors for the period of 1982–2012. Following up on the content analysis by Chiu et al. discussed above, Yang (Chap. 6) analyzed 106 articles published in the area of learners' epistemic beliefs and their effects on science learning. Specifically, it was shown that students' epistemic beliefs were influenced differently based on the cultural context types of their country. Comparing data from three countries, namely, Taiwan, the US, and Turkey, it was found that in lower-context culture countries, such as Taiwan and the USA, students were more easily influenced by instructional interventions than were students from higher-context culture countries such as Turkey. Interestingly, lower-context countries were also more likely to believe in one's innate ability than higher-context countries. A deeper look into the differences seems like a worthy topic for further research.

In Chap. 7, Tam, elaborates on how and why the two-tier item design, that were used to diagnose elementary, middle, and secondary students' conceptual understanding in science, can serve the purpose of diagnosing students' conceptions, and what limitations this research method might have.

Finally, Lu and Lien (Chap. 8) uncovered the factors that attributed to the outstanding performance in science on TIMSS by Taiwan's fourth graders. Traits such as adequate school infrastructure, emphasis on physical sciences in the textbooks, and focus on carrying out experiments were found to be key features in Taiwanese elementary school science lessons. Additional features such as less emphasis on memorization were also listed for further research.

Treagust (Chap. 9) commented on the four chapters in this section with different perspective on the issues related to science learning. He drew some conclusions and made suggestions for future direction of science education for each chapter.

### *1.2.3 Section Three: Innovative Technology for Science Learning and Instruction*

The positive influences on innovative technology on science learning seem no longer to be questionable in science education research. Lin and Tsai (Chap. 10) conducted a review and analysis of technology-assisted science learning studies from Taiwan. It was found that there was a shift to mobile technology in Taiwan and a predilection for quantitative and experimental research methods. Hsu and Wu (Chap. 11) developed a technology-infused learning environment to arouse students' learning motivation and cultivate their inquiry skills. They took seasons, air pollution, and water reservoirs as real-life examples to illustrate how to design technology-rich materials to facilitate students' conceptual understanding and development as independent learners. More recently, there have been new trends in conducting science education, namely EEG and eye tracking, which were widely used in psychology and neuroscience research. Liu and Huang (Chap. 12), with a particular interest in the role of brain waves, investigated how brain waves could be used in interpreting learners' cognitive learning in science. They argued that neuroscience data can provide researchers with an objective measure of science learning. If this objective measure is available for more researchers to explain how and why learners have difficulty in learning science, successful and effective instruction can be designed to facilitate our understanding of the obstacles in learning science.

Eye tracking techniques used in science education are one of the current trends in science education. These techniques were used to depict the degree of attention in reading or other cognitive activities via the investigation of locations, durations, and number of gazes. Yen and Yang (Chap. 13) analyzed 15 articles published by scholars from Taiwan and comment that although there was limited research completed in the area of eye tracking in science education, the fruitful outcomes of eye tracking lead to new directions of explaining the fine-grain size of analysis of cognitive processing of learners.

As the last chapter of this section, Huang (Chap. 14) identifies the unexpected impact of media on science. He discusses the power of the media has over people's conceptions of science. However, due to a limited number of researchers with science education engaged in media education, the quality of reports in the media or press makes them insufficient to guide the public.

Krajcik (Chap. 15) commented that innovative technologies and techniques facilitate teaching and learning across different science disciplines and throughout K-12. The advantages of the use of technologies have been widely recognized across the globe. However, he also caveated although innovative technologies can serve their purposes of scaffolding students' learning, the role of teachers in science class, design and development of technologies for learning, and new teaching strategies still remains prominent and necessary.

### *1.2.4 Section Four: Curriculum and Teacher Professional Development*

Ever since Shulman (1986) proposed the concept of pedagogical content knowledge (PCK), a big revolutionary wave has swept over teacher professional development research. Taiwan was not immune from this wave. A great amount of research was carried out to uncover what difficulties teachers have in developing their instructional skills and knowledge to transform students from naïve to experienced learners. Tuan, Wang, and Chang (Chap. 16) identify several issues relevant to the quality of teachers in teaching science. Along the same line, Su, Tsai, Chang, Chang, and Lin (Chap. 17) also discuss the interrelation among curriculum, teaching, and learning in science and align the goals of curriculum for instruction. They argue that although designing curriculum modules facilitates school teachers' understanding of curriculum and teaching and learning, teachers are usually concerned about the limitations of time and resources in practice.

Kao, Lin, Su, and Chang (Chap. 18) extended their research to indigenous students' learning via their culture. This approach echoed the call for learning in context. Culture and social impacts influence the perceptions of science among learners who have been marginalized in the general society. Liu (Chap. 19) emphasizes the importance of integrating science curriculum with socio-scientific issues and science, technology, society, and environment to extend students' points of view of science and urges teachers to develop controversial issues for discussion in school practice.

De Jong (Chap 20) commented that factors of science education reform and teacher professional development are tied closely and influenced by the culture, in particular, Confucian culture, in Taiwan. He also drew some comparisons of science curriculum reform and teacher learning between Western countries and Taiwan to shed light of our understanding of this field.

### *1.2.5 International Reflections*

The last section of the book is organized from the international perspective. The first part is Chap. 21, written by the senior science editors of International Journal of Science and Mathematics Education (IJSME) to share their personal experiences working with local scholars in Taiwan. Yore, Shymansky, and Treagust's unique experiences and expertise in science education have initiated and shaped some of the country's research in science education. Although their viewpoints cannot represent all international scholars' positions on science education in Taiwan, the lenses they used to infer how science education research developed over the past two decades can tell an inspiring story about the history of Taiwanese science education.

Along the same line, Chap 22 includes comments and reflections from international scholars who have been to Taiwan for different purposes, such as delivering speeches at conferences or conducting workshops in Taiwan. They share what they saw and what they felt to allow us to see for ourselves both from the outside as well as from the inside.

The story of Taiwan's experience and achievement is continuously being developed to promote science education for future generations. Taiwan is not a big place and has little natural resources. What Taiwan has, however, are its people. The never-ending challenge of science education is the bridging of the gap between research and practice to develop and utilize this natural resource. We have solid research outcomes that form the basis for promoting science education research and should be ready to face the reality of school practice. All these will allow us to see the strengths we have and the challenges we face such that we can continue to strive toward high-quality science education for future generations (also see Chap. 23).

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# Part I
# Overview of Science Education in Taiwan

The development of science education research was highly influenced by the country's growing societal and economic status, which allowed for the capacity of institutes to be expanded. Taiwan was fortunate to have experienced an economic boom in the late 1980s. Science education research has benefited from this rapid economic growth. Guo and Chiu (Chap. 2) reviewed governmental documents and academic reports on science education during 1982–2012 and provided historical points of view on the progress of science education research in Taiwan. They argued that the findings and successes from the research of the last 30 years were attributed to factors such as government financial support, local scholars' deep involvement, a formal evaluation system of researchers' academic contributions, and interaction with international scholars. The retrospective reviews allow readers to look back at the history of science education in Taiwan as well as look forward into the possible impacts and challenges of international and local publications.

Chiu et al. (Chap. 3) analyzed 394 articles published in Chinese Journal of Science Education (CJSE), the official journal of the Chinese Association for Science Education in Taiwan, from 1993 to 2012. The findings revealed that a majority of articles were empirical studies, and among them, 34.5 % were related to learning. In contrast, relatively low percentages of studies were in the areas of informal learning (1.8 %) and text and textbook analysis (1 %). The major trend of science education research in CJSE was aligned with established international research trends. The authors point out the most challenging tasks might be to have science education research contribute both to local and international journals, to putting research outcomes into practice, and to contexualize the research.

Finally, Duit commented the two chapters and highlighted the challenges of the role of English as lingua franca for many non-English speakers. He further pinpointed the influential elements of the development of science education research as well as challenged the future direction of science education to be developed in Taiwan.

# Chapter 2
# Research Projects on Science Education Funded by the National Science Council in Taiwan from 1982 to 2012: A Historical Review

**Chorng-Jee Guo and Mei-Hung Chiu**

**Abstract** The National Science Council (NSC) in Taiwan supports research in science education and is a major funding agency for such research. The major themes and trends of science education research projects funded by the Department of Science Education (DSE) of the NSC from 1982 to 2012 are reviewed in this chapter. This review includes official documents from the NSC, such as Calls for Proposals and Annual Reports, which include information about the goals of science education research, research strategies implemented, number of projects funded annually, and the distribution of the funded research projects across the evolving scheme for categorizing research in science education. Special emphasized research topics that occurred from time to time are also highlighted. NSC research projects are granted financial support based on a well-developed evaluation system. Specific features of the evaluation system, their impact on the research community, and additional measures to promote science education research are also described in this chapter. Certain objective data are used to illustrate the outcomes and achievements of the NSC-funded projects. Since the principal investigators are the direct and key participants involved in the DSE funding process, a questionnaire was developed to better understand their experiences and viewpoints regarding the impact of the DSE-funded research projects. The implications from this review and the survey results are discussed in terms of improving the funding process and policies, and informing future directions in science education research.

## 2.1 Introduction

Research in science education plays an important role in better understanding how students learn science and how teachers can teach science more effectively. In order to prepare scientifically literate citizens and ensure countries can use science to solve

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problems and advance their quality of life, both science education and research in it are considered integral parts of numerous nations' plans for development in science and technology. For Taiwan, a small island with limited natural resources, the importance of national development in science and technology has been widely recognized as witnessed by the establishment of the National Science Council (NSC) in 1959 and the publication of a series of national White Papers on Science and Technology. With the formal establishment of the Department of Science Education (DSE) in 1982, the NSC began to provide strong support and leadership for research in science education.

Since then, research in science education in Taiwan has flourished. In recent years, research from Taiwan has even risen in prominence in the international science education community (Chang 2012). Whether this success is the result of long-term coordinated efforts or coincidence, and whether the heyday of research in science education in Taiwan has just begun or is doomed to soon pass remain unanswered questions. In addition, we must ask what lessons can be learned from the past in order to inform the DSE and the Taiwanese research community so that Taiwan continues to contribute to the field of science education locally, nationally, and internationally. Only by answering these questions can we ensure future generations will be well prepared for the worldwide socio-scientific challenges that lay ahead.

### *2.1.1 The Purpose of this Chapter*

A good understanding of the background and growth of research in science education in Taiwan can identify the effectiveness and limitations of the DSE-funding policies and practices and offer insight into future possibilities. With this in mind, the purpose of this chapter is to provide a historical account pertaining to the following questions:

- What were the aims of the DSE for funding research projects on science education?
- What were the funding policies, funding schemes, evaluation criteria, and practices regarding research ethics and how did they evolve in time?
- What kinds of research projects were funded and what were their trends over the years?
- Who were the participants involved in these research efforts? What were the products, outcomes, and impacts of these research projects?
- What lessons were learned from such a historical review?

### *2.1.2 Contextual Background of Science Education Research in Taiwan*

To provide background for international readers, this section gives a brief account of the status of research on science education in Taiwan. First, most parents and the general public alike tend to consider school education, in general, and science teaching and learning, in particular, as important. Most parents and teachers have high expectations for their children and students in terms of their behavior, attitude, and academic performance. Following elementary school, students compete fervently to enter prestigious high schools and colleges/universities. It is a common phenomenon for teachers and their students to be willing to participate in research studies if they believe such participation could help the students get higher test scores. However, this is not true at grades 9 and 12 when it is generally very difficult to negotiate or persuade schools and teachers to allow 9th- and 12th-grade students to take part in research studies. The main reason for this difference is that teachers are busy preparing their students at these grades to take tests that essentially will decide which high schools or universities the students may enroll in. In addition, extraneous factors that could confound research results must be considered since many Taiwanese students from grades 1 through 12 attend a wide variety of enrichment classes and academic activities after school. Aiming at helping students get higher test scores, it is a common practice for teachers at so-called "cram schools" to emphasize improving students' knowledge and skills via memorization and contrived drill-and-practice problems instead of putting emphasis on meaningful conceptual understanding and application of core concepts and basic principles.

Although the students participating in a study funded by the DES may include kindergarten to university students and the general public, typically most studies focus on science education at the elementary, junior high-, and senior high school levels. For these studies, it is easy to invite teachers, school administrators, and principals to participate in a research study if they have finished their degrees at, or are currently enrolled in a professional development program offered by the home institution of the primary investigators and associated researchers. Of course, there are ethical and pragmatic pros and cons of such a practice, and one has to be careful in interpreting and generalizing the research results so obtained.

Science education researchers in Taiwan come from a number of institutional sources, including normal universities (referring to universities training students to be teachers), colleges and universities of education, colleges and universities offering educational courses and professional development programs, science museums, etc. Since preparing science teachers is part of science education researchers' professional responsibility, faculty members in the teacher preparation institutions have the advantage of combining teaching and research. They are also in close contact with schools and teachers and generally in a better position to invite teachers, school administrators, and principals to participate in a research study. There are some, but relatively less, principal investigators and researchers who teach science, mathematics, and other interdisciplinary courses at the college and university level. Principal investigators for research projects on science education funded by the DSE are mostly PhD degree holders majoring in science education (including mathematics education, etc.), or in science, mathematics, technology, information science, medical science, cognitive science and other related fields. While many cross-disciplinary projects may involve associated researchers majoring in education, the humanities, and other related fields, faculty members who major in these areas are less likely to be principal investigators on research projects in science education. For those investigators and researchers who come from higher education institutions and government-supported science museums, conducting research studies and publishing the results is an essential part of their professional activity and helps them to develop professionally and move toward the upper ends of the academic and administrative ladders.

Since the first establishment of the DSE at the NSC in 1982, science education research and related research activities have flourished in Taiwan as evidenced by the increasing number of junior faculty members going abroad to do their advanced studies in science education, the number of returning PhD and EdD degree holders majoring in science education, the initiation of master's and PhD degree programs in science education in Taiwan since 1987, the establishment of the Chinese Science Education Association in 1988, and the publication of the first issue of the *Chinese Journal of Science Education* in 1993. Concurrent with the implementation of a series of educational reform initiatives since the mid-1980s, science educators/researchers in Taiwan have produced a wide range of research results that significantly impacted science teacher education and professional development and resulted in better understanding of students' learning in science and mathematics, the improvement of science/mathematics teaching and assessment, and the development of more effective teaching materials and strategies. Meanwhile, science education researchers in Taiwan actively participate in international conferences and publish the results of their studies in well-known international journals on science, mathematics, technology education, and so on. Many internationally well-known science educators and scholars from Taiwan have been invited to participate and speak at workshops, seminars, and conferences. Currently, a number of Taiwanese science education researchers actively participate in the science education community internationally, including for instance, Chang, C. Y. (editorial board, *Journal of Research in Science Teaching*, JRST; associate editor, *International Journal of Science and Mathematics Education*, IJSME), Chiu, M. H. (associate editor, JRST; editorial board, IJSME), Lin, J. W. (editorial board, JRST), Tuan, H. L. (former associate editor, JRST; editorial board, IJSME), Lin, H. S. (editor-in-chief, IJSME), Tsai, C. C. (editor-in-chief, *Computers and Education*; former associate editor, IJSME), and Wu, H. K. (editorial board, *Science Education*).

Across a span of a few decades, research on science education in Taiwan has grown tremendously. It is a collective effort to which the government and many individuals have made significant contributions. From the 1980s onward, the establishment of national policies on science and technology was a major concern of the central government. This resulted in continued interest and support for research in science education during a period of economic growth. As a result, there was improvement in the national infrastructure, the transformation of nine normal schools into normal colleges, a substantial increase in the number of higher education institutions, and a series of educational reforms including reforms in science education. All these wider contextual events are important factors influencing the development of science education research in Taiwan.

### *2.1.3 The Scope, Limitations, Methods, and Implications*

The DSE provides funds, on a competitive basis, for researchers to do research in a range of fields, including primarily mathematics, biology, chemistry, and physics. However, substantial funds are also available for educational research in other closely related fields such as technology, information science, engineering, environmental science, medical studies, public science, and so on. It is therefore worthwhile pointing out that, unless explicitly mentioned, the term "science education" is used in the broadest sense so that it refers to educational studies in disciplinary areas including science, technology, environment, mathematics, and other closely related fields.

As with other fields in education, science education can be taken as a policy–practice–research triad occurring in a context influenced by personal, social, educational, cultural, economic, and political factors. It is a complex system within which the constituent parts, their interrelationships, and the system boundaries are changing over time in a way which may not be easily identified, predicted, and/or explained. A systematic study of the system unavoidably will include close examination into the inputs, the contents, the contexts, the processes, and the products and their mutual relationships at different levels of investigation, or "grain sizes." Realizing the complex nature of the science education enterprise, we shall focus our attention primarily on the aspects that are directly related to research in science education, while only briefly touching upon the aspects concerned with practice and policy in science education. Our historical review focuses on characteristics of the DSE funding policies and practices and the outcomes and impacts of funded projects at the collective level, and no attempts are made in this study to evaluate the performance and effectiveness of an individual research grant, a specific funding scheme, a particular research field, or the DSE as a funding agency.

In essence, no attempt is made to answer questions such as: Was the time and money spent on the funded project worthwhile and what were the reasons for the success/failure of the funded program? Certainly, these kinds of evaluative and cause-and-effect questions are proper and important, and in fact a major concern of many reports and publications (Cressman et al. 2009; National Academy of Sciences 2011; Reinhardt and Milzow 2012). However, realizing that valid and justified answers to these questions would require much more rigorous methodologies and efforts than what we can afford to do in the present chapter, the authors chose a primarily qualitative and descriptive approach to answer the set of questions mentioned at the beginning of this chapter.

In this study, we shall look at the mission and role of the DSE at the NSC, closely examine its funding policies and funding schemes, together with the evaluation criteria and practices on research ethics, and see how it uses the resources available to help the science education research community in Taiwan rise in prominence internationally. The approach taken is similar to the Case Study Evaluation Model described by Stufflebeam (2001), especially since the case study approach is characterized as a context-bound questions/methods-oriented approach rather than an improvement/accountability approach. Aiming at presenting a historical review of the research projects on science education funded by the NSC in Taiwan from 1982 to 2012, the authors echoed the "attempt to systematically recapture the complex nuances, the people, meanings, events, and even ideas of the past that have influenced and shaped the present" (Berg and Lure 2012, p. 305).

Official documents from the NSC and the DSE, such as White Papers on Science and Technology, Yearbook of Science and Technology, NSC Review, National Science and Technology Development Plans, DSE Calls for Proposals and self-evaluation reports, and additional special reports were reviewed. Some of these documents are available in English, often in abridged versions. For instance, a series of official documents concerning national policies on science and technology can be found online at the NSC website: http://web1.nsc.gov.tw/ct.aspx?xItem=9257&CtNode=1000&mp=7. A set of science and technology yearbooks from 2002 to 2012 are available in English at the NSC website: http://yearbook.stpi.org.tw/englishpdf.html, while the Chinese version, originally in hard copy, can be traced back to 1983. These reports include important information such as the number of projects funded, the research funds spent, the number of researchers involved, important research activities and results, the total number of papers published, and other research products and outcomes. Following general guidelines of historical research (Berg and Lune 2012), the authors paid special attention to the selection, organization, and analysis of the most pertinent collected evidence. Data from the official documents were cross-checked to verify the authenticity and accuracy of source materials.

In addition to the aforementioned tangible measures, there are other important effects that are less obvious, take time to build up, and are hard to measure quantitatively. As the authors have played a range of roles at different stages , including principal investigators, coordinators/leaders of large-scale research projects, primary and secondary reviewers, consultants to the DSE, and director of the DSE (the first author), we are able to assess and judge the validity and accuracy of the information presented in various official documents collected in this study, to assess the effectiveness of the DSE funding policies and practices, and to make qualitative assessments of the outcomes and impacts of the DSE-funded projects, based not only on our experiences but also on reflections of our own career paths and the observations of the professional trajectories of many science education researchers in Taiwan. However, in order to downplay the roles of our subjective opinions, we developed a short questionnaire to uncover principal investigators' perceptions on these matters.

In principle, research results obtained from the DSE-funded projects have implications for policymakers, researchers in the science education community, science education practitioners, students, parents, and the general public. It is beyond the scope of the current study to carry out a comprehensive survey on such a wide range of stakeholders regarding their viewpoints on the impact of DSE-funded research projects. Since the principal investigators are the most direct and key participants involved in DSE-funded research projects, a 25-item questionnaire was developed in this study, using a four-point Likert scale, to find out their viewpoints on the impact of DSE-funded research projects. The data obtained from the questionnaire were used to substantiate our assessments and comments on the impact of DSE-funded projects.

Through our historical review, we hope that international and domestic science educators and researchers will have a more holistic understanding of what the science education research community in Taiwan has done, what we have achieved so far, what remains to be done, and continue to pursue success and excellence in doing science education research. However, because of differences in educational, cultural, social, and historical backgrounds among different countries or geometrical areas, what seems to work in Taiwan may or may not work elsewhere. Therefore, for the interests of the international readers of this book, we hope to share our experiences as a case and leave readers to figure out what lessons are of interest or use to them.

## 2.2 Overview of the Funding of Science Education Research by the NSC

### *2.2.1 Historical and Organizational Background*

The NSC, established in 1959, plays a significant role in supporting university faculty members' research in a wide range of fields, not explicitly including science education in the beginning. The burgeoning of science education research in Taiwan can be traced back to the official establishment of the DSE at the NSC in 1982. Since then, the DSE has been charged with the special mission, among others, to plan and promote research and development of science education. Of course, this does not imply that there are no other government funding organizations for research and development in science education, nor does it mean that research and development of science education were nonexistent in Taiwan prior to 1982. In fact, at the government level, both the Ministry of Education and the NSC had initiated important programs related to the research and development of science education as far back as the 1950s. Concurrent with science education reforms worldwide, initial efforts on science education at that time focused mainly on the development of science curriculum, teacher professional development, and evaluation of students' achievement in mathematics and science. By the early 1970s, there were a handful of professors, including Chin-Chi Chao at the National Taiwan Normal University, who began to advocate the importance of research in science education. However, prior to 1982, the number of government-funded research studies, the researchers involved, and the research budgets spent on science education research were limited.

Concerning the promotion of research and development in science education, the NSC and the Ministry of Education reached a consensus in 1985 that the NSC would be responsible for basic research and exploratory developmental studies, while the latter would be responsible for the implementation and application of more practically oriented studies. Such a consensus has been honored throughout the years, although there are clearly the cases in which both parties worked collaboratively. Representative examples of such collaborative works include the joint efforts of the two governmental agencies on the improvement of assessment of students' learning in science and mathematics in the 1980s, and the participation of Taiwanese students in Trends in International Mathematics and Science Study (TIMSS) and Program for International Student Assessment (PISA) in recent years.

As a subordinate unit of the NSC, the missions and strategies to plan and promote the research and development of science education at the DSE follow the goals and visions on science and technology determined by the NSC and the Executive Yuan. A useful official document—Yearbook of Science and Technology Republic of China—provides a comprehensive description of the national policies, strategies, and progress in science and technology and is compiled annually by the NSC since 1983. Online versions in English have been available since 2002 (http://yearbook.stpi.org.tw/englishpdf.html). As can be seen from a glimpse at these yearbooks, the development of a population literate in science and technology continues to be a major national concern, and development of science education is part of the entire design. In fact, each yearbook contains a summary of the number of sponsored projects, the population of researchers, and the number of topics funded by the NSC each year.

According to the NSC Charter, the DSE is responsible for the following (also see http://www.nsc.gov.tw/sci/ct.asp?xItem=5233&CtNode=1347):

- To plan and promote the research and development of science education.
- To review and approve funding for research projects in science education.
- To research, guide, and expand popular science education.
- To publish scientific journals.

Officially, a department director is appointed to take charge of the DSE, which comprises a dozen or so staff members. Compared to other governmental organizations, a distinct feature of the NSC concerning personnel affairs is that it operates under a more flexible system of rules and regulations. For example, the director of the DES, typically an active and experienced science education educator/researcher, is chosen from the research community to serve at the NSC for a term of 2 years. It can be renewed for an additional term. The staff members working at the DES are also hired and promoted through a channel emphasizing research competencies rather than administrative knowledge and skills. In addition, a number of panels and ad hoc committees composed of members of the university research communities help the DES function at its best and provide needed advice.

According to a special report (in Chinese) celebrating the 30th anniversary of the NSC, the DSE, back in 1984, commissioned a group of six professors, including Cheng-Hsia Wang, to come up with a preliminary report delineating the future direction of science education research. The report displayed a three-dimensional structure of science education in terms of subject matter disciplines, substantial elements, and organizations. It also specified the levels, categories, and subjects of research in science education. In addition, research areas and important research topics were illustrated. In 1986, the DSE recommissioned a wider group of science and mathematics educators/researchers to prepare position papers for the four major disciplines that are included in the elementary and high school curriculum, namely, mathematics, physics, chemistry, and biology. Important research domains and topics within each of these disciplines were delineated in these documents, providing a useful reference for the DSE to prepare the annual Call for Proposals and for researchers to choose research topics. Of course, with time, suggestions and recommendations from these earlier documents were revised or replaced with more relevant ones, in response to various internal and external changes.

In order to meet the demands of mid- to long-term plans on national progress and development, the Ministry of Education and the NSC jointly held the First National Conference on Science Education during December 20–21 in 2002. The DSE played an important role in preparing a first draft of the White Paper on Science Education in 2001 and initiated six public hearings prior to the conference, in which a wide range of scholars, government officials, as well as opinion leaders from the general public were invited to participate. The consensus and conclusions reached at the 2002 conference resulted in the publication of the White Paper on Science Education in December 2003 by the Ministry of Education. A Chinese version of the White Paper is available online (MOE 2004). In addition to setting out the visions, goals, and implementation strategies, the importance of research in science education and research focus and priorities was emphasized. Calls for establishing adequate science education policy and environment were also included. The White Paper on Science Education has served as an important guide for research in science education for the past 10 years.

### *2.2.2 Evolving Funding Policies and Practices*

Just like other government offices, the annual budget for the DSE has to go through a standard review procedure that takes into account both the DSE's prior performance and proposed plans for the future. Once the annual proposal and the required budget are formally approved, the DES is responsible for carrying out its assigned missions, including most importantly the planning and promotion of science education research. Following broad guidelines from the NSC, the DES assumes the responsibility for developing pertinent funding policies and implementation strategies, generally with input from a number of ad hoc committees. With this input, the DES announces a Call for Proposals each year, delineating the important research themes and topics that the DES wants to encourage researchers to work on. In response to various external and internal influences, the research focuses and priorities as revealed in the annual Call for Proposals evolve and change over time. In addition to the annually announced Call for Proposals, the DSE also puts forward mission-oriented research programs from time to time, either autonomously or jointly with other government funding organizations, and invites researchers to apply for available grants.

Since the submitted proposals are awarded on a competitive basis, application forms and criteria for evaluation are also included in the Call for Proposals. The submitted proposals are evaluated through a unique review process that consists of two stages—a preliminary formative stage and a final decision stage. At first, each proposal is individually peer-reviewed by two referees. According to the policies and practices emphasized in the Call for Proposals, evaluation forms and guidelines to the reviewers have been developed and revised from time to time. The evolving evaluation criteria adopted in the first-stage review typically include categories such as the significance and quality of the proposal, research outcomes and impacts from previous research projects, the publication records and other bibliographic measures, the competencies of the principal investigator, and so on. In the early 1980s, submitting a research report may be considered as having fulfilled the criteria of producing research outcomes and impacts from previous research projects. Good publication records were taken into account since the early 1990s, and comprehensive schemes were developed to provide quantitative measures for this category. Since then, research articles published in *Social Science Citation Index* (SSCI), *Science Citation Index* (SCI), and *Engineering Index* (EI) journals with high impact factors and a few domestic science education journals were assigned higher credits, as compared to other journals, books published, and papers presented in seminars and conferences. However, the reviewers are also requested to evaluate the quality of the published papers and the potential contributions and impacts of the research outcomes.

As an example, the preliminary stage review form for a great majority of research proposals submitted to the DSE for the 2013 school year mainly consists of the following four categories: (1) alignment with the Call for Proposals (10 %), (2) contribution to science education and novelty (20 %), (3) contents of the proposal, that is, whether the proposal is well prepared (30 %), and (4) principal investigator's previous research outcomes and competencies (40 %). Besides these, the reviewers are also requested to provide a summary of evaluation, make suggestions for financial supports, check whether adequate approvals are provided in case the research involves human subjects in biomedical and behavioral studies, and a list of overall comments to be forwarded to the DSE and reviewers at the secondary stage.

The above example serves to illustrate that the evaluation criteria adopted by the DSE are designed to help increase research involvement in selected research areas and improve the quality and impacts of research outcomes. As major research granting agencies, the NSC and the DSE also pay particular attention to issues related to research ethics. Especially in recent years, research projects that involve human subjects in biomedical and behavioral research are required to obtain permissions from Institutional Review Board (IRB). Particular attention is paid to issues on intellectual property rights and research misconducts such as fabrication, falsification, and plagiarism in proposing, performing, or reviewing research, or in reporting research results. Within the NSC, there are guidelines for dealing with cases on research misconducts, the latest version (in Chinese) being updated in February 2013.

As mentioned above, the referees at the first stage are required to write detailed comments and suggestions about the proposal. These written comments and suggestions are then forwarded anonymously by the DSE to the original researcher, who is encouraged to make explications in response, and/or provide additional supporting arguments and materials. These supplementary materials, together with the original proposals and their first-stage review results, are further reviewed by a panel at the second stage. The panel consists of typically 5–7 senior researchers who work in the same field as the topic of the proposal. Panel members at the second review stage meet in person to review and discuss research proposals belonging to an assigned field and to make final judgments and suggestions as to which proposal(s) should be funded, for how long (typically from 1 to 3 years), and for how much (typically from US$ 10,000 to 50,000 per project per year). Depending on the quality of the proposal, the panel may also decide whether the approved budget will cover traveling expenses to attend international conferences, to appoint full-time or part-time assistants, and so on. It is worthwhile noting that in the above-mentioned review process there are built-in opportunities for science education researchers to learn and develop professionally. This is important, considering that research in science education is a young and growing field in the academic circle in Taiwan and some researchers at the university level have not been involved in doing science education research.

As a major funding organization for research in science education, the DSE also takes other measures to promote science education research. For instance, the DSE requires the principal investigators to not only prepare and submit written mid-term and year-end reports but also present their research results publicly in specially organized seminars. Researchers working in the same field are invited to participate in these seminars to share research findings and experiences. Distinguished science education researchers from abroad are often invited to give special talks on such occasions in order to introduce recent research trends, methodologies, and theoretical perspectives. The DSE also offers a range of opportunities for domestic scholars to present abroad. For instance, during the mid-1980s to mid-1990s, in response to the demand for more qualified teaching staff in the nine normal colleges which were newly transformed from normal schools to normal colleges, the DSE initiated a program offering scholarships to faculty members from the teacher preparation institutions to study abroad in doctoral programs. About two dozen scholars successfully completed their degrees and returned to their home institutions to teach and to continue doing research in science education. The DSE also actively initiated multiple programs to send scholars abroad to visit internationally well-known research groups, science education centers, or research institutions to observe how they promote science education and science education research, and to explore the possibility of exchange visits and collaborative studies. On several occasions, both authors have been invited as group leaders and participants to visit various institutions in the Australia, England, Finland, German, Japan, the Netherlands, USA, and other Nordic and European countries.

Typically, the DSE funding for research projects is awarded to a single principal investigator or collectively to a group of researchers coordinated by a lead investigator. In the latter case, there are variations in the number of subprojects and researchers included, the ways the research teams are organized, and the means they use to achieve the common goals. This kind of collaborative work often takes place across different departments and/or different institutions. It forms a favorable community for the researchers to work together, learn, and develop professionally. In addition to other practical advantages, it is expected to produce research results that are easier to compare and synthesize. Strategically, the DSE encourages researchers to form such research teams by granting funds to carry out various activities from regular group meetings to attending international conferences.

Within the NSC and across all the academic disciplines, and in association with the review of research proposals, there is an award system that encourages researchers to excel in research. Within the sociocultural background of Taiwan, this is a well-received practice providing not only substantial financial initiatives but also recognition of outstanding professional achievements. Another reason that this is a welcome system is that, as a general practice in Taiwan, there used to be a salary scale that was applicable to all government-supported colleges and universities, and private universities tended to follow this scale as well. According to this salary scale, a faculty member at the professor rank would receive basically the same amount of monthly salary regardless of which public university or college he/she worked at or how well his/her professional performance was. Since applying for research funding, conducting a research project, and publishing the results involve a significant amount of time and effort on the part of the researcher, it was considered fair and natural to offer some form of an award to those who went above and beyond to actively conduct research. In recent years, significant modifications to the payment policy and national salary scale have been implemented and each university may come up with different ways to subsidize and/or award its faculty members who demonstrate outstanding performance in teaching and/or research.

An important issue concerning the award system is whether to award relatively few researchers who demonstrate outstanding performance or to include as many recipients as possible whose performance is above average. Various approaches have been practiced, including the above two extremes as well as other alternatives. Adding an extra category that awards researchers scoring in the top 2–5 % has also been tried. The different approaches to the award system are based on different philosophies and are intended to achieve different goals. The award system and evaluation procedures adopted by the NSC are well received by the research community, and most researchers consider the award a personal honor and professional goal. In many universities, receiving an award from the NSC facilitates promotion to higher ranking academic and/or administrative positions.

## 2.3 Themes and Trends of the Science Education Research Projects Funded by the NSC: 1986–2012

This work summarizes an analysis of the projects funded by the NSC, including a comparison of the number of projects supported in different areas, reviews of the annual reports of the NSC, and an evaluation of the publications resulting from the NSC-funded projects that have appeared in international science journals. This analysis shows the progression of the science education research projects (SERP) over the past three decades.

### *2.3.1 Themes and Trends of the SERP Funded by the NSC: 1986–2012*

Over the past three decades, the DSE has called for proposals related to specific themes derived from the educational and societal needs at the time. For instance, in 1986, the Call for Proposals in science education focused on chemistry, physics, and biology education. Natural science was first introduced in the classroom and as part of teacher training programs in 1997 and then included in science education in 2004. Other areas have also evolved during the past 30 years, such as information education (e.g., computer-aided instruction, digital learning, web-based learning, and e-learning) and applied science (e.g., applied technology, industrial, special education in mathematics and science, practical work, and applied science education). Recently, public science education, general education at university level, informal science education, indigenous science education, and science education and communication were also emphasized to increase the diversity of the research in Taiwan and support equality in science education both locally and globally.

According to the data presented in the annual reports of the NSC between 1986 and 2012, the top three areas that received research funding were science education, information science, and applied science (see Table 2.1). These annual reports also revealed that there were rapidly increasing numbers of projects being sponsored by the DSE starting in 1996. The areas with the highest number of grants were information science and applied science. Meanwhile, public science education also gained attention from local researchers over the past 15 years. To our surprise, decreasing numbers of projects in environmental education were found. Beginning in 2006, this topic was merged as a subcategory with other areas (National Science Council 2006). With the environmental education policy announced in 2010, the

**Table 2.1** Total number of projects sponsored by the NSC from 1986 to 2012

| | 1986–1990 | 1991–1995 | 1996–2000 | 2001–2005 | 2006–2010 | 2011–2012 | 1986–2012 |
|---|---|---|---|---|---|---|---|
| Science education | 206 | 330 | 635 | 879 | 956 | 222 | 3228 |
| Mathematics education | 148 | 218 | 313 | 397 | 292 | 149 | 1517 |
| Environment education | 35 | 95 | 44 | 54 | 0 | 0 | 228 |
| Information science | 5 | 103 | 469 | 730 | 830 | 408 | 2545 |
| Applied science | 18 | 348 | 1060 | 802 | 1346 | 524 | 4098 |
| Public science education | 0 | 0 | 78 | 209 | 474 | 412 | 1173 |
| Others | 21 | 162 | 91 | 543 | 3 | 69 | 889 |

lack of attention by the DSE to promote research in environmental education was unexpected. These trends appear in Table 2.1. The number of sponsored projects started blooming during the period between 1996 and 2000, and then grew steadily from 2001 through present. Due to the growing NSC funding, there has been a rapid increase in the number of publications, based on sponsored projects, appearing in international journals.

To go a step further in investigating the impact of the DSE, articles from five influential and international science education journals (*Journal of Research in Science Teaching, Science Education, International Journal of Science Education, Research in Science Education, and International Journal of Science and Mathematics Education*) were selected and the publication rate for Taiwanese scholars in these journals was calculated. These findings appear in Table 2.2. First, there were very few publications by Taiwanese researchers in these five journals from 1993 to 1997. The first three articles by Taiwanese authors appeared in JRST and *Science Education*, and this low publication rate has not changed much, especially for JRST, over the past three decades. Second, publications by Taiwanese researchers started to appear in IJSE during 1998–2002 and appeared regularly in this publication from 2002 through present. Among the five journals selected, the highest percentage (43 %) of publications by Taiwanese researchers appeared in IJSE compared with articles in other journals. Third, local scholars were late in publishing papers in RISE. Unlike JRST, SE, and IJSE, which are well known among science educators in Taiwan, RISE did not appear on the SSCI journal list until 2010, which might explain why Taiwanese researchers did not immediately submit their work to this journal. As far back as 2007, SSCI became highly influential and was used as an indicator for evaluating researchers' accomplishments for promotion in university and/or research grant from government. SSCI ratings were important to researchers because around this time universities set a maximum number of years (i.e., 6) for assistant and associate professors to be promoted in Taiwan. Once the IJSME was founded in 2003, by the NSC, local researchers started translating their work into English and submitting their research for publication. The impact of the IJSME

**Table 2.2** Distribution of publications from Taiwanese scholars in selected journals

| | 1993–1997 | 1998–2002 | 2003–2007 | 2008–2012 | 1993–2012 |
|---|---|---|---|---|---|
| *Journal of Research in Science Teaching* (JRST) | 2 (67 %) | 3 (12 %) | 6 (8 %) | 3 (4 %) | 14 (7 %) |
| *Science Education* (SE) | 1 (33 %) | 7 (27 %) | 10 (13 %) | 6 (7 %) | 24 (13 %) |
| *International Journal of Science Education* (IJSE) | 0 | 15 (58 %) | 32 (42 %) | 35 (42 %) | 82 (43 %) |
| *Research in Science Education* (RISE) | 0 | 1 (4 %) | 2 (3 %) | 10 (12 %) | 13 (7 %) |
| *International Journal of Science and Mathematics Education* (IJSME) | 0 | 0 | 26 (34 %) | 30 (36 %) | 56 (30 %) |
| Total | 3 | 26 | 76 | 84 | 189 |

came about gradually. As the figures show, 30 % of the papers published in IJSME were from Taiwanese researchers since 2003. IJSME became an SSCI journal in 2010 which attracted more international scholars, including more Taiwanese researchers, to submit their work to the journal.

Although studies (e.g., Tsai and Wen 2005) and our analysis have revealed impressive contributions from Taiwan to the global science education community and increasing number of publications appearing in the SSCI science education journals over the past 30 years; there are still only limited numbers of articles published in the two top journals (JRST and *Science Education*). Publishing the research findings in prestigious science education journals should be a priority for science educators in Taiwan. This would help the educators make a great impact on the global science education community, especially if they want to play a leading role in science education research.

From the five selected journals between 1993 and 2012, we found that on average, 3.71 % of the publications were from Taiwanese researchers (see Table 2.3). Although the figure is small, considering the number of researchers in science education and the total population of Taiwan (about 2.3 million), this is a true indicator of Taiwan's significant achievement in the field of science education. Having said this, there is a room for further improvement. As the results show, a relatively high percentage (about 5 %) of articles published in the IJSE originated from Taiwan. Taiwanese scholars tended to make more contributions to the IJSME with 15 % of its published articles originating in Taiwan.

To understand the influence of the NSC funding on the number of publications from Taiwanese researchers in the five selected journals between 1993 and 2012, we checked each acknowledgement section to see if any NSC grant numbers were mentioned (see Table 2.4). Among the Taiwanese papers published in the five journals, we found that on average, 72.68 % of these papers received the NSC support. This high rate of support underscores how the NSC made a concerted effort to help researchers carry out quality research and disseminate their findings to the international science community. Without question, the NSC plays an influential role in promoting research that is carried out locally and recognized internationally.

Researchers in Taiwan recognized the importance of publishing their research in international journals and moved from publishing in local journals to international journals. Three events influenced this change: (1) MOE's policy of evaluation of effectiveness of higher education based upon international visibility (such as the number of SSCI articles), (2) promotion within the university and college systems dependent upon the number of SSCI journal publications, and (3) MOE increased the research grants to promote local universities and help them earn international recognition. However, there is always a debate as to whether the outcomes of research should be disseminated locally in order to have a more immediate impact on local teachers, students, and policymakers versus publishing in international journals. Taiwan has strived to find the right balance between localization and globalization of research outcomes in science education.

**Table 2.3** The percentage of articles from Taiwan compared to all the articles published in the five journals

| Journals | 1993–1997 | | | 1998–2002 | | | 2003–2007 | | | 2008–2012 | | | 1993–2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | *N* | % | *n* | *N* | % | *n* | *N* | % | *n* | *N* | % | *n* | *N* | % |
| *Journal of Research in Science Teaching* (JRST) | 2 | 398 | 0.50 | 3 | 327 | 0.92 | 6 | 264 | 2.27 | 3 | 280 | 1.07 | 14 | 1269 | 1.10 |
| *Science Education* (SE) | 1 | 216 | 0.46 | 7 | 246 | 2.85 | 10 | 318 | 3.14 | 6 | 286 | 2.10 | 24 | 1066 | 2.25 |
| *International Journal of Science Education* (IJSE) | 0 | 340 | 0.00 | 15 | 381 | 3.94 | 32 | 458 | 6.99 | 35 | 554 | 6.32 | 82 | 1733 | 4.73 |
| *Research in Science Education* (RISE) | 0 | 186 | 0.00 | 1 | 148 | 0.68 | 2 | 121 | 1.65 | 10 | 213 | 4.69 | 13 | 668 | 1.95 |
| *International Journal of Science and Mathematics Education* (IJSME) | 0 | 0 | NA | 0 | 0 | NA | 26 | 134 | 19.40 | 35 | 265 | 13.21 | 56 | 365 | 15.34 |
| Total | 3 | 1140 | 0.26 | 26 | 1102 | 2.36 | 76 | 1295 | 5.87 | 89 | 1598 | 5.57 | 189 | 5101 | 3.71 |

**Table 2.4** The number of the NSC-funded studies published in the five journals between 1993 and 2012

| Journals | 1993–1997 | | | 1998–2002 | | | 2003–2007 | | | 2008–2012 | | | 1993–2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | *N* | % | *n* | *N* | % | *n* | *N* | % | *n* | *N* | % | *n* | *N* | % |
| *Journal of Research in Science Teaching* (JRST) | 0 | 2 | 0.00 | 3 | 3 | 100.00 | 4 | 6 | 66.67 | 1 | 3 | 33.33 | 8 | 14 | 57.14 |
| *Science Education* (SE) | 0 | 1 | 0.00 | 5 | 7 | 71.43 | 6 | 10 | 60.00 | 4 | 6 | 66.67 | 15 | 24 | 62.50 |
| *International Journal of Science Education* (IJSE) | 0 | 0 | NA | 10 | 15 | 66.67 | 26 | 32 | 81.25 | 27 | 35 | 77.14 | 63 | 82 | 76.83 |
| *Research in Science Education* (RISE) | 0 | 0 | NA | 0 | 1 | 0.00 | 2 | 2 | 100.00 | 6 | 10 | 60.00 | 8 | 13 | 61.54 |
| *International Journal of Science and Mathematics Education* (IJSME) | 0 | 0 | NA | 0 | 0 | NA | 25 | 26 | 96.15 | 22 | 35 | 62.86 | 47 | 61 | 77.05 |
| Total | 0 | 3 | 0.00 | 18 | 26 | 69.23 | 63 | 76 | 82.89 | 60 | 89 | 67.42 | 141 | 194 | 72.68 |

### 2.3.2 Factors Contributing to Changes of SERP Themes and Trends

In the past few decades, the DSE evaluation criteria for reviewing research proposals and for the research awards have gradually evolved. For instance, throughout the 1980s and the early 1990s, oral presentations of research results and submission of written reports were acceptable for completing a funded research project cycle/process. At the same time, research proposals were evaluated based primarily on the quality and soundness of the proposal, including, for instance, the relevance and significance of the research questions, whether there was a comprehensive literature review, how well the research design was conceived, and so on. Opportunities for researchers to attend international conferences, to do research, and to pursue a higher degree in science education were also offered by the DSE. Meanwhile, in order to raise the quality of science education research, the researchers were encouraged to publish their research findings in domestic and international journals. The DSE provided funds for various institutions or groups of research teams to organize seminars and workshops aimed at helping the interested parties and informing faculty members of the latest research trends. The seminar also taught them how to write research proposals, how to conduct well-designed research studies, and how to present their research results in international conferences and publish them in reputed journals. Starting from the mid-1990s, the DSE developed an evaluation system for reviewing research proposals that took into account the researchers' publishing record and the quality of those published research papers. This is an important factor that contributed to the growth of papers being published annually in SCI and SSCI journals by Taiwanese science education researchers.

## 2.4 Impact of the DSE on Science Education Research in Taiwan

As mentioned earlier, in order to substantiate the authors' qualitative assessment of the effectiveness of the DSE funding policies and the impact of the funded research projects, a short questionnaire was administered online to a sample of principal investigators recently submitting or receiving research grants. A total of 49 participants filled the questionnaire. The participants included researchers with a wide range of research experience in science education. There were 10.2 % participants having less than 5 years of research experience in science education, 30.6 % between 6 and10 years, 32.7 % between 11 and 20 years, and 26.5 % more than 20 years.

The questionnaire consisted of two parts. Part 1, items 1–19, was intended to find out the principal investigators' perception of the usefulness of the various funding policies and practices adopted by the DSE. Part 2, items 20–25, aimed at finding out the respondents' assessment of the overall impact of the DSE-funded projects on science and mathematics teaching and learning. Table 2.5 summarizes the results

**Table 2.5** Percentage of responses to the questionnaire

| Topic Option (%) | Most helpful | Helpful | Not helpful | Detrimental |
|---|---|---|---|---|
| *Part 1. How helpful it is, please answer the following questions:* | | | | |
| 1. Regarding the submission of my research proposal, the instructions in the Call for Proposals from the Department of Science Education are: | 42.9 | 53.1 | 4.1 | 0.0 |
| 2. In terms of gaining significant research findings, the strategies adopted by the Department of Science Education encouraging research teams to jointly apply for research grants are: | 30.6 | 63.3 | 4.1 | 2.0 |
| 3. In terms of enhancing the applicants' professional proficiencies, the research proposal assessment criteria set by the Department of Science Education are: | 26.5 | 59.2 | 14.3 | 0.0 |
| 4. The practice allowing applicants to provide supplementary explanations and materials to clarify the reviewers' initial comments on their research proposals is: | 34.7 | 59.2 | 6.1 | 0.0 |
| 5. The Department of Science Education provided workshops informing new scholars, especially those coming from other disciplinary areas, how to write a research proposal in science education | 42.9 | 44.9 | 12.2 | 0.0 |
| 6. The Department of Science Education supported workshops on how to prepare research papers to be published | 36.7 | 53.1 | 10.2 | 0.0 |
| 7. The Department of Science Education requires the principal investigator to present an oral report following the completion of the funded project | 30.6 | 61.2 | 8.0 | 0.0 |
| 8. In terms of enhancing my research capacity, my participation in research projects funded by the Department of Science Education has been: | 67.3 | 28.6 | 4.1 | 0.0 |
| 9. Regarding the quality and quantity of my published papers, my participation in research projects funded by the Department of Science Education has been: | 46.9 | 49.0 | 4.1 | 0.0 |
| 10. Teaching courses in science, mathematics and other related subjects, my participation in doing research projects funded by the Department of Science Education has been: | 30.6 | 65.3 | 2.0 | 2.0 |

**Table 2.5** (continued)

| Topic | Option (%) | Most helpful | Helpful | Not helpful | Detrimental |
|---|---|---|---|---|---|
| 11. In regard to developing the competence of research assistants, my participation in doing research projects funded by the Department of Science Education has been: | | 44.9 | 51.0 | 2.0 | 2.0 |
| 12. Regarding the supervision of undergraduate and/or graduate students, my participation in doing research projects funded by the Department of Science Education has been: | | 44.9 | 46.9 | 6.1 | 2.0 |
| 13. In regard to advancing in academic rank, my participation in doing research projects funded by the Department of Science Education has been: | | 44.9 | 49.0 | 6.1 | 0.0 |
| 14. In regard to administrative promotions, my participation in doing research projects funded by the Department of Science Education has been: | | 20.4 | 55.1 | 24.5 | 0.0 |
| 15. In regard to my participation in science education research communities at home and abroad, my engagement in doing research projects funded by the Department of Science Education has been: | | 49.0 | 49.0 | 2.0 | 0.0 |
| 16. In regard to my participation in science education outreach services, my engagement in doing research projects funded by the Department of Science Education has been: | | 24.5 | 71.4 | 4.1 | 0.0 |
| 17. In regard to conducting a research study, financial support from the Department of Science Education is: | | 69.4 | 28.6 | 2.0 | 0.0 |
| 18. In regard to providing adequate incentives for university faculty to engage in academic research, the award system adopted by the Department of Science Education at the National Science Council is: | | 51.0 | 44.9 | 4.1 | 0.0 |
| 19. In regard to upgrading the quality of domestic academic research in science education, the award system adopted by the Department of Science Education at the National Science Council is: | | 49.0 | 42.9 | 8.2 | 0.0 |
| *Part 2. How helpful are the findings and/or products obtained from the DSE-funded projects with respect to:* | | | | | |
| 20. The preparation of science and mathematics teachers at the primary and secondary school levels? | | 36.7 | 44.9 | 16.3 | 2.0 |

**Table 2.5** (continued)

| Topic | Option (%) | Most helpful | Helpful | Not helpful | Detrimental |
|---|---|---|---|---|---|
| 21. The improvement of science and mathematics teaching at the primary and secondary school levels? | | 32.7 | 51.0 | 14.3 | 2.0 |
| 22. The development of science and mathematics curriculum standards at the primary and secondary school levels? | | 16.3 | 57.1 | 24.5 | 2.0 |
| 23. The development of science and mathematics instructional materials at the primary and secondary school levels? | | 34.7 | 53.1 | 10.2 | 2.0 |
| 24. The evaluation of primary and secondary school students' learning outcomes in science and mathematics? | | 34.7 | 46.9 | 18.4 | 0.0 |
| 25. The development of scientific literacy for all citizens? | | 22.4 | 63.3 | 14.3 | 0.0 |

of the questionnaire and indicates an overall positive trend for the responses. Results for part 1 revealed for 3 items (Q3, Q5, and Q14) that about 12–25 % of the respondents think the impacts of the DSE efforts and/or funded projects were "not helpful." The results for the other 16 items in part 1 indicated that more than 90 % of the respondents believed that the various funding policies and practices adopted by the DSE were either "helpful" or "most helpful." However, there were 8 items for which a minority (10–20 %) of the respondents thought that the efforts and the impacts of the DSE-funded projects were "not helpful." The results for all 6 items in part 2 indicated that the majority (75–90 %) of respondents believed that overall efforts of the DSE-funded projects were helpful, but a minority (10–25 %) of the respondents rated the overall impact of the DSE-funded projects on science and mathematics teaching and learning as "not helpful." Within these general patterns of responses to parts 1 and 2 were three mutually related aspects: the quality of science education research, the development of human resources, and the improvement of science teaching and learning, which we shall discuss in details in the following section.

### *2.4.1 The Quality of Science Education Research*

The DSE began to support researchers to conduct science education research soon after its formal establishment in 1982. Various measures were developed in the funding policies, schemes, and procedures to encourage faculty members at colleges and universities to apply for the research funds, get the research results published, raise the quality of the research, and publicize and make good use of the research results. For instance, guided by the evaluation criteria for reviewing research proposals, the researchers were required to establish and maintain good publishing records and upgrade the quality and usefulness of their publications by targeting recognized journals and informing educational policy and classroom practices. In combination with the NSC research award system and the requirements for faculty promotion in higher education institutions, the growth of papers published annually in SCI and SSCI journals by Taiwanese science education researchers has been noteworthy over the past 10–15 years (Chang 2012). Of course, increasing the number of papers presented at international conferences and published in prestigious journals is only a first step toward building awareness in the research community about the quality of their research efforts and the significance of their potential outcomes and impacts. Assessing the quality and impact of a published paper is difficult. Besides, it can be assessed from different perspectives using different criteria. At any rate, a simple bibliographic count is insufficient and a more comprehensive evaluation scheme is needed. Such concerns are reflected in the DSE Call for Proposals and the accompanying review criteria in recent years.

The responses to questions 1, 2, 9, 17, 18, and 19 pertain to the application of funded projects and the upgradation of the quality of research products. More than 90 % of the respondents rated these items as either "helpful" or "most helpful." It is worth noting that for Q17 (In regard to conducting a research study, how helpful finacial support from the DSE is:), 69.4 % of the respondents selected "most helpful."

A thriving research community must consider the development of highly qualified human resources. It is apparent that through the DSE research funds distributed over the past few decades, a cohort of science education researchers, primarily college and university faculty, have been nurtured, prepared, and supported. Engaging in the DSE-funded research projects provided rich opportunities to the faculty members for their development of professional proficiencies in terms of research, teaching, and outreach services, and allowed them to move up along the academic and administrative ladders. The DSE took a number of measures to encourage novice and less experienced researchers, especially those from other fields associated with science education, such as engineering, medical science, nanoscience and nanotechnology, cognitive science, etc. to apply for research funds. The review criteria for research proposals submitted by first time applicants are less stringent for the first 5 years, so that they have sufficient time to learn and build up their research capabilities. For example, for the school year 2013, the differences between the first-stage review form for these researchers compared with the great majority of researchers mentioned earlier are the following: more emphasis is placed on the category "contents of the proposal" (45 % as compared to 30 %) and less emphasis on "principal investigator's previous research outcomes and competencies" (25 % as compared to 40 %). Again, the two-stage review process provides valuable learning experiences to the applicants. They get a feedback from preliminary reviewers about their research proposal, which helps them revise or enrich their original proposals for the next panel review. Furthermore, these research grant applicants are encouraged to attend workshops and seminars specially organized to help familiarize them with the theoretical and methodological aspects of science education research, and to inform them on how to write research proposals and get their research results published.

New and established applicants are also encouraged to join senior researchers in forming a joint research team or to take part in a special interest group. Questions 3–8 pertain to the development of researchers' research capacity. Most of the responses of the participants were positive to these items, especially for Q8 (In terms of enhancing my research capacity, my participation in research projects funded by the DSE has been:), where 67.3 % of the respondents answered "most helpful." It is interesting to observe that for Q3–Q7, small minority (6–15 %) of respondents replied that the corresponding measures taken by the DSE were "not helpful." This is perhaps understandable, considering that these measures were originally designed to help the novice and less experienced researchers, and approximately 60 % the respondents expressing this lack of support had engaged in the DSE-funded projects for more than 10 years.

The development of researchers' professional proficiencies in teaching and outreach services is essential for effective knowledge transfer or utilization where research results help inform policy and practice. The responses to questions 10–16 pertain to the development of professional proficiencies in teaching and outreach services. Again, most respondents were very positive, except when it came to Q14 (In regard to administrative promotions, my participation in doing research projects funded by the DSE has been), which is quite reasonable after all. Our observations and experiences suggest that continued support from the DSE and active participation in the DSE-initiated activities were very helpful to many science education researchers in disseminating their research results to various audiences. These researchers not only have successfully moved up the academic ladder from assistant professor to associate professor and professor but also have developed the capacity to become coordinators of research teams, project reviewers, department chairpersons, college deans, university presidents, and get involved in national and international knowledge transfer and internship opportunities. They also play important roles in a wide range of professional activities, such as textbook writers, journal editors, and consultants or advisors to the Ministry of Education, and actively participate in science education associations, both domestically and internationally (such as NARST, the National Association for Research in Science Teaching and EASE, the East-Asian Association for Science Education). Many of the principal investigators of the DSE-funded projects are directly involved in the preparation of pre-service and in-service K-12 science and mathematics teachers. Some of them are also involved in teaching and supervising science and mathematics graduate students at the university level. The use of research internships/apprenticeships (associate researchers, postdoctoral fellowships, and full-time and part-time research assistants) is a common practice within a funded project and local schools and teachers are invited to participate as collaborative schools and action research partners. Many school administrators and teachers are also invited to attend science education seminars and workshops organized by research projects funded by the DSE. These activities are central to the research enterprise and the research results inform and empower each participant of these activities.

### 2.4.2 The Improvement of K-12 Science Teaching and Learning

The DSE emphasized that the funded research studies should produce significant results that lead to the improvement in science teaching and learning, especially for K-12. Questions 20–25 pertain to the improvement of science teaching and learning. For these questions, the percentage of respondents who answered “helpful” or “most helpful” varied from 88 % (Q23) to 73 % (Q22). The influences on science education appear to be from the interviewees’ direct involvement and knowledge transfer. School administrators and teachers who participated in the research studies benefitted from being active in the design, conduct, and practical results of the school- and classroom-based studies. Others teachers who took courses delivered by science education researchers were informed by the research findings and suggestions and an even larger number of teachers heard or read messages through seminars, workshops, and publications organized and written by the researchers. In recent years, the DSE also encouraged researchers to publish books and develop instructional resources/media based on their research results. The results of the DSE-funded research projects included a better understanding of how students learn science and mathematics at school, and the development of a wide range of teaching strategies, teaching materials, instructional media, and assessment tools to facilitate science teaching and learning. As has been emphasized in the Call for Proposals and the evaluation criteria, the researchers are encouraged to make the research results available to teachers. It would be nice to see that these efforts lead to improvements in science teaching and learning. However, these improvements involve many other important factors such as students’ prior knowledge, inquiry skills, motivation, teacher characteristics, and so on. The time delay for the effects of the contributing factors to a noticeable level is a limitation in such an impact study. Research studies focusing on the assessment of the impact of the DSE-funded projects on the improvement of science teaching and learning are needed.

### 2.4.3 The Development of Human Resources

According to the reports from the National Applied Research Laboratories (1986–1996) and personal communication with senior researcher T. L. Yang at the NSC (1997–2012), the distribution of human resources having different levels of expertise in science education who received NSC research grants from 1986 to 2012 is shown in Table 2.6. The table reveals that there was a rapid increase in the number of researchers from 1998 to 2002 at all levels. In the past 5 years (2008–2012), the number of levels of expertise has increased. This promising phenomenon of the size of researchers might attribute to more research products as shown in other tables (such as the increasing numbers of grant proposals and publications).

**Table 2.6.** The distribution of human resources from 1986 to 2012

| | | | 1986–1987 | 1988–1992 | 1993–1997 | 1998–2002 | 2003–2007 | 2008–2012 |
|---|---|---|---|---|---|---|---|---|
| | | Professor | 39 | 75 | 187 | 345 | 516 | 749 |
| | | Associate professor | 26 | 51 | 295 | 564 | 488 | 624 |
| | PI | Assistant professor | 0 | 0 | 0 | 89 | 249 | 494 |
| University College | | Lecturer | 10 | 7 | 10 | 58 | 55 | 65 |
| | | Postdoctorate | 0 | 0 | 3 | 36 | 49 | 137 |
| | | Others | 0 | 0 | 0 | 0 | 8 | 0 |
| | | Full time | 43 | 52 | 107 | 159 | 205 | 298 |
| | | Part time | 0 | 0 | 0 | 0 | 74 | 304 |
| | Assistant | Lecturer | 7 | 24 | 70 | 117 | 41 | 0 |
| | | TA | 0 | 140 | 278 | 351 | 98 | 0 |
| | | Graduate | 24 | 69 | 451 | 974 | 1848 | 2506 |
| | Total | | 147 | 418 | 477 | 2694 | 3631 | 5176 |

## 2.5 Looking Back and Looking Forward

With ever-changing political, sociocultural, and educational conditions, the environment for research and development of science and technology in Taiwan is facing great challenges, and potential threats exist for the development of research in science education. Based on the historical review in this study, we will read about the accomplishments of research in science education in Taiwan over the past few decades and then turn to discussions on the challenges and opportunities for the future. Finally, we address the issue concerning what implications our review has for the readers of this chapter, by pointing out possible reasons that might account for the apparent success of research in science education in Taiwan. Recommendations will be made with the hope and expectation that research in science education in Taiwan will continue to move forward and make important contributions both domestically and internationally.

### *2.5.1 Accomplishments and Reflections*

The mission to plan and promote research in science education has been entrusted to the DSE by the NSC in Taiwan. During the past three decades, the DSE has played a critical role in helping to create an active science education research community and culture through its funding policies and practices. It has provided strong support and leadership, helping science education researchers learn, grow, and excel. In terms of the development of human resources, the DSE has succeeded in drawing a significant number of scholars to do research in science education, and in providing a favorable environment for conducting research and for professional development. A great number of postdoctorates, PhD and master's degree students, full-time and part-time research assistants, and science teachers have participated in the DSE-funded research projects for an extended period of time. They took the opportunities to develop and improve their knowledge and skills in doing science education research. With the support and leadership provided by the DSE, a wide range of research activities have flourished in Taiwan, and the quality of science education research has greatly improved. However, the quality and relevance of science education research are concerns and there are still important questions that need be answered, such as:

- Do research findings improve science teaching and learning for students in Taiwan? Is research in science education as a whole in Taiwan making progress or spinning its wheels?
- Do the research results from the DSE-funded projects make noteworthy contributions to the international knowledge base on science teaching and learning?
- What future directions should our research efforts follow?

Questions such as these are critical, and many chapters in this volume address these concerns. Certainly, better understanding of the answers to these questions will help the policymakers, the DSE, and the researchers to make wise choices that will keep the current research momentum in science education going.

Although the evolving funding policies and practices at the DSE, combined with researchers' motivation for professional growth and the persistent "publish or perish" culture in universities, have led to the apparent success of research in science education, especially in terms of the bibliographic paper counts, there are side effects that need to be taken into consideration. For instance, in the 1990s, the evaluation criteria and award system at the DSE were designed to prize and honor research papers published in the SSCI and SCI journals. Although this is well justified to establish the identity of science education as a distinct discipline in university settings, there is a downside to adopting this strategy. That is, it tends to place lower priority on research studies aimed at solving more practical and local problems that may inform science teachers and be more suitable for publication in domestic journals. Over the years there have been several science educators/researchers who have made significant contributions to research and development of practical works in science education, such as developing hands-on activities using household devices and materials, creating websites for interactive simulated experiments in physics, developing remedial learning materials on the web for indigenous students, and so on. Although these researchers were able to obtain research funding from the DSE, they were disqualified for the "Outstanding Research Award in Science Education," because the criterion for judging this award was based upon the number of publications published in the SSCI journals. It may be the time to reconsider and readjust the research priority and criteria in the award and evaluation system. High-quality research results that make significant contributions to a better understanding of science teaching and learning in a global context are important indeed; however, as clearly pointed out in the White Paper on Science Education, more emphasis should be devoted to address local problems and issues that are related to policy and practice aspects of science education in Taiwan.

### *2.5.2 Challenges and Opportunities*

Collective efforts of the DSE and the participants of the science education research community are not the only factors contributing to the accomplishments of research projects outlined above. There are other favorable conditions that contributed significantly to the success, such as international and national reforms and changes. Over the past 30 years, important educational reforms and political and economic developments have taken place. This has helped create an environment in which research and development in science education, which is an essential part of the gross national development plan, is in demand, supported, and appreciated. However, there are a number of changes that are potential threats to the development of research in science education in Taiwan. First, the number of newborn babies each year has dropped from around 320,000 in the mid-1980s to a low record of around 170,000 in 2010. This has slightly improved in the past few years and is expected to stay around 200,000 for the next few years. With less demand for school teachers, the effects are that many teacher preparation colleges, departments, and programs have been transformed, merged, or closed down in recent years. The associated demand for faculty members in science education at the university level has also reduced. What kind of impact this will have on the science education research is not yet clear.

In addition, science education research in the near future will get more complicated and challenging as the compulsory education system in Taiwan has been extended from 9 to 12 years in 2014 (Ministry of Education 2012). Enrollment in senior high schools will be tuition-free and require no admission tests. A major change here is to place students in senior high school primarily based on their residential school districts, thereby reducing the effects of their prior performance at school and basic competence test scores. Simply put, the intention is to overcome the shortcomings of traditional test-driven teaching and learning, end the intensive competitions for entering prestigious senior high schools, and improve the quality of basic education for all students up to grade 12. New educational goals and curriculum guidelines have been announced, and new text materials are to be developed. It is expected that significant changes will take place in the teaching and learning of school subjects, including science and mathematics. At a time like this, science education educators and researchers are expected to play important roles in the science education reform activities. The research community is expected to provide relevant and useful information to policymakers, textbook developers, school administrators, and other practitioners. On the other hand, in terms of the implementation of various reform initiatives, there is no one better suited to understand and address such issues. Science education researchers should take this opportunity to find out what kind of problems arise or still exist in the K-12 science teaching and learning that are most important and urgent for a range of stakeholders, and set out to help solve these problems. To be sure, certain research studies along this line have been done in recent years, including national surveys of students' performance in science and science teachers' perceptions of their professional proficiencies. More collaborative efforts between researchers, policymakers, and practitioners would be helpful in identifying research problems and deciding on priorities.

In an effort to improve government efficiency and national competitive capability, the central government in Taiwan is undergoing a process of reorganization, aimed at reducing the number of cabinet-level organizations from 37 to 29 over a 3-year period between January 1, 2012 and December 31, 2014 (Executive Yuan 2012). Within the new Executive Yuan, six new ministries will be created through the reorganization or consolidation of existing agencies, meanwhile, several agencies will cease to exist after their functions are transferred to other commissions or ministries. The NSC and the Atomic Energy Council merged into the Ministry of Science and Technology on March 3, 2014, while the DSE was consolidated with a former division at the NSC to become The Department of International Cooperation and Science Education. These changes mean that support and leadership for science education research is uncertain once the original DSE ceases to exist. While diminished recognition and support for research in science education threaten the development of science education, there simultaneously exist new opportunities to expand in terms of interdisciplinary and international collaborations.

The national effort to develop the population in terms of science and technology and to seek academic excellence internationally has encouraged the Ministry of Education to develop several action plans that are related to expected breakthroughs at the higher education level. Significant amounts of resources will be available for the top universities in Taiwan to strive for excellence in higher education, enhance their cooperative and exchange research activities with outstanding research centers abroad, play leadership roles among the eastern Asian countries, and strengthen vocational education to foster creative and innovative workforce. Many professors, working on research projects funded by the DSE, have participated in similar research studies and have established sound foundations for continuing research studies along this line. The prospect of this being supported in the future by the new Department of International Cooperation and Science Education and resulting in excellent contributions to these fields looks very promising. Also, as there are now more frequent and friendly cultural and scholarly exchanges between Taiwan and mainland China, new opportunities have arisen for cooperation and exchange in the area of science education research, a possibility that Lunetta and Lederman (1998) mentioned many years ago.

### *2.5.3 Conclusions and Recommendations*

Our review indicates that, as a whole, the DSE-funded research projects over the past three decades have successfully accomplished the intended goals: (a) upgrading the quality of science education research, (b) developing human resources, and (c) improving K-12 science and mathematics teaching in Taiwan. Although the extent to which progress along these broad goals has been made may vary, the results obtained from our questionnaire strongly support that the above goals have been accomplished and are widely accepted by science educators. Undoubtedly, this success must be attributed to both the favorable external conditions and the concerted efforts of the DSE and the science education research community. It is clear from our review that the DSE plays important roles in planning, guiding, and supporting science education research.

Judging from our own experiences and the observations of many science education researchers, we recognize that the DSE plays crucial roles in providing, shaping, and improving a favorable environment for members of the science education research community in Taiwan to do research and develop professionally. Science education researchers in Taiwan are formally and informally connected within a network consisting of researchers working individually and in collaborative research groups. Collaboration may take place for researchers belonging to different institutions and across different disciplinary areas. It may involve researchers from a number of significant interest groups, whose research interests may be in different strands or themes related to science education research (such as learning, teaching, assessment, teacher education, educational technology, and so on).

While the funding of research projects is based on meritocratic principles, the DSE uses various strategies and procedures to encourage and support groups of researchers. Since the reviewers, the panel members, and the Chairman of the DSE all come from academia, the mutual understanding, communication, and cooperation between the DSE and the rest of the science education community are excellent. The DSE should make pertinent changes to the funding policies, funding schemes, award system, and other related practices in response to changing external environments and internal demands from the science education research community. In effect, guided by the national policies and strategies on science and technology, the DSE effectively uses its available financial and human resources with science education researchers in Taiwan to form a community that continues to learn, develop, and accomplish the expected missions. This is perhaps a strategy or a model that a government funding organization can execute fruitfully with the researchers, the research institutions, and the wider research community. Taking "researchers as learners," it is interesting to note that the model above appears to have met the kind of learning environment that is advocated in the book titled *How People Learn: Brain, Mind, Experience, and School*, in the sense that an effective learning environment should be learner, subject matter, assessment, and community centered (National Research Council 2000).

Many changes are taking place concerning the development of research in science education in Taiwan. The situation is complex and there are many uncertainties. Based on the historical review in this study, we would like to make a few recommendations. First, based on the results of the questionnaire, future research in science education needs to pay attention to its impact on the teaching and learning of science and mathematics and on educational reforms in general. The DSE has encouraged faculty members working in areas closely related to science and mathematics to apply for research grants in science education. While widening the range of acceptable academic disciplines and encouraging cross-disciplinary faculty members to apply for research grants to the DSE diverts funds away from mathematics and science, in terms of implementing the visions and goals of science education reforms, it appears to be a good strategy to inform more faculty members about the importance of education, and science education in particular, and invite them to work together toward common goals. In fact, it is always desirable to establish closer links between research, practice, and policy in science education. Since there are very rich research findings and products accumulated over the years, a more systematic effort needs to be made to distill and summarize the research results and make them easier for practitioners and policymakers to use.

Second, in recent years, the DSE has been advocating cooperation between researchers and business partners in an effort to produce research results that can be turned into marketable educational products for both the domestic and international markets. There has been some initial success, and it is recommended that it is the time to carefully assess the outcomes and impacts, and consider the possibility of scaling up such efforts. How to coordinate the interactions between the DSE, the researchers, and the businesspeople to produce marketable research products becomes a new challenge. Perhaps the existing symbiotic relationship between the DSE and the science education researchers can serve as a model in this respect.

Third, from the point of view of government funding policy, it is important to decide which research field to invest focused supports and resources so that they will lead to satisfactory outcomes. In Taiwan, science education research appears to be a field which has the potential to reach academic excellence and find practical applications. Factors contributing to this include, for instance, that mathematics and science are important school subjects, there is a good supply of talented researchers, the demands for financial supports and a science literate workforce in conducting research are relatively low, it is relatively easy for the number of researchers to reach a "critical mass," and there are open and friendly international research communities providing abundant research findings and learning opportunities. Of course, an effective and efficient funding agency, a cohort of competent and devoted researchers, a supportive wider environment, and wise decisions made at the right time are indispensable. The case story in this review serves to echo a quote by Aristotle (http://www.goodreads.com/author/quotes/2192.Aristotle): "Excellence is never an accident. It is always the result of high intention, sincere effort, and intelligent execution; it represents the wise choice of many alternatives—choice, not chance, determines your destiny." (n.d.)

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# Chapter 3
# Trends in Science Education Research in Taiwan: A Content Analysis of the *Chinese Journal of Science Education* from 1993 to 2012

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**Abstract** This chapter describes a content analysis that served three purposes. First, it investigated science education research trends in Taiwan as represented by publications from 1993 to 2012 in the *Chinese Journal of Science Education* (*CJSE*), an official journal of the Chinese Association for Science Education in Taiwan. This was done by breaking down the 20-year interval into four periods. Second, the results were compared with those in international journals. Finally, we analyzed trends in authorship as well as in the tendency to publish in *CJSE* compared to the international journals. We analyzed 394 articles published in the first 20 years of *CJSE* (1993–2012). The results showed that *CJSE* published a very high percentage of empirical studies (96%) over the past 20 years. The most common research area involved learning (26.4%), including 15.0% of concept learning and 11.4% of process skills, followed by teacher education (12.9%), and teaching strategies (12.9%). Studies investigating goals, policy, curriculum (2.3%), informal learning (1.8%) or textbook and text analysis (1/0%) were equality absent. In addition, *CJSE* published several relatively balanced quantitative and qualitative studies. Twenty-six percent of the articles were pure quantitative data while 22.6% were qualitative reports. Moreover, there was a high percentage (25.3%) of articles, which include both quantitative and qualitative data. We also found that about 74.6% of the studies used students as their participants, while 28.4% had samples composed of teachers (including pre- and in-service teachers). Finally, the results revealed that science education researchers in Taiwan tended to publish in either *CJSE or* international journals. Very few Taiwanese researchers published in both. Implications for the future of science education research in Taiwan are discussed in this chapter.

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## 3.1 Introduction

An academic journal devoted to one discipline and operated in accordance with the standards of that discipline's professional society serves many purposes. It not only provides a platform where researchers can share their research but also highlights the development of the field over time. The Chinese Association for Science Education in Taiwan was established in 1988 and now has a membership around 1200 (Chiu 2000). In 1993, the Chinese Association for Science Education launched its first official journal, *Chinese Journal of Science Education (CJSE)*. In the beginning, *CJSE* published articles twice a year. Then in 1997, it became a quarterly journal. In 2006, *CJSE* began publishing six times a year. This national journal is one of the most influential academic journals in science education research in Taiwan. *CJSE* has long been recognized for its quality publications and, in 2010, was included in the Taiwan Social Science Citation Index (TSSCI). The Ministry of Science and Technology (formerly known as National Science Council) in Taiwan financially supports *CJSE*.

Chang et al. (2002) used three subjective indicators (i.e., expert judgment, paper submission preferences, and reading preferences) to identify the status of national journals in Taiwan. The results showed that *CJSE*, *Proceedings of the NSC Part D*: *Science and Technology Research* (former journal of *International Journal of Science and Mathematics Education*, *IJSME*), and *Journal of National Taiwan Normal University (NTNU): Mathematics & Science Education* (currently known as *Journal of Research in Education Sciences*) were consistently ranked the highest regardless of which indicator was used. In this chapter, we focus our analysis on *CJSE* because the *Proceedings of the NSC Part D* was transformed into an international journal that accepts manuscripts from all over the world and uses English as its official language, and the journal of NTNU was reorganized to accept manuscripts related to interdisciplinary areas in education. Therefore, these two journals were not considered for analysis in this study.

In order to uncover the development of science education research in Taiwan, we compared publications in *CJSE* with content analysis of science education research published in other journals (Chen et al. 2005; Lee et al. 2009; Tsai and Wen 2005) As for research types and topics, we compared our results with those found in Lee et al.'s review (1998–2007), and for the research methods we compared our results with those found in Chen et al.'s study (2000–2004). Below, we discuss the procedures used to identify the national journals and publications that were included in this content analysis. The results of this content analysis show Taiwan's standing in the international science community and highlight current and future trends in research and publishing both locally and internationally. All sub-tables denoted with an "a" (such as Table X-a) would signify trends in *CJSE* while all sub-tables with a "b" (such as Table X-b) would be for international comparisons (research question 3 stated below).

## 3.2 Conceptual Background

### *3.2.1 Chinese Journal of Science Education*

The Chinese Association for Science Education (ASE) in Taiwan launched its own professional journal, *Chinese Journal of Science Education* (*CJSE*), as the official journal of ASE in 1993. The purpose of *CJSE* is to promote high-quality mathematics and science education research and facilitate the communication between research and practice. While the publication schedule for *CJSE* has changed over the years, it currently publishes four issues each calendar year: March, June, September, and December. *CJSE* invites research involving experiments, case studies, surveys, philosophical or historical reports, and commentaries on literature and theoretical analysis. *CJSE* is considered the top science education journal in Taiwan. It joined the list of TSSCI journals in 2010. In general, the *CJSE* editorship lasts for a term of 3 years. Next, we describe the international journals selected for comparison purposes.

### *3.2.2 Selected SSCI International Journals in Science Education*

There are several leading science education journals that influence science educators' research across the globe. These five well-known international journals include *Science Education, Journal of Research and Science Teaching (JRST)*, *International Journal of Science Education (IJSE, formerly known as European Journal of Science Education), Research in Science Education (RISE),* and *International Journal of Science and Mathematics Education (IJSME)*. Some of these journals have a long history of publishing professional articles while others have a relatively shorter history. However, each journal plays a unique role in the field and has its own vision to fulfill. The following is a brief description of each of the selected journals.

In 1916, *Science Education* was launched in the USA under its original title, *General Science Quarterly.* The journal published one issue in 1916 and three issues in 1917 with the length of each article ranging from 2 to 10 pages. The name of the journal was changed to *Science Education in 1930,* and that is the name currently used today. The journal currently publishes six issues per year and has done so since 1989. For nearly a century, this journal has provided opportunities for science education researchers to share ideas and outcomes within and across domains.

In 1963, *Journal of Research and Science Teaching (JRST)* was launched as the official journal of the National Association for Research in Science Teaching (NARST), which is the biggest science education research association in the USA. In celebration of *JRST*'s 50th anniversary, the journal published a special virtual issue highlighting the most influential works over the past 50 years JRST in 2013.

Topics covered in the special issue included cognitive development, inquiry learning, conceptual change, sociocultural learning, scientific literacy, teacher professional development, and argumentation in school practice. *JRST* publishes ten issues per year and has done so since 1990.

*International Journal of Science Education (IJSE)* was formerly known as *European Journal of Science Education* but changed its name in 1986. The journal increased the number of issues it published from 4 in 1979 to 10 in 1997 and then to 18 issues in 2009, which was the highest number of annual issues for any of the five top international journals.

*Research in Science Education* is the official journal of the Australasian Science Education Research Association (ASERA). The ASERA is the second oldest science education research body in the world after the National Association for Research in Science Teaching in the USA (http://asera.org.au/). In 1972, the journal was titled *Research* and, in 1973, was retitled *Science Education: Research*. Finally, in 1974 a permanent name was adopted, *Research in Science Education (RISE)*. In 1995, *RISE* was transformed into a journal that readers see today, and it was no longer linked to the ASERA conference. In 2003, *RISE* became an Institute for Scientific Information (ISI)-listed journal and thus joined *JRST*, *Science Education*, and *IJSE* as one of the major international science education research journals. *RISE* publishes a varying number of issues each year with the annual number of issues being three to six.

*International Journal of Mathematics and Science Education (IJSME)* was launched in 1993 to provide both science and mathematics educators an opportunity to publish their work in this integrative journal sponsored by the National Science Council in Taiwan. The former name of this journal was *Proceedings of the NSC Part D: Science and Technology Research*. Before *IJSME* became an international journal, it was ranked as the top journal for science educators to submit formal research reports in Taiwan. In 2010, *IJSME* became one of the SSCI journals.

The impact factors, over the past 20 years, for each of these international journals are listed in Table 3.1. In general, their impact has been steadily increasing.

### *3.2.3 Comparisons with Former Studies*

Smith (1993) pointed out that content analysis is a way of systematically analyzing the content of a large body of information. This systematic analysis reveals the "obvious and embedded content of a body of communicated material by classifying, organizing, and evaluating its major assertions, symbols, and themes in order to assess its meaning and impact" (p. 209). Since *CJSE* has been publishing for 20 years, it provides an excellent medium for investigating trends in research topics and methodologies. This chapter explores these research trends in Taiwan and compares the findings to trends in international journals. Due to the recent practice of evaluating researchers' performance based on the number of publications in journals on the SSCI list, there was an abrupt increase in the percentage of articles in SSCI publications written by scholars in Taiwan. For instance, over the past 20 years, scholars in

**Table 3.1** Impact factors of the selected international journals

| | 1993–1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JRST | NA | 0.880 | 1.008 | 0.992 | 0.664 | 0.990 | 1.094 | 1.202 | 1.011 | 1.022 | 1.148 | 1.048 | 1.910 | 2.728 | 2.639 | 2.552 | *1.393* |
| SE | NA | 0.695 | 0.987 | 0.918 | 0.840 | 0.900 | 0.877 | 1.312 | 1.159 | 1.362 | 0.936 | 1.088 | 1.625 | 1.900 | 1.775 | 2.382 | *1.250* |
| IJSE | NA | 0.483 | 0.405 | 0.705 | 0.476 | 0.416 | 0.574 | 0.436 | 0.553 | 0.415 | 0.541 | 0.690 | 1.047 | 1.063 | 1.232 | 1.340 | *0.692* |
| RISE | NA | – | – | – | – | – | – | 0.269 | 0.370 | 0.152 | 0.317 | 0.500 | 1.088 | 0.853 | 1.342 | 1.104 | *0.666* |
| IJSME | NA | – | – | – | – | – | – | – | – | – | – | – | – | – | 0.529 | 0.460 | *0.495* |

Taiwan published 14 articles in *JRST*, 24 articles in *Science Education*, 82 articles in *IJSE*, 13 articles in *RISE*, and 61 articles in *IJSME* (see Chap. 1 of this book). In addition, we discuss the impact of increasing numbers of research studies conducted by researchers in Taiwan being published in international journals. In other words, does increase in the number of Taiwanese researchers publishing in international journals result in a decrease in the number of submissions from senior researchers to national journals? There are some local concerns raised by this question. In this chapter, we present our content analysis and compare the research trends in Taiwan with those in the international community and elucidate the implications for science education in Taiwan and beyond.

In recent years, increasing numbers of content-analysis studies have been published, and these studies demonstrate trends in science education research (Chang et al. 2010; Chen et al. 2005; Eybe and Schmidt 2001; Lee et al. 2009; Sozbilir et al. 2012; Tsai and Wen 2005; Tsai et al. 2011; White 2001). The focus of these studies was mainly on research types, science subjects, research methods (including quantitative, qualitative, quantifying qualitative data), participants, data collection, data analyses, and statistics methods.

In this chapter, in order to compare our results to the other existing studies, we chose two articles (Chen et al. 2005; Lee et al. 2009) with which we compare our analysis. Below are descriptions of these two studies.

Aimed at understanding the direction of science education between 2000 and 2004, Chen et al. (2005) conducted a content analysis of 934 articles from four international science education journals. Seven dimensions were examined: topic, type of article, type of empirical research, method of data collection, method of data analysis, quantitative methodology, and the demographic distribution of participants. The results showed that there was a dominance of research on conceptual learning. Article type was mostly empirical research. Among these empirical research studies, case studies were most prevalent. For method of data collection, there were slightly more single data source-based studies than multi-data source-based studies. Among the multi-data source-based studies, tests and surveys dominated. In terms of the method of data analysis, single-method studies outnumbered multi-method studies with qualitative studies leading among the single-method studies. What is noteworthy is the gradual increase in the number of studies that adopted multiple data sources and multiple analysis methods over the years. Over half of the studies had multiple data sources, and just over one-third adopted multiple analysis methods. For quantitative methodology, *t*-test and ANOVA were performed most often. Although multivariate analysis was used less often, it still had a substantial presence. In terms of participants, students, especially secondary level students, were the most common category. Yet, there was a gradual increase in the use of the general public and other kinds of participants. Lastly, there were differences among the four journals. In terms of topic, relatively high percentages of articles appeared in *IJSE* (51.3 %) and *SE* (41.3 %) focused on conceptual learning compared to *JRST* (32.0 %) and *RISE* (28.7 %). *RISE* tended to have more articles (17.1 %) related to teaching compared to the other journals. Among these journals, *JRST* had a relatively high percentage of culture-related articles (12.7 %) while the others were lower than 5 %. In the method of data analysis, the proportion of quantitative analyses in *RISE* was lower than in the other journals. On statistical methods, descriptive statistics dominated *RISE,* while the other three journals had mainly inferential statistics.

Lee et al.'s (2009) study adopted the content analysis methods developed by Tsai and Wen (2005) and investigated a total of 869 papers published in three journals between 2003 and 2007. In their article, Lin et al. also compared research trends between 2003 and 2007 to those between 1998 and 2002 that were analyzed by Tsai and Wen. According to their analyses, science educators showed relatively more interest in research topics involving the context of student learning. Science educators shifted their research interests from student learning and conceptual change (1998–2002) to student-learning contexts (2003–2007).

Although there are existing sources for analyzing the contents of the published journal articles, due to the objectives of this research, we developed pedagogical categories for analyzing our target journal, *CJSE*, and for comparing *CJSE* with international journals.

## 3.3 Research Questions

There are three main research questions and four sub-questions answered in this report. They are:

Research Question 1: What was the distribution of all the articles, including the most cited articles, in *CJSE* from 1993–2012?

1. : What was the distribution of research types and topics?
2. : What were the research methods used for data collection?
3. : What were the research methods used for data analysis?
4. : What were the distributions of authorship as categorized by academic status?

Research Question 2: How did the authors' number of articles in *CJSE* compare to their number of articles published in the international articles?

Research Question 3: Did the trends in science education research in Taiwan parallel those evident from the international journals?

## 3.4 Methods

In order to answer the research questions as stated in the previous section, an extensive content analysis was conducted on all published articles in *CJSE* from 1992 through 2012. The method that was undertaken is explained in the following section, which begins by specifying the target articles. This is followed by an explanation of how the coding scheme was set up within the content analysis procedure. The steps involved in coding the articles are then described. The method section closes with an explanation of the analyses used in this study.

### 3.4.1 Target Articles

Since *CJSE* is highly regarded as the most important journal in the area of science education in Taiwan, most scholars will attempt to send their better manuscripts, written in Chinese, to this journal for publication consideration. In view of the level of significance of this journal, we decided to incorporate as many articles published in *CJSE* as possible for subsequent inspection. Accordingly, we decided to include every article into our study starting from the first issue of *CJSE*. The preparation of the project started in October, 2012, and the coding procedure started in February, 2013. It was deemed more convenient to include articles published up to the last issue of the previous year. As a result, we identified a total of 394 articles as our target articles that were published within the 20-year period starting from 1993 to 2012. In order to compare our findings with Lee et al.'s (2009) study, which used a 5-year period as their interval for analysis, we broke down the 20 years into four periods of 5 years each to show trends over time in research and publication. Table 3.2 reports the number of published articles for every 5-year period starting from 1993 when the journal was first launched. There were fewer articles published during the first 5-year period because there were only two issues in each of the first four volumes of the journal. Together, there were only 29 papers published in the first 4 volumes. Starting from 1997, *CJSE* evolved into a quarterly journal that published five articles per issue. Then in 2006, the journal further expanded and started delivering six issues per year in order to accommodate the increasing volume of papers submitted for publication consideration.

### 3.4.2 Formation of an Analytical Framework

In this chapter, we used content analysis method with special interest in the following topics, namely, methodological issues, scientific disciplines, and authorships, to analyze the selected journal articles. Our analysis would provide support for the implementation and the making of policies as well as for international comparisons aimed at promoting scientific literacy and educational reforms (See Fig. 3.1).

**Table 3.2** Number of articles published in *CJSE* from 1993 to 2012

| Year | 1993–1997 | 1998–2002 | 2003–2007 | 2008–2012 | Total |
|---|---|---|---|---|---|
| # of articles | 49 | 100 | 120 | 125 | 394 |

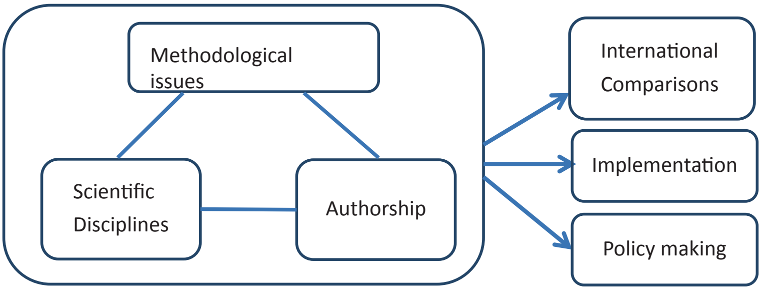


**Fig. 3.1.** The framework for content analysis of this study

### *3.4.3* Coding Scheme *(Including Development, Criterion, Validity, and Reliability)*

The coding schemes were established in two stages. In early October, 2012, the three authors along with a research assistant first convened to discuss how to establish a coding scheme to capture various features of the target articles so as to answer the research questions. It was decided we could begin by studying the coding schemes that were developed by Tsai and Wen (2005), Lee et al. (2009), and Chen et al. (2005). The former paper applied a coding scheme to the research topics of published articles in three international journals. This coding scheme included nine categories adopted by the National Association for Research in Science Teaching (NARST) organization for classifying submitted papers. The latter paper employed a richer classification on the types of research and also on the types of data analysis being reported in articles published in four international science education journals. Hence in this study, we decided to combine the approaches of both papers in order to compare our results with past findings that reflected international research efforts. Nevertheless, necessary modifications were added whenever appropriate, especially with respect to the expansion of the original categories to accommodate the emphasis of more recent research. The components of our coding scheme are described below.

*Research Type.* All of the articles were categorized as empirical or nonempirical. The subcategories under empirical included pre-experimental design, true experimental design, quasi-experiment, correlation, survey, action research, case study, field investigation, meta-analysis, and content analysis. The subcategories for nonempirical studies included theoretical and review articles. These subcategories were developed based on the commonly used research methods (i.e., Cohen et al. 2007).

*Research Topics* In order to answer the research questions that guided this study, we used Chen et al.'s (2005) and Tsai and Wen's (2005) categories but modified and extended them from nine to eleven types of topics. The topics included:

1. Teacher Education: Included preservice and continuing professional development of teachers, teacher education programs and policies, field experience, issues related to teacher education reform, teacher as researcher/action research, leadership, induction, pedagogical content knowledge, teacher beliefs, teacher cognition, pedagogical knowledge and pedagogical content knowledge, forms of knowledge representation (e.g., metaphors, images), exemplary teachers, and teacher thinking.
2. Teaching: Included teaching behaviors and strategies, argumentation instruction, analogical teaching, instructional representation and strategies, specific instruction, and teaching methods.
3. Learning I: Included students' alternative conceptions, conceptual change, conceptual development, and methods for investigating student understanding. Two new sub-categories were developed, namely conceptual learning and process skills (such as process skills, problem solving, reasoning, and reflective, creative, and logical thinking, argumentation, and metacognitive strategies).
4. Learning II (contextualized learning): Included student motivation, affective dimensions of science learning, attitude, self-efficacy, teacher–student interactions, peer interactions, language, writing and discourse in learning, laboratory and learning context, cooperative learning, individual differences, exceptionality, and cognitive style.
5. Goals, Policy, and Curriculum: Included curriculum development, dissemination and evaluation, curriculum policy and reform, teacher evaluation, and identifying effective schools.
6. Evaluation and Assessment: Included educational measurement, alternative forms of assessment, program evaluation, and development and implementation of research instrument.
7. Cultural, Social, and Gender Issues: Included multicultural, bilingual, ethnic, gender issues, comparative studies, and diversity issues related to science education (such as disparity between urban and rural areas, social scientific issues, science-technology-society, and environmental education).
8. History, Philosophy, Epistemology, and Nature of Science: Included historical (i.e., history of science or mathematics), philosophical, epistemological, ethical and moral issues (general), nature of science, worldview, research methods from the perspectives of NOS, and scientific literacy.
9. Educational Technology: Included computers, interactive multimedia, video, integration of technology into teaching, and learning and assessment involving the use of technology.
10. Informal Learning: Included science learning in informal contexts (e.g., museums, outdoor settings) and public awareness of science.
11. Textbook and Text Analysis: Included school science textbooks and selected text for analysis.

*Data Collection Methods* We analyzed all of the empirical studies and the methods used to collect the research data. One paper could have multiple codes if it used more than one method to collect data. The codes included paper and pencil test, questionnaire, interview, observation, drawing, concept map, on-line data collection, related document (i.e., worksheets, portfolio), and experiment in the science laboratory.

*Participants* Three major categories were investigated: students, teachers, and others. The student category included before elementary, elementary, junior, and senior high school students, as well as undergraduate and graduate students. The teacher category included preservice and in-service teachers. Finally, the third category had a wide range of participants such as administrators, scientists, science education experts, authority figures, parents, the public, even the textbook/curriculum, and academic articles.

*Data Analysis Types* This aspect was adopted from Chen et al. (2005) and included qualitative, quantitative, quantifying qualitative data, and combinations of two or three methods.

*Quantitative Data Analysis Methods* Descriptive and inferential statistics were the focus of the analyses. Inferential statistics included *t*-test, Chi-square test, ANOVA and GLM, ANCOVA, correlation, MANOVA, MANCOVA, regression, factor analysis, path analysis, HLM, SEM, MDS, and nonparametric methods. Also, we used an additional category to code papers that used self-developed instruments with reliability and validity provided.

*Authorship* Based on the hypothesis that fewer authors with full professorship in Taiwan published their research in *CJSE*, we analyzed article authorship by categorizing the status of the first author (including graduate students and in-service teachers), as well as any noted relationship between the first author and other authors (e.g., adviser–advisee relationship). Either single author or multiple authors were also identified.

*Researchers' Recognition and Contribution.* As the last aspects were to be investigated, highly cited articles in *CJSE* were identified, and researchers' publication preference for *CJSE* over international journals was calculated. First, we used the Database of Research in Science Education (DORISE) to calculate the citations for each article published in *CJSE* during 1993–2012. Due to the difference in publication years among articles, the number of citations was divided by the number of years until 2012. For instance, if an article was published in 2003 and the number of citations for this article was 20, then the average citation of the article was 2 (20 citations divided by 10 years). Fifteen articles that were cited more than once per year were analyzed for seven dimensions mentioned above and compared with all the articles published in *CJSE*. The details are tabulated in Appendix A.

Second, for each researcher who published his/her article in *CJSE*, we calculated the number of articles the author published in *CJSE* and the number by the same author published in five international journals (i.e., *JRST*, *SE*, *IJSE*, *RISE*, and *IJSME*) over the time period 1993–2012. Then, proportions of publications in *CJSE* over all six journals were calculated to reveal the author's contribution to *CJSE* compared with the author's contribution to international science education journals.

### *3.4.4 Procedures*

The establishment of the coding scheme was divided into two phases. The main focus of the first phase was to design a coding scheme for the classification of the research types in the published articles in *CJSE* from 1993–2012. The three authors plus a research assistant formed a committee and met from October of 2012 to March of 2013 for a total of eight meetings for this purpose. At the beginning, the committee decided to basically follow the framework laid down by Tsai and Wen (2005) and made minor modifications as deemed appropriate. For example, we extended their learning–conception category into the category emphasizing students' conceptions and conceptual change. Furthermore, we extended their category on learning–context to classroom contexts and learner characteristics. These changes reflected the specific interest of local authors to contribute to the area of science learning in Taiwan. It was further decided that each article should be classified into only one type of research. In case there were articles that served multiple purposes and could be classified into multiple categories, only the dominant purpose of the study was used for classification.

After the coding scheme was preliminarily established, the three authors decided to try out the tentative coding scheme on the articles published in the first five volumes of *CJSE.* This was done by requiring the three authors to carefully read and independently code each article with respect to the type of research it represented. At subsequent meetings, we compared our classifications with one another in order to check the appropriateness of the coding scheme. If there was any discrepancy, it was discussed on the spot. The whole committee would then read the abstract and the whole article together, followed by further discussion until a consensus was reached to everyone's satisfaction. The same procedure was maintained until the whole coding process was completed. Based on our discussion at later meetings, we decided to add extra categories, such as informal learning and textbook and text analysis, to the list.

The main purpose of the second phase was to find out the rest of the features that were of interest to us, such as the types of research methods, including both the quantitative and the qualitative paradigm, that were being used by science education researchers. Other specific features included the instruments being used to collect the data as well as the background of the research participants. This portion involved many features, and six meetings were held from April to September of 2013. During these meetings, the committee discussed and decided to follow various coding schemes as devised by Chen et al. (2005) but with modifications that were deemed necessary to accommodate research trends after 2005. Afterward, the three authors tried out the tentative coding schemes on several volumes, as was done during the first phase of this project. The coding was then compared. Discussions ensued whenever discrepancies were identified. When modifications of the coding schemes were more or less settled, the three authors were paired up in different ways to code the rest of the journal articles. For example, the first and the third authors were responsible for coding all articles in volume 17, the first two authors were responsible for coding all articles in volume 18, and the second and the third authors were responsible for coding all articles in volume 19. Their codes were then compared, and discrepancies (if present) were discussed. This phase was more difficult because there were many features being investigated, and within each feature there were multiple codes available. For example, in relation to the exact type of statistics used, some authors used a number of analysis procedures. In these circumstances, more discrepancies were identified. As a result, there were nine extra meetings between each pair of coders to discuss the discrepancies in their codes.

### *3.4.5 Data analysis*

After discrepancies were resolved, the codes were tallied and inter-rater reliabilities were computed. Since for certain features multiple codes were allowed in classifying the publications, we decided to use percentage agreements and kappa as a means to check for inter-rater reliability. Since there were many features being considered, we report in this chapter the percentage agreement only for volumes 17–19 for the sake of simplicity. Out of the various features being coded, the percentage agreements among the raters ranged from 46 to 96 %, with a mean of 71.3 % and a median of 71 %. This range is quite typical of those found in the other volumes. A word of explanation about why there was agreement as low as 46 % should be given here. This was basically due to differences among coders in terms of assigning multiple codes. This kind of mismatch was not considered serious by our committee. All discrepancies were discussed and the articles were re-read and reclassified until final consensus was achieved. So by the last meeting in September, a final set of coding was produced, and the codes were tallied and aggregated into various tables. Analyses were performed by way of descriptive statistics, trend tests, and correspondence analysis. Due to the limitation of publishing space, only the results from descriptive statistics are reported here.

## 3.5 Findings and Discussions

The following sections present the data based upon the research questions:

Research Question 1: What was the distribution of all the articles, including the most cited articles, in *CJSE* from 1993–2012?

RQ 1-1: What was the distribution of research types and topics in *CJSE* from 1993–2012?

*Research types.* According to Table 3.3, the majority of articles (97.5 %) were empirical studies over the past 20 years (1993–2012). Among these empirical studies, 29.9 % were survey studies, 22.6 % were case studies, and 20.1 % were quasi-experimental designs. These three research types were the most commonly used by science education researchers over the past 20 years. The rankings were quite

**Table 3.3** The percentages of articles by research type in *CJSE* from 1993–2012

| Years, *n* (%) | 1993–1997 (*n* = 49) | | 1998–2002 (*n* = 100) | | 2003–2007 (*n* = 120) | | 2008–2012 (*n* = 125) | | 1993–2012 (*n* = 349) | | Most cited articles *n* = 15 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Research type | *n* | (%) | *n* | (%) | *n* | (%) | *n* | (%) | *n* | (%) | *n* | (%) |
| 1. Empirical | 48 | (98.0) | 96 | (96.0) | 119 | (99.2) | 121 | (96.8) | 384 | (97.5) | 14 | (93.3) |
| 1-1 Pre-experimental design | 4 | (8.2) | 6 | (6.0) | 14 | (11.7) | 9 | (7.2) | 33 | (8.4) | 1 | (6.7) |
| 1-2. True experimental design | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| 1-3. Quasi-experimental | 11 | (22.4) | 15 | (15.0) | 23 | (19.2) | 30 | (24.0) | 79 | (20.1) | 5 | (33.3) |
| 1-4. Correlational studies | 2 | (4.1) | 5 | (5.0) | 4 | (3.3) | 8 | (6.4) | 19 | (4.8) | 0 | (0.0) |
| 1-5. Survey studies | 13 | (26.5) | 36 | (36.0) | 39 | (32.5) | 30 | (24.0) | 118 | (29.9) | 4 | (26.7) |
| 1-6. Action research | 4 | (8.2) | 9 | (9.0) | 8 | (6.7) | 2 | (1.6) | 23 | (5.8) | 1 | (6.7) |
| 1-7. Case study | 12 | (24.5) | 19 | (19.0) | 26 | (21.7) | 32 | (25.6) | 89 | (22.6) | 2 | (13.3) |
| 1-8. Field investigation | 0 | (0.0) | 2 | (2.0) | 0 | (0.0) | 3 | (2.4) | 5 | (1.3) | 0 | (0.0) |
| 1-9. Meta-Analysis | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.8) | 1 | (0.3) | 0 | (0.0) |
| 1-10. Content analysis | 2 | (4.1) | 4 | (4.0) | 5 | (4.2) | 6 | (4.8) | 17 | (4.3) | 1 | (6.7) |
| 2. Non-empirical study | 3 | (6.1) | 6 | (6.0) | 2 | (1.7) | 5 | (4.0) | 16 | (4.1) | 1 | (6.7) |
| 2-1. Theoretical article | 1 | (2.0) | 1 | (1.0) | 0 | (0.0) | 2 | (1.6) | 4 | (1.0) | 0 | (0.0) |
| 2-2. Review article | 2 | (4.1) | 5 | (5.0) | 2 | (1.7) | 3 | (2.4) | 12 | (3.0) | 1 | (6.7) |

Note: Some articles included both empirical and non-empirical studies so they might be double-coded for these comparisons.

**Table 3.4** Comparisons of percentages of research types between 1998–2002 and 2003–2007 (Lee et al. 2009; Chen et al. 2005)

| Study | Lee et al. (2009) | | Chen et al. (2005) | | This study | |
|---|---|---|---|---|---|---|
| Years ($n$) | 1998–2002 ($n$=802) | 2003–2007 ($n$=869) | 2000–2002 ($n$=546) | 2003–2007 ($n$=388) | 1998–2002 ($n$=100) | 2003–2007 ($n$=120) |
| Empirical (%) | 86.9 | 87.8 | 82.4 | 87.4 | 96.0 | 99.2 |
| Non-Empirical (%) | 13.1 | 12.2 | 17.6 | 12.6 | 6.0 | 1.7 |

consistent except during the period of 2008–2012 when case studies ranked number one (25.6 %), while the other two were ranked equally (24.0 %). Among the total research types, there was only one article that used the meta-analysis approach. As for the non-empirical articles, the majority were reviews of existing literature. Not surprisingly, no true experimental studies were found in the sample. As Cohen et al. (2007) pointed out, most empirical studies in educational settings are undertaken with intact groups rather than random selection.

The 15 most cited articles had a similar pattern to that of all the articles. Specifically, most of them were empirical studies while one of them was a literature review comparing theories about conceptual change. For the 14 articles that were empirical studies, five, four, and two of them used quasi-experimental methods, surveys, and case studies, respectively. These three methods were the most frequently used in all articles in *CJSE*. In addition, there was one single article that used a pre-experimental design, one that used action research, and one that used content analysis. These three methods were infrequently used in the other articles as well.

Table 3.4 indicates that there were consistently high percentages of empirical studies published in both national and international journals. In particular, *CJSE* tended to have higher percentages of papers in the area of empirical research compared to the international journals. These results are not surprising; however, the relatively high percentage of empirical research might set a caveat for us to be more reflective about the impact of these studies in school science practice. On the other hand, science education researchers need to be cautious about implanting or developing theoretical frameworks for school science.

*Research topics*. According to Table 3.5, 26.4 % of the empirical studies were in the area of learning, 12.9 % were in teacher education, and 12.9 % were in teaching strategies. This was followed by "evaluation and assessment" (9.6 %), contextualized learning (8.1 %), and "history, philosophy, epistemology and nature of science" (7.1 %). Very low percentages of articles were published in the area of policy and curriculum, cultural and gender aspects, informal learning, and text and textbook analysis. However, we did observe a peak of evaluation and assessment during the period 2003–2007. This was due to a national survey on students' conceptions in science sponsored by the National Science Council during the period 2001–2004. Therefore, the outcomes of those projects were expected to be published in *CJSE* during that period.

**Table 3.5** The numbers and percentages of research topics in *CJSE* from 1993–2012

| Years, *n* (%) | 1993–1997 (*n*=49) | | 1998–2002 (*n*=100) | | 2003–2007 (*n*=120) | | 2008–2012 (*n*=125) | | 1993–2012 (*n*=394) | | Most cited article (*n*=15) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Research topics | Empirical (%) | Nonempirical (%) | Empirical (%) | Nonempirical (%) | Empirical (%) | Nonempirical (%) | Empirical (%) | Nonempirical (%) | Empirical (%) | Nonempirical (%) | Empirical (%) | Nonempirical (%) |
| 1. Teacher education | 7 (14.3) | 1 (2.0) | 13 (13.0) | 0 (0.0) | 15 (12.5) | 0 (0.0) | 16 (12.8) | 0 (0.0) | 51 (12.9) | 1 (0.3) | 3 (20.0) | 0 (0.0) |
| 2. Teaching strategies | 5 (10.2) | 0 (0.0) | 9 (9.0) | 0 (0.0) | 19 (15.8) | 0 (0.0) | 18 (14.4) | 0 (0.0) | 51 (12.9) | 0 (0.0) | 1 (6.7) | 0 (0.0) |
| 3. Learning - I | 14 (28.6) | 0 (0.0) | 23 (23.0) | 3 (3.0) | 21 (17.5) | 1 (0.8) | 46 (36.8) | 0 (0.0) | 104 (26.4) | 4 (1.0) | 5 (33.3) | 1 (6.7) |
| 3-1. Concept learning | 9 (18.4) | 0 (0.0) | 14 (14.0) | 2 (2.0) | 14 (11.7) | 1 (0.8) | 22 (17.6) | 0 (0.0) | 59 (15.0) | 3 (0.8) | 2 (13.3) | 1 (6.7) |
| 3-2. Process skill, argumentation, problem solving, etc. | 5 (10.2) | 0 (0.0) | 9 (9.0) | 1 (1.0) | 7 (5.8) | 0 (0.0) | 24 (19.2) | 0 (0.0) | 45 (11.4) | 1 (0.3) | 3 (20.0) | 0 (0.0) |
| 4. Learning - II | 5 (10.2) | 0 (0.0) | 9 (9.0) | 0 (0.0) | 13 (10.8) | 0 (0.0) | 5 (4.0) | 0 (0.0) | 32 (8.1) | 0 (0.0) | 1 (6.7) | 0 (0.0) |
| 5. Goals, policy, curriculum | 1 (2.0) | 0 (0.0) | 1 (1.0) | 0 (0.0) | 1 (0.8) | 1 (0.8) | 6 (4.8) | 0 (0.0) | 9 (2.3) | 1 (0.3) | 1 (6.7) | 0 (0.0) |
| 6. Evaluation and assessment | 3 (6.1) | 0 (0.0) | 8 (8.0) | 0 (0.0) | 17 (14.2) | 0 (0.0) | 10 (8.0) | 0 (0.0) | 38 (9.6) | 0 (0.0) | 2 (13.3) | 0 (0.0) |
| 7. Cultural, social, and gender issues | 5 (10.2) | 0 (0.0) | 6 (6.0) | 1 (1.0) | 3 (2.5) | 0 (0.0) | 6 (4.8) | 2 (1.6) | 20 (5.1) | 3 (0.8) | 0 (0.0) | 0 (0.0) |

**Table 3.5** (continued)

| Years, $n$ (%) | 1993–1997 ($n$=49) | | | | 1998–2002 ($n$=100) | | | | 2003–2007 ($n$=120) | | | | 2008–2012 ($n$=125) | | | | 1993–2012 ($n$=394) | | | | Most cited article ($n$=15) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Research topics | Empirical (%) | | Nonempirical (%) | | Empirical (%) | | Nonempirical (%) | | Empirical (%) | | Nonempirical (%) | | Empirical (%) | | Nonempirical (%) | | Empirical (%) | | Nonempirical (%) | | Empirical (%) | | Nonempirical (%) | |
| 8. History, philosophy, epistemology, and nature of Science | 1 | (2.0) | 2 | (4.1) | 8 | (8.0) | 2 | (2.0) | 11 | (9.2) | 0 | (0.0) | 8 | (6.4) | 3 | (2.4) | 28 | (7.1) | 7 | (1.8) | 1 | (6.7) | 0 | (0.0) |
| 9. Educational technology | 2 | (4.1) | 0 | (0.0) | 13 | (13.0) | 0 | (0.0) | 10 | (8.3) | 0 | (0.0) | 2 | (1.6) | 0 | (0.0) | 27 | (6.9) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| 10. informal learning | 2 | (4.1) | 0 | (0.0) | 3 | (3.0) | 0 | (0.0) | 1 | (0.8) | 0 | (0.0) | 1 | (0.8) | 0 | (0.0) | 7 | (1.8) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| 11. Textbook and text analysis | 1 | (2.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (1.7) | 0 | (0.0) | 1 | (0.8) | 0 | (0.0) | 4 | (1.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| 12. Other | 0 | (0.0) | 0 | (0.0) | 1 | (1.0) | 0 | (0.0) | 5 | (4.2) | 0 | (0.0) | 1 | (0.8) | 0 | (0.0) | 7 | (1.8) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |

As for the nonempirical studies, the topics were mainly on “history, philosophy, epistemology and nature of science,” “cultural, social, and gender issues,” and “learning I.” The distribution of the topics for nonempirical studies was different from the empirical studies. This is understandable because most of the empirical studies dealt with school science in practice so the topics centered around teaching and learning; however, the nonempirical studies were concerned with personal viewpoints on different issues and provided reflective suggestions for science education reform.

For the 15 most cited articles, 6 dealt with learning, three were related to “teacher education,” and two with “evaluation and assessment.” This pattern was analogous to those found in all the articles in *CJSE*, although “teaching strategies” was underrepresented in most cited articles (i.e., only one out of 15 articles involved this issue). There were three individual articles that each investigated “contextualized learning,” “goal, policy and curriculum,” and “history, philosophy, epistemology, and nature of science” respectively.

Compared to the studies of Lee et al.’s (2009), we found that *CJSE* had relatively high percentages of studies in the areas of: (a) teacher education, (b) process skills, argumentation, and problem solving, and (c) educational technology (see Table 3.6). The percentages of articles on (a) contextualized learning and (b) policy, society, and gender issues were lower for *CJSE* than for the international journals. Compared to international journals, there are only a limited number of studies that investigated how research impacts policy and how cultural and scietal factors influence school science teaching and learning. Therefore, this is another direction that needs more attention from science education researchers.

RQ 1-2: What were the research methods used for data collection in *CJSE* from 1993–2012?

*Participants* As shown in Table 3.7, over the past 20 years, about 74.6 % of the participants were students. Among them, 27.4 % were elementary school students and 33.2 % were secondary school students. Besides, about 21.6 % of the participants were in-service teachers. There were low percentages with administrators, parents, general public, or curricula.

Consistent with the findings from all the articles, of the 14 most cited articles (excluding the nonempirical study), 10 of them studied students. Among these articles, elementary and junior high school students were the main participants. There was one study that used senior high school students as participants. One article studied preservice teachers, and three articles studied in-service teachers. Two articles studied both in-service teachers and junior high school students. There was one article that used science education experts and one other article that investigated textbooks.

The trend is quite similar between *CJSE* and international journals. The data were merged from 2000 to 2004 in the study of Chen et al. (2005), and 1998 to 2007 in this study because of the data format presented in Chen et al. From Table 3.8, it is evident that the majority of research investigated students’ learning and related issues whereas only one fourth of the studies investigated teachers’ teaching, beliefs,

**Table 3.6** Comparisons of the percentages of research topics in international and national studies from 1998 to 2007

| Study | Lee et al. (2009) | | This study | |
|---|---|---|---|---|
| Years (*n*) | 1998–2002 (*n* = 802) | 2003–2007 (*n* = 869) | 1998–2002 (*n* = 100) | 2003–2007 (*n* = 120) |
| 1. Teacher education | 6.9 | 9.0 | 13.0 | 12.5 |
| 2. Teaching | 6.6 | 13.9 | 9.0 | 15.8 |
| 3. Learning | 24.8 | 15.3 | 23.0 | 17.5 |
| 3-1. Concept learning | 24.8 | 15.3 | 14.0 | 11.7 |
| 3-2. Process skill, argumentation, problem solving, etc. | - | - | 9.0 | 5.8 |
| 4. Learning II (Contextulized learning) | 17.9 | 23.5 | 9.0 | 10.8 |
| 5. GPC | 13.7 | 12.7 | 1.0 | 0.8 |
| 6. E&A | - | - | 8.0 | 14.2 |
| 7. CSG | 14.4 | 6.8 | 6.0 | 2.5 |
| 8. HPE & NOS | 8.5 | 8.2 | 8.0 | 9.2 |
| 9. Educational technology | 3.4 | 5.4 | 13.0 | 8.3 |
| 10. Informal learning | 3.8 | 5.3 | 3.0 | 0.8 |
| 11. Textbook and text analysis | - | - | 0.0 | 1.7 |
| 12. Other | - | - | 1.0 | 4.2 |

Note 1: *GPC*: Goal, policy, and curriculum; *E & A*: Evaluation and assessment; *CSG*: Culture, society, and gender; *HPE & NOS*: History, philosophy, epistemology, and nature of Science.

**Table 3.7** The distribution of participants in the studies in *CJSE* from 1993–2012

| Years, *n* (%) | 1993–1997 (*n* = 49) | | 1998–2002 (*n* = 100) | | 2003–2007 (*n* = 120) | | 2008–2012 (*n* = 125) | | 1993–2012 (*n* = 394) | | Most cited articles (*n* = 14) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Participants | *n* (%) | | *n* (%) | | *n* (%) | | *n* (%) | | *n* (%) | | *n* (%) | |
| 1. Students | 37 | (75.5) | 72 | (72.0) | 96 | (80.0) | 89 | (71.2) | 294 | (74.6) | 10 | (71.4) |
| 1-1. prior to elementary school | 0 | (0.0) | 2 | (2.0) | 3 | (2.5) | 5 | (4.0) | 10 | (2.5) | 0 | (0.0) |
| 1-2. elementary school students | 12 | (24.5) | 21 | (21.0) | 41 | (34.2) | 34 | (27.2) | 108 | (27.4) | 5 | (35.7) |
| 1-3. junior high school students | 13 | (26.5) | 15 | (15.0) | 25 | (20.8) | 24 | (19.2) | 77 | (19.5) | 4 | (28.6) |
| 1-4. senior high school students | 7 | (14.3) | 20 | (20.0) | 13 | (10.8) | 14 | (11.2) | 54 | (13.7) | 1 | (7.1) |
| 1-5. Undergraduate and graduate students | 5 | (10.2) | 14 | (14.0) | 14 | (11.7) | 12 | (9.6) | 45 | (11.4) | 0 | (0.0) |
| 2. Teacher | 16 | (32.7) | 37 | (37.0) | 29 | (24.2) | 30 | (24.0) | 112 | (28.4) | 4 | (28.6) |
| 2-1. Pre-Service teacher | 7 | (14.3) | 9 | (9.0) | 6 | (5.0) | 5 | (4.0) | 27 | (6.9) | 1 | (7.1) |
| 2-2. In-Service teacher | 9 | (18.4) | 28 | (28.0) | 23 | (19.2) | 25 | (20.0) | 85 | (21.6) | 3 | (21.4) |
| 3. Others | 4 | (8.2) | 13 | (13.0) | 22 | (18.3) | 21 | (16.8) | 60 | (15.2) | 2 | (14.3) |
| 3-1. School administrators | 0 | (0.0) | 0 | (0.0) | 1 | (0.8) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) |
| 3-2. Scientists | 1 | (2.0) | 2 | (2.0) | 2 | (1.7) | 1 | (0.8) | 6 | (1.5) | 0 | (0.0) |
| 3-3. Science education experts | 1 | (2.0) | 1 | (1.0) | 2 | (1.7) | 5 | (4.0) | 9 | (2.3) | 1 | (7.1) |
| 3-4. Authority person (or other expert) | 1 | (2.0) | 1 | (1.0) | 3 | (2.5) | 3 | (2.4) | 8 | (2.0) | 0 | (0.0) |
| 3-5. Parents | 0 | (0.0) | 1 | (1.0) | 0 | (0.0) | 2 | (1.6) | 3 | (0.8) | 0 | (0.0) |
| 3-6. General public | 0 | (0.0) | 3 | (3.0) | 1 | (0.8) | 0 | (0.0) | 4 | (1.0) | 0 | (0.0) |
| 3-7. Textbooks | 0 | (0.0) | 0 | (0.0) | 2 | (1.7) | 5 | (4.0) | 7 | (1.8) | 1 | (7.1) |
| 3-8. Curricula | 0 | (0.0) | 0 | (0.0) | 2 | (1.7) | 2 | (1.6) | 4 | (1.0) | 0 | (0.0) |
| 3-9. Academic articles | 0 | (0.0) | 2 | (2.0) | 4 | (3.3) | 1 | (0.8) | 7 | (1.8) | 0 | (0.0) |
| 3-10. Other | 1 | (2.0) | 3 | (3.0) | 5 | (4.2) | 2 | (1.6) | 11 | (2.8) | 0 | (0.0) |

**Table 3.8** Comparisons of the percentages of participants in the four international journals and *CJSE* from 1998 to 2007

| | Chen et al. (2005) | This study |
|---|---|---|
| Year,% Participants | 2000–2004 ($n = 934$) | 1998–2007 ($n = 220$) |
| 1. Students | 51.3 | 76.4 |
| 1-1. Elementary school students | 16.5 [a] | 48.6 [b] |
| 1-2. Secondary school students | 21.7 [c] | 15.0 [d] |
| 1-3. Undergraduate and graduate students | 13.1 | 12.7 |
| 2. Teacher | 23.8 | 30.0 |
| 2-1. Preservice teacher | 6.7 | 6.8 |
| 2-2. In-service teacher | 17.1 | 23.2 |
| 3. Others | 9.9 | 15.9 |
| 3-1. Administrator | - | 0.5 |
| 3-2. Scientists | 2.2 | 1.8 |
| 3-3. Authority person (or other expert) | 1.5 | 1.8 |
| 3-4. Parents | - | 0.5 |
| 3-5. The public | 2.6 | 1.8 |
| 3-6. Textbooks | 1.9 | 0.9 |
| 3-7. Curriculum | 1.2 | 0.9 |
| 3-8. Academic articles | - | 2.7 |
| 3-9. Other | 0.5 | 3.6 |

*a* grades K-8, *b* grades K-9, *c* grades 9-12, *d* grades 10-12

or professional development. Among the studies with student participants, most included elementary and secondary school students. As for teacher participants, most of the studies included in-service teachers.

*Data Collection Methods* As shown in Table 3.9, the percentage of the most prevalent data collection methods was interview (50.8 %), questionnaire (47.0 %), paper and pencil test (34.5 %), and observation (33.8 %). As for the interview category, we included thinking aloud in this category because of its very low percentage. Also, we found high percentages of related documents (26.9 %) were collected. However, in several cases, these extra documents were not used for data analysis. The use of concept maps (2.0 %) and drawings (2.5 %) in studies was limited. Both of these data collection methods were developed in science education (e.g., White and Gunstone 1992). However, to our surprise, not many publications used these methods for research purposes. We speculated that these research methods were not widely used because they are qualitative and difficult to score, especially if the sample is a large classroom in Taiwan.

For the 14 most cited articles (excluding the nonempirical study), half of them used a questionnaire and/or an interview to collect data. Five of these articles also used the observation method. This pattern was similar to the pattern of all of the articles in *CJSE*. However, the usage of “paper and pencil test” and “related

**Table 3.9** The percentages of data collection tools used in *CJSE* from 1993 to 2012

| Year, N(%) Data collection methods | 1993–1997 (*n* = 49) | 1998–2002 (*n* = 100) | 2003–2007 (*n* = 120) | 2008–2012 (*n* = 125) | 1993–2012 (*n* = 394) | Most cited articles (*n* = 14) |
|---|---|---|---|---|---|---|
| | *n* (%) | *n* (%) | *n* (%) | *n* (%) | *n* (%) | *n* (%) |
| Paper and pencil test | 23 (46.9) | 30 (30.0) | 42 (35.0) | 41 (32.8) | 136 (34.5) | 2 (14.3) |
| Question-naire | 19 (38.8) | 48 (48.0) | 60 (50.0) | 58 (46.4) | 185 (47.0) | 7 (50.0) |
| Interview | 27 (55.1) | 55 (55.0) | 61 (50.8) | 57 (45.6) | 200 (50.8) | 7 (50.0) |
| Observation (i.e., video and voice recording, field notes, check list) | 14 (28.6) | 37 (37.0) | 46 (38.3) | 36 (28.8) | 133 (33.8) | 5 (35.7) |
| Drawing | 4 (8.2) | 3 (3.0) | 1 (0.8) | 2 (1.6) | 10 (2.5) | 0 (0.0) |
| Concept map | 0 (0.0) | 3 (3.0) | 4 (3.3) | 1 (0.8) | 8 (2.0) | 0 (0.0) |
| Online data collection | 1 (2.0) | 10 (10.0) | 10 (8.3) | 10 (8.0) | 31 (7.9) | 1 (7.1) |
| Related documents (i.e., learning sheets, portfolio) | 9 (18.4) | 20 (20.0) | 43 (35.8) | 34 (27.2) | 106 (26.9) | 2 (14.3) |
| Experiment | 4 (8.2) | 0 (0.0) | 0 (0.0) | 1 (0.8) | 5 (1.3) | 0 (0.0) |
| Others | 0 (0.0) | 9 (9.0) | 11 (9.2) | 9 (7.2) | 29 (7.4) | 1 (7.1) |

documents" was less frequent than the overall total. In addition, one article conducted content analysis, so its data collection method was coded as "other."

As shown in Table 3.10, the three major data collection methods were test item/questionnaire, interview, and observation. These held true for both international and *CJSE* articles. Alternative data collection methods, such as concept map and drawing, were relatively low and should be encouraged.

RQ 1–3: What were the research methods used for data analysis in CJSE from 1993 to 2012?

*Data Analysis Approach* As shown in Table 3.11, there were more "pure" (only one approach) quantitative (25.1 %) than qualitative studies (22.6 %), followed by quantifying qualitative data studies (15.0 %). Table 3.11 shows that quantitative data analysis dominated the research direction in *CJSE*.

The trend was different for the 14 most cited articles (excluding the nonempirical study). About 57 % of these articles used combined methods. They combined qualitative and quantitative (including quantifying qualitative data) methods. About 43 % of the articles used a single method with an equal number of articles in each research method category.

**Table 3.10** Comparisons of the percentages of data collection methods used in international and national studies from 1998 to 2007

| | Chen et al. (2005) | This study |
|---|---|---|
| Year, % Data collection methods | 2000–2004 (*n* = 934) | 1998–2007 (*n* = 220) |
| Paper & Pencil test/ | 43.4 | 32.7 |
| Questionnaire | | 49.1 |
| Interview | 45.7 | 52.7 |
| Observation | 33.2 | 37.7 |
| Drawing | 1.5 | 1.8 |
| Concept map | 2.2 | 3.2 |
| Online data collection | - | 9.1 |
| Related documents | 20.9 | 28.6 |
| Experiment | - | 0.0 |
| Other | 2.0 | 9.1 |

**Table 3.11** The distributions and percentages of data analysis methods used in *CJSE* from 1993 to 2012

| Year, *n* (%) Data analysis methods | 1993–1997 (*n* = 49) | | 1998–2002 (*n* = 100) | | 2003–2007 (*n* = 120) | | 2008–2012 (*n* = 125) | | 1993–2012 (*n* = 394) | | Most cited articles (*n* = 14) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* (%) | | *n* (%) | | *n* (%) | | *n* (%) | | *n* (%) | | *n* (%) | |
| 1. Qualitative | 13 | (26.5) | 26 | (26.0) | 27 | (22.5) | 23 | (18.4) | 89 | (22.6) | 2 | (14.3) |
| 2. Quantitative | 10 | (20.4) | 26 | (26.0) | 28 | (23.3) | 35 | (28.0) | 99 | (25.1) | 2 | (14.3) |
| 3. Quantifying qualitative data | 6 | (12.2) | 15 | (15.0) | 18 | (15.0) | 20 | (16.0) | 59 | (15.0) | 2 | (14.3) |
| Combinations | | | | | | | | | | | | |
| (2, 3) | 6 | (12.2) | 1 | (1.0) | 12 | (10.0) | 10 | (8.0) | 29 | (7.4) | 0 | (0.0) |
| (1, 2) | 2 | (4.1) | 17 | (17.0) | 21 | (17.5) | 14 | (11.2) | 54 | (13.7) | 4 | (28.6) |
| (1, 3) | 7 | (14.3) | 5 | (5.0) | 11 | (9.2) | 13 | (10.4) | 36 | (9.1) | 3 | (21.4) |
| (1, 2, 3) | 2 | (4.1) | 4 | (4.0) | 0 | (0.0) | 4 | (3.2) | 10 | (2.5) | 1 | (7.1) |

Comparing the articles published in the international journals with those published in *CJSE*, we had two findings. First, we found that *CJSE* published almost equal numbers of qualitative and quantitative articles (single method) during the period 1998–2007. The articles in the international journals had more qualitative studies than quantitative studies if studies with combined methods were excluded. Second, there were relatively low percentages of studies that integrated qualitative data and quantified qualitative data in the international journals (Table 3.12).

**Table 3.12** Comparisons of the percentages of research methods used in international and national studies from 1998 to 2007

| Study | Chen et al. (2005) | This study |
|---|---|---|
| Years | 2000–2004 ($n = 934$) | 1998–2007 ($n = 220$) |
| 1. Qualitative | 40.9 | 24.1 |
| 2. Quantitative | 14.6 | 24.5 |
| 3. Quantifying qualitative data | 7.9 | 15.0 |
| Combined methods | | |
| 2+3 | 4.1 | 5.9 |
| 1+2 | 15.7 | 17.3 |
| 1+3 | 1.1 | 7.3 |
| 1+2+3 | 0.1 | 1.8 |

*Quantitative Methods* As demonstrated in Table 3.13, on average 68.5 % of the studies provided descriptive statistics for data analysis. As for the inferential statistic methods, the most prevalent methods were *t*-tests (24.9 %), ANOVA & GLM (17.8 %), correlation analysis (12.9 %), ANCOVA (12.2 %), and Chi-square (10.7 %). Several statistics methods were used infrequently and included MANOVA, MANCOVA, path analysis, and several advanced statistics methods.

For the 15 most cited articles, 12 of them used quantitative methods (including quantifying qualitative data). Of these 12 articles, 11 of them reported descriptive statistics while 10 of them used inferential statistics. Similar to the pattern of all the articles in *CJSE*, *t*-test and ANOVA & GLM were used most frequently. Other methods commonly used were Chi-square test (2), ANCOVA (2), correlation (2), MANOVA (2), MANCOVA (1), regression (1), and factor analysis (2). Three articles used self-developed instruments with the reliability and validity of those instruments reported. As many of the articles (out of 12 total articles) reported inferential statistics, the order of specific statistics used was similar to that for all the articles but with a higher proportion.

The percentage of each statistics methods used in international journals was smaller than that in *CJSE* because fewer international journals adopt quantitative data analysis approaches (see Table 3.12). Nevertheless, the ranking of commonly used quantitative methods was similar between international journals and *CJSE*. Specifically, *t*-test was used most frequently, followed by ANOVA & GLM, correlation, and chi-square (with the exception of ANCOVA). Similarly, advanced techniques such as MANOVA, MANCOVA, path analysis, and HLM & SEM, were rarely used (Table 3.14).

RQ 1–4: What were the distributions of authorship as categorized by academic status in CJSE from 1993–2012?

As seen in Table 3.15, about two thirds (68.0 %) of the first authors were professors and 22.3 % were graduate students (including in-service teachers). Table 3.15 shows that there were more professors (31.2 %) as single authors compared to students (1.0 %). In other words, even though the graduate students might be the first author,

**Table 3.13** The percentages of quantitative methods used in *CJSE* from 1993 to 2012

| Year, N (%) Quantitative Methods | 1993–1997 ($n = 49$) | | 1998–2002 ($n = 100$) | | 2003–2007 ($n = 120$) | | 2008–2012 ($n = 125$) | | 1993–2012 ($n = 394$) | | Most cited Articles ($n = 12$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % |
| 1. Descriptive statistics | 33 | (67.3) | 63 | (63.0) | 84 | (70.0) | 90 | (72.0) | 270 | (68.5) | 11 | (91.7) |
| 2. Inferential statistics | 22 | (44.9) | 49 | (49.0) | 69 | (57.5) | 79 | (63.2) | 219 | (55.6) | 10 | (83.3) |
| 2-1. T-test | 9 | (18.4) | 20 | (20.0) | 35 | (29.2) | 34 | (27.2) | 98 | (24.9) | 6 | (50.0) |
| 2-2. Chi-square test | 6 | (12.2) | 5 | (5.0) | 15 | (12.5) | 16 | (12.8) | 42 | (10.7) | 2 | (16.7) |
| 2-3. ANOVA & GLM | 6 | (12.2) | 19 | (19.0) | 20 | (16.7) | 25 | (20.0) | 70 | (17.8) | 5 | (41.7) |
| 2-4. ANCOVA | 4 | (8.2) | 5 | (5.0) | 18 | (15.0) | 21 | (16.8) | 48 | (12.2) | 2 | (16.7) |
| 2-5. Correlation | 7 | (14.3) | 12 | (12.0) | 17 | (14.2) | 15 | (12.0) | 51 | (12.9) | 2 | (16.7) |
| 2-6. MANOVA | 1 | (2.0) | 1 | (1.0) | 7 | (5.8) | 1 | (0.8) | 10 | (2.5) | 2 | (16.7) |
| 2-7. MANCOVA | 0 | (0.0) | 1 | (1.0) | 3 | (2.5) | 2 | (1.6) | 6 | (1.5) | 1 | (8.3) |
| 2-8. Regression | 1 | (2.0) | 7 | (7.0) | 6 | (5.0) | 7 | (5.6) | 21 | (5.3) | 1 | (8.3) |
| 2-9. Factor analysis | 3 | (6.1) | 6 | (6.0) | 7 | (5.8) | 11 | (8.8) | 27 | (6.9) | 2 | (16.7) |
| 2-10. Path analysis | 0 | (0.0) | 1 | (1.0) | 2 | (1.7) | 1 | (0.8) | 4 | (1.0) | 0 | (0.0) |
| 2-11. HLM & SEM | 0 | (0.0) | 0 | (0.0) | 2 | (1.7) | 5 | (4.0) | 7 | (1.8) | 0 | (0.0) |
| 2-12. nonparametric method | 2 | (4.1) | 3 | (3.0) | 6 | (5.0) | 4 | (3.2) | 15 | (3.8) | 1 | (8.3) |
| 2-13. Others | 3 | (6.1) | 3 | (3.0) | 3 | (2.5) | 8 | (6.4) | 17 | (4.3) | 0 | (0.0) |
| 3. Self-developed instrument (reliability and validity) | 2 | (4.1) | 6 | (6.0) | 2 | (1.7) | 9 | (7.2) | 19 | (4.8) | 3 | (25.0) |

**Table 3.14** Comparisons of the percentages of quantitative methods used in international and national studies from 1998 to 2007

| | Chen et al. (2005) | This study |
|---|---|---|
| Year, % Quantitative methods | 2000–2004 ($n$ = 934) | 1998–2007 ($n$ = 220) |
| 1. Descriptive statistics | 18.5 | 66.8 |
| 2. Inferential statistics | | |
| 2-1. *t*-test | 9.3 | 25.0 |
| 2-2. Chi-square test | 4.1 | 9.1 |
| 2-3. ANOVA & GLM | 7.6 | 17.7 |
| 2-4. ANCOVA | 1.3 | 10.5 |
| 2-5. Correlation | 4.4 | 13.2 |
| 2-6. MANOVA | 1.0 | 3.6 |
| 2-7. MANCOVA | 0.4 | 1.8 |
| 2-8. Regression | 2.0 | 5.9 |
| 2-9. Factor analysis | 1.9 | 5.9 |
| 2-10. Path analysis | 0.1 | 1.4 |
| 2-11. HLM & SEM | 1.4 | 0.9 |
| 2-12. nonparametric method | 0.2 | 4.1 |
| 2-13. Others | 1.1 | 2.7 |
| 3. Self-developed instrument (reliability and validity) | - | 3.6 |

**Table 3.15** The distribution of first authorship in the studies in *CJSE* from 1993 to 2012

| Years, $n$ (%) | 1993–1997 ($n$ = 49) | 1998–2002 ($n$ = 100) | 2003–2007 ($n$ = 120) | 2008–2012 ($n$ = 125) | 1993–2012 ($n$ = 394) | Most cited articles ($n$ = 15) |
|---|---|---|---|---|---|---|
| 1. Students/ In-Service teachers | 2 (4.1) | 10 (10.0) | 37 (30.8) | 39 (31.2) | 88 (22.3) | 4 (26.7) |
| 1.1 Single author | 0 (0.0) | 1 (1.0) | 1 (0.8) | 2 (1.6) | 4 (1.0) | 0 (0.0) |
| 1.2 Multiple authors | 2 (4.1) | 9 (9.0) | 36 (30.0) | 37 (29.6) | 84 (21.3) | 4(26.7) |
| 2. Professor | 46 (93.9) | 80 (80.0) | 75 (62.5) | 67 (53.6) | 268 (68.0) | 8 (53.3) |
| 2.1 Single author | 23 (46.9) | 38 (38.0) | 39 (32.5) | 23 (18.4) | 123 (31.2) | 4 (26.7) |
| 2.2 Multiple author | 23 (46.9) | 42 (42.0) | 36 (30.0) | 44 (35.2) | 145 (36.8) | 4 (26.7) |
| 3. Adviser-advisee | 1 (2.0) | 10 (10.0) | 8 (6.7) | 19 (15.2) | 38 (9.6) | 3 (20.0) |

**Table 3.16** Proportion of publications in *CJSE* over six selected journals. (*CJSE, JRST, SE, IJSE, RISE*, and *IJSME*)

| | *CJSE* / (*CJSE* +*SSCI*) | | | | |
|---|---|---|---|---|---|
| Total no. of publications | less *CJSE* (0–39 %) | equal (40–60 %) | more *CJSE* (61–99 %) | all *CJSE* (100 %) | Sum |
| ≥ 10<br>1 article in *CJSE*<br>1 article in SSCI | 5 (5.6)<br>0 (0.0) | 2 (2.2) | 12 (13.5)<br>2 (2.2) | 0 (0.0) | 19 (21.3) |
| < 10<br>1 article in *CJSE*<br>1 article in SSCI<br>No article in SSCI | 13 (14.6)<br>12 (13.5) | 7 (7.9) | 14 (15.7)<br><br>12 (13.5) | 36 (40.4)<br><br><br>36 (40.4) | 70 (78.7) |
| Sum | 18 (20.2) | 9 (10.1) | 26 (29.2) | 36 (40.4) | 89 (100) |

they almost always published with multiple authors. There was a sharp increase in the number of students as first authors beginning in 2003. At the same time, the percentage of professors as first authors dropped dramatically from 80.0 % to 53.6 %.

Similarly, for the 15 most cited articles, the first author was a professor in eight of these articles, a student in four of the articles, and an advisee (not graduate students any more) in three of the articles. Four of these 15 articles had a single author.

Research Question 2: How did the authors' number of articles in *CJSE* compare to their number of articles published in international articles?

Publication preference for local (*CJSE*) or international journals was analyzed using the following steps. First, for each science education researcher in Taiwan who had at least one publication in *CJSE*, the number of the same author's published articles in *CJSE* as well as those in the five selected SSCI journals (i.e., *JRST*, *SE*, *IJSE*, *RISE*, and *IJSME*) was calculated. Second, 89 researchers with at least 3 publications in these 6 journals (*CJSE*+5 SSCI) were included for analysis. To further investigate publication preference, 19 researchers who had at least 10 total publications were analyzed separately from the other 70 researchers. Third, the proportion of publications in *CJSE* over these six journals was calculated. If the ratio was less than 40 %, the researcher was described to be publishing in international journals (i.e., less *CJSE*). If the proportion was more than 60 %, the researcher was described to be publishing in *CJSE* (i.e., more *CJSE*). If the ratio was between 40 and 60 %, the publication tendency was almost equal between local and international journals. The results are summarized in Table 3.16. Specifically, among all researchers, 62 of them tended to publish their work in *CJSE*. Out of the 62 researchers, 36 published their work only in *CJSE*. On the other hand, about one fifth of the researchers tended to publish their work more in international journals than in *CJSE*. Only nine researchers had an almost equal publication record. This trend (i.e., more researchers publishing more in *CJSE*, fewer researchers publishing more in international journals, and fewest researchers having an almost equal publication record) held for both researchers with more or less publications (using a total of 10 articles as the cutoff point). For researchers, who had at least ten publications, two of them had a strong tendency to publish their work in *CJSE* (i.e., they each had only one publication in international journals). On the contrary, most researchers (60/70) who had less than ten publications had a strong tendency to publish their work in either *CJSE* or the international journals. In one extreme situation, 36 researchers published their work only in *CJSE* from among the 6 journals, and 12 researchers had only one publication in international journals. In another extreme, 12 researchers had only one publication in *CJSE*. To summarize, researchers had their own preference for publication, some of them even had a strong tendency to publish in either local journals or international journals. Only a few researchers had an almost equal publication record.

## 3.6 Concluding Remarks

*CJSE* had its 20th birthday in 2012. Over the past 20 years,many great science educators have contributed to this journal in various fields of science education. This content analysis study compared *CJSE* with international journals and reported on trends in science research both locally and globally.

### *3.6.1 Claim 1: Empirical Studies More than Nonempirical Studies*

As found in the international journals, we found that *CJSE* published more articles in the empirical area than in the nonempirical area. However, the proportion of empirical studies was very high (97.5 %) compared to others. Most of the research used case study, survey, and quasi-experimental approaches. There was only limited research in the area of correlation test, content analysis, meta-analysis, and field investigation.

### *3.6.2 Claim 2: More Studies on Learning than Other Research Topics*

Among the 11 topics we investigated, we found that learning scientific concepts was the main focus of the research in Taiwan. Teacher education and instruction issues were the second most frequent research topics. Very low percentages of research in the area of sociocultural and policy aspects were conducted. Given the low percentage of articles published in the area of education technology, we wonder if articles in education technology might be published in other journals directly related to innovative technology.

### 3.6.3 Claim 3: Multiple Approaches for Data Collection

On average, interview was ranked as the most common data collection method among the various methods investigated in this study. High percentages were also found for the use of questionnaire, as well as paper and pencil test. However, alternative data collection methods (e.g., drawing and concept map) were underrepresented.

### 3.6.4 Claim 4: Integrating the Use of both Quantitative and Qualitative Data Analyses

We found that both quantitative and qualitative data analyses were performed in *CJSE*. Specifically, the most commonly used quantitative methods were descriptive statistics, *t*-test, and ANOVA. This is unique because according to the analysis in Chen et al. (2005), over the period 2000–2004, a relatively high percentage of research used the qualitative approach. Even though the investigated period was not exactly the same, the current study shows different research approaches during that period.

### 3.6.5 Claim 5: Decreasing Percentages of Articles with Professors as the First Authors

As expected, more professors than graduate students were the first author for the journal articles. However, we found that there were dramatic drops in the percentage of professors as the first author during the period 2003–2012. Although it is a part of professional training to expect graduate students to write journal articles as first authors, we believe that fewer professors taking leading roles in research and publication might limit the quality and scope of innovative ideas in science education.

### 3.6.6 Claim 6: Disparity in Distribution of Publications between CJSE and International Journals

Our results revealed that for those authors with at least ten published articles, they tended to publish their research more in *CJSE* than in the selected international journals. As for the authors with fewer than ten publications, they fell into one of the two extreme cases: either they published more in *CJSE* or they published more in the international journals. In both cases, very few researchers contributed to *CJSE* and the international journals equally. Therefore, we believe that publishing research in local journals should be local researchers' obligations as publications should serve the following functions (also see Chiu, Lin, and Chou, in this book):

- To share research findings and experiences within the community
- To increase researchers' awareness of current international trend in theoretical framework and methodological issues
- To transform research outcomes into practice
- To influence policy making and local curriculum reforms
- To improve teaching and learning in school science practice
- To build a culture of sharing and to cultivate research competence, in particular, for young scholars
- To establish a mentor–mentee system for science educators
- To generate a local theory of learning and teaching in science

## 3.7 Suggestions for Future Research

The importance of learning performance and effect of teaching methods is emphasized by their dominant roles in science educational research. In addition to considering prior knowledge as a factor for individual difference, cultural, social, and gender issues also demand more attention so as to scrutinize boundary conditions for an effective instruction. Furthermore, how research findings influence goals, policies, and curriculums should be investigated as well.

As for methodology, more variety in data collection methods is needed. For example, most studies in national and international journals used test items/questionnaire, interview, and observation as data collection methods. However, drawing, concept map, and experiment may reveal a more fine-grained level of comprehension. In addition, online data collection and related documents could provide information from the learning process that is above and beyond what we can obtain from the final outcome. On the other hand, both quantitative and qualitative data analyses were used in *CJSE*, which is different from the dominance of qualitative data analysis observed in Chen et al. (2005). Since these three analytic methods (including quantifying qualitative data) provide different aspects of learning outcome, it will be more informative to use a combination of them, as suggested by us.

In addition, with limited articles discussing theories of learning sciences locally, we suggest senior researchers to integrate evidence collected from local students and teachers in the studies published in *CJSE* as well as other journals to develop contextualized theories of learning and instruction that can potentially uncover problems in school teaching. This suggestion is not unique to our society as it is also applied in other countries that are keen to link research and practice, and value the impact of culture and society on sciences learning.

## 3.8 Implications for Science Education Research

The right policy will lead research in the right direction. However, one has to decide what is good about a given policy, what the advantages and disadvantages of the policy are, and what the challenges and impact may be once the policy is implemented. In this chapter, we presented a content analysis of *CJSE* that has been publishing science education research for over 20 years to see if the results could provide insight for future research and policy making. *CJSE* as a professional journal allows researchers in Taiwan to share research outcomes and professional commentary about issues related to science education research and practice with the national science community. The trend in local research did match the trend of international research. Detailed analysis should be investigated, such as the impact of research on theory and practice both locally and internationally.

Also, with the analyses and discussions presented above, we wondered whether Taiwan had developed a unique theoretical framework for learning and teaching that reflected the country's cultural and demographic characteristics. If so, what is this theoretical framework and what is its impact on research and practice in science education? If this is not the case, then we should be reflective about the appropriateness of theories and methods from Western countries.

While showing Taiwan's global contribution to science education, we still need to reflect on how research emanating from Taiwan influences local school practice and policies regarding science education. Taiwan's focus must remain on how best to elicit students' meaningful learning in science and improve teacher professional knowledge and skills in order to ensure high-quality science education.

As Chiu and Duit (2010) depicted, it is challenging for non-English speakers to publish articles in international journals. Lack of proficient writing skills eliminates the opportunity to publish in international journals. Native English-speaking researchers have an advantage in terms of language that has contributed to the dominance of Western researchers publishing in international journals. However, non-English speakers can overcome, catch up, and even lead the world in terms of international science publications. With a population of only 24 million people, Taiwan is a little giant when it comes to publishing science education research. To continue to raise Taiwan's presence in international journals, we must make a continuous effort through policy support from the government to promote quality research. In the meantime, while recognizing the differences of culture and societal expectations among countries and through our presentation of a journey of science education journal that Taiwan has taken, we hope that our work can also lead to some reflections among other countries that are interested in promoting science education.

## Appendix A:

Average number of citations per year, title, publication year, research type, research topic, participants, data collection method, data analysis method, and quantitative method in the 15 most cited articles in *CJSE*

| Average no. of citations per year | Title | Publication year | Research type | Topic | Participants | Data collection method | Data analysis method | Quantitative methods | The first author | CP |
|---|---|---|---|---|---|---|---|---|---|---|
| 3.3 | Comparing seventh grade algebra textbooks used in Taiwan, USA, and Singapore | 2010 | 1-10 | 5 | 3-2 | 10 | 3 | 1 | 1 | 2 |
| 2.7 | Reflections and Implications of Research on Conceptual Change | 2000 | 2-2 | 3-1 | | | | | 2 | 9 |
| 1.8 | The Development and Validation of the Understanding of the Nature of Science Scale | 1996 | 1-5 | 6 | 1-4 | 2 | 2 | 1, 2-1, 2-3, 2-5, 3 | 2 | 9 |
| 1.8 | Students' Constructing Argumentation About a Socioscientific Issue—The Differences Between Sixth Graders With Different Levels of Academic Achievement | 2009 | 1-3 | 3-2 | 1-2 | 2, 4 | 1, 3 | 1, 2-2, 2-3, 2-4 | 2 | 8 |

| Average no. of citations per year | Title | Publication year | Research type | Topic | Participants | Data collection method | Data analysis method | Quantitative methods | The first author | CP |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.7 | Investigation of the Nested-inquiry Instruction Model on the 8th Graders' Motivation Toward Learning Physical Science | 2007 | 1-3 | 4 | 1-3 | 2 | 2 | 1, 2-1, 2-4, 2-5, 2-6, 2-7, 2-8 | 1 | 2 |
| 1.6 | A Cross-National Study of Perceived Classroom Environments in Taiwan and Western Australia: Combining Quantitative and Qualitative Approaches | 1998 | 1-5 | 6 | 1-3, 2-2 | 2, 3, 4 | 1, 2 | 1, 2-1, 2-3, 2-9,3 | 2 | 8 |
| 1.5 | The Methods Used by Sixth Grade Students in Taiwan When Responded Number Sense Questions | 2000 | 1-7 | 3-2 | 1-2 | 3 | 1, 3 | 1 | 2 | 9 |
| 1.3 | The Learning of a Probationary Teacher: Growth in the Interaction of Motives, Identities, and Reflections | 2003 | 1-7 | 1 | 2-1 | 3, 4, 9 | 1 | NA | 3 | 2 |

| Average no. of citations per year | Title | Publication year | Research type | Topic | Participants | Data collection method | Data analysis method | Quantitative methods | The first author | CP |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.2 | A Study of Pupils' Web Argumentation Ability and Scientific Conceptual Learning | 2008 | 1-1 | 3-2 | 1-2 | 8 | 3 | 1, 2-1, 2-2, 2-3 | 1 | 2 |
| 1.2 | The Standards for Development in Elementary Mathematics Teaching: Perspectives of Elementary Mathematics Educators | 2008 | 1-5 | 1 | 3-7 | 2 | 1, 2 | 1, 2-3 | 3 | 2 |
| 1.1 | Exploring the Scaffolding Strategies of Inserting Mathematical Modeling into Teaching of Secondary Mathematics and the Latent Mechanism of Promoting Teachers' Reflection | 2006 | 1-6 | 1 | 2-2 | 4, 9 | 1 | NA | 3 | 2 |
| 1.1 | The Influence of Inquiry-Based Laboratory Teaching on 8th Graders' Motivation Toward Learning Physical Science | 2005 | 1-3 | 2 | 1-3 | 2, 3 | 1, 2 | 2-1, 2-6 | 1 | 2 |

| Average no. of citations per year | Title | Publication year | Research type | Topic | Participants | Data collection method | Data analysis method | Quantitative methods | The first author | CP |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | Using Multiple Analogies for Investigating Changes of Children's Mental Models of Electricity | 2002 | 1-3 | 3-1 | 1-2 | 1, 3 | 1, 3 | 1, 2-12 | 2 | 2 |
| 1.1 | A Study of Sixth Grade Students' Development of Number Sense Through Well-Designed Number Sense Activities | 2002 | 1-3 | 3-1 | 1-2 | 1, 3 | 1, 2, 3 | 1, 2-1 | 2 | 9 |
| 1.1 | Study on Teacher's Beliefs about Science and Their Effect on Classroom Environment in Junior High School | 1998 | 1-5 | 8 | 1-3, 2-2 | 2, 3, 4 | 1, 2 | 1, 2-9, 3 | 2 | 8 |

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# Chapter 4
# Comments on Section 1: Development of Science Education Research in Taiwan

**Reinders Duit**

**Abstract** The international community of science education research has developed tremendously during the past 30–40 years, especially since the early 1990s. In the 1990s, the annual conferences of the US organization National Association of Research in Science Teaching (NARST), for instance, were attended by some 400 colleagues, but recent meetings have seen more than 1300 participants. Similar developments have occurred around the world.

## 4.1 Preliminary Remark

Comments on two chapters of the present volume are presented as follows:

a. Research projects on science education funded by the National Science Council (NSC) in Taiwan from 1982 to 2012: A historical review (Chorn-Jee Guo and Mei-Hung Chiu)
b. Trends in science education research in Taiwan: A content analysis of the Chinese Journal of Science Education (CJSE) from 1993 to 2012 (Mei-Hung Chiu, Hak-Ping Tam, and Miao-Hsuan Yen)

## 4.2 A Brief Overview of the Development of Science Education Research Internationally

The international community of science education research has developed tremendously over the past 30–40 years, especially since the early 1990s. Whereas in the 1990s, the annual conferences of the US organization National Association of Research in Science Teaching (NARST), for instance, were attended by some 400

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colleagues, but recent meetings have seen more than 1300 participants. Similar developments have occurred around the world.

NARST was established in 1928 as a national organization for promoting research in science education. Some 40 years later, many science education research organizations were founded worldwide as a reaction of the "Western world" to the "Sputnik shock" of the 1960s—on national and regional levels. The *Australian Science Education Research Association* was established, for instance, as early as 1970. In 1990, 20 years later, the organization changed the name to Australasian Science Education Research Association (ASERA) to take into account that New Zealand science educators also joined ASERA[1] and to indicate the openness to the Asian area. The European Science Education Research Association (ESERA) was established in 1995.[2] Meanwhile, ESERA has grown to a size that nearly may measure up with NARST—regarding membership and participants of the biannual ESERA conferences. There are also other regional science education organizations such as East Asian Organization for Science Education (EASE)[3] that was founded in 2009. In addition, numerous national science education research organizations were founded around the world—for example, the German organization Gesellschaft für Didaktik der Chemie und Physik (GDCP[4]) in 1973 and the Taiwanese organization Chinese Association for Science Education (CASEC) in 1994. The number of national and international journals on science education research has increased significantly, especially since the 1990s. Now at least five of these journals are listed in the "Web of Science," namely, Journal of Research in Science Education, Science Education, International Journal of Science Education, Research in Science Education, International Journal of Science, and Mathematics Education.

Briefly summarized, science education has grown into a strong and mature research domain over the past decades with an improving "output" of high-quality research and development. As more and more science educators from different cultural backgrounds meet at conferences or closely cooperate, it is quite likely that the different national and regional views of science education research and on teaching and learning science in schools and universities will lead to further improvements in research results and science teaching and learning worldwide.

## 4.3 On the Predominance of "Western" Traditions and the Role of English as Lingua Franca

Gough (2008) claims that "Western" traditions are predominating in science education and are at least to a certain extent "superimposed" on different cultures. Clearly, Gough addresses a significant issue. It is necessary that the richness of

[1] http://asera.org.au (all URLs cited were retrieved April 10, 2015)

[2] http://esera.org

[3] http://new.theease.org

[4] http://www.gdcp.de

the various cultures and traditions of science education research and instructional practice is not replaced by a one-size-fits-all solution, but that the richness is used to further develop the positions in various countries. In other words, globalization of science education should strive for enriching the different cultures of science education and avoid superimposing predominating positions (Chiu and Duit 2011; Benzce et al. 2013).

Martin and Siry (2011) argue that in the international science education community, there is a predominance of science education researchers stemming from countries where English is the native language or, at least, the working language. Most of the editors, as well as the majority of reviewers, of the above leading (i.e., Web of Science) science education journals stem from these countries. Clearly, English has become the contemporary "lingua franca." Nevertheless, it has to be acknowledged that most science educators worldwide need another attempt to publish their findings internationally. One may argue that this also holds true for science in general. However, it must be remembered that publishing science research findings in English is much easier than publishing science education findings. For publishing science research findings, a comparitively lesser competency in English is needed as a formal (e.g., mathematical) code is available. Publishing in science education affords to employ the whole complexity of English to address educational processes adequately (Bencze et al. 2013).

## 4.4 On the Development of Science Education Research in Taiwan

I have been invited to comment on the previous two chapters of this volume. I discuss two issues here: first, the funding of science education research by the NSC in Taiwan over the past 40 years (1982–2012), and second, an analysis of science education publications in the national CJSE over some 20 years (1993–2012).

I should briefly mention that I am familiar with the development of science education research in Taiwan. I met Taiwanese colleagues at NARST annual meetings in the early 1990s. I was also invited for two conferences (1993 and 1997) organized by colleagues in Taipei to learn about the international state of science education. Constructivist conceptual-change approaches played a significant role in both of these meetings. Since then I have met a steadily growing number of Taiwanese colleagues at various international conferences. A group of colleagues also visited my home institute in Kiel (Germany). More recently, a Taiwanese colleague and I edited a special issue on globalization (Chiu and Duit 2011).

The development of science education research in Taiwan between the early 1990s and 2013 is rather impressive. The country now has become a strong player within the international league of science education. It seems that the following issues have played a significant role in this process:

1. *Deliberately establishing science education as a research field in Taiwan*

The two chapters, under review here, provide minute analyses of the funding of science education research by the NSC from 1982 to 2012 and a critical review of the role of the CJSE from 1993 to 2012.

2. *International support*

Science education researchers from various countries were invited to help develop science education research in Taiwan. Prof. James Shymansky (USA) played a significant role by supporting the Taiwanese colleagues in various ways since the early 1990s. He first helped organizing, for instance, conferences on constructivist views on science teaching and learning. International scholars were invited for keynote addresses and critical discussions. Prof. Shymansky also played a significant role in establishing the International Journal of Science and Mathematics Education (IJSME), which is now one of the five international science education journals listed in the Web of Science.

3. *Becoming familiar with the international state of the art in science education*

Taiwanese science educators visited the major international conferences (such as NARST and ESERA). In addition, researchers visited major science education research institutes worldwide.

Meanwhile, Taiwan itself has grown to a mature player in international science education. Taiwanese colleagues are invited worldwide, for instance, to contribute to the international handbooks (e.g. Yang and Tsai 2012) or other volumes (e.g. Chiu and Chen 2012).

## 4.5 Research Projects Funded by the National Science Council (NSC) in Taiwan (1982– 2012)

An analysis of research studies funded by the NSC clearly is a valid means to document the development of research (see the chapter by Chorn-Jee Guo and Mei-Hung Chiu). It seems that their analysis fully meets the quality criteria of analytical research of this kind. It is interesting to note that funding science education research by the NSC has played a significant role in Taiwan from 1986 to 2012. This research seems to be strongly oriented at the quality criteria of educational research, i.e., the criteria set by the NSC—which is oriented with the criteria of international educational research. It is impressive to see the steady increase of research articles published in thefive Web of Science listed science education journals.

This means Taiwan is internationally competitive within the science education community as represented by the mentioned journals and national as well as international science education organizations. Taking into account a review of science education internationally (Duit 2007); it seems to become obvious that various—and partly significantly different—conceptions of science education research and development may be identified. Hence drawing on the criteria set by NSC, science education conception is just one (powerful) conception. Based on the Model of Educational Reconstruction Duit et al. (2012) developed a conception of science education research that is more inclusive. The differences between analytical and empirical researches have been clearly defined. *Analytical* research focuses on the aims of science instruction and the structure of the particular science content addressed in a study, whereas *empirical* research focuses on various issues of teaching and learning science concepts, principles, and views of the nature of science. It is essential that the science content should not be seen as given but must undergo a process of educational reconstruction in order to allow construction of science instruction. With regard to the NSC position adopted for science education research in Taiwan, the way in which design-based research fits into this conception does not seem to be fully analyzed (Cobb et al. 2003). In other words, it would be valuable to fully clarify the conception of science education research adopted and to make the quality criteria used for "good" research more explicit. That concerns the view of good educational research from the perspective of NSC in general and science education in Taiwan in particular.

Interestingly, the analyses provided include a critical discussion of the role of science education research in improving instructional practice. It is well known that there is a deep gap between the state of science education research (and educational research in general) on the one hand and the practice of science teaching on the other (e.g., Pekarek et al. 1996). It is rather valuable that this point is critically discussed at the end of the chapter, e.g., by stating "Since there are very rich research findings and products accumulated over the years, what needs to be done is a more systematic effort to distil and summarize the research results and convert them into something that will be easier for practitioners and policymakers to use" (in the chapter under review here at p. XX).

Briefly summarized, the chapter by Guo and Chiu provides a rather valuable overview of the development of science education research in Taiwan—drawing on a 40-year development of science education research projects funded by the NSC in Taiwan.

## 4.6 Trends in Science Education Research in Taiwan: A Content Analysis of the CJSE from 1993 to 2012

The positions outlined in the chapter by Mei-Hung Chiu, Hak-Ping Tam, and Miao-Hsuan Yen are commented in the following. As mentioned above, in various countries around the world where English is neither a mother tongue nor an official working language, science education research journals have been established as a significant means to improve the quality of science education research and development. The German Journal of Science Education Research (ZfDN—Zeitschrift für Didaktik der Naturwissenschaften[5]) started in 1995. A more recent European example is NORDINA[6] (Nordic Studies in Science Education) established by Scandinavian science educators in 2004. The German journal (like many other national journals) publishes most articles in its mother tongue, whereas the Nordic journal in the international lingua franca English. The content analysis of the CJSE is an interesting model for providing information on the development of science education in various countries. So far, analyses of this kind are rarely found in the literature.

The methods used for the analysis are well taken, and the summarizing claims are backed up by evidence. It is interesting that the findings presented in the various tables indicate that there are only minute changes of emphases of research during the period under inspection (1993–2012). Table 3.3, in Chapter 3, shows that empirical studies strongly predominated from 1993 to 2012—with a percentage around 95 %. Hence, nonempirical studies were very rarely carried out. Table 3.4 gives a similar impression. There is no notable trend concerning the distribution of the various research topics that range from Teacher Education to Textbook Analysis. Clearly studies on student learning of science concepts and process skills predominate. Interestingly, nonempirical research (i.e., analytical research in the above sense) seems to be given only rather little attention—and, as mentioned earlier, apparently there are no significant changes concerning the predominance of empirical research—analyzed for the period 1993–2012. Similar results seem to hold true for the remaining tables showing developments; for example, Table 3.5 indicates that 66.6 % of the studies investigate students' competencies compared with 26.9 % of the studies dealing with teachers.

Regarding data collection tools, interviews are somewhat frequently used (about 24 %) whereas questionnaires and paper and pencil tests are used about 38 %. Also, more or less the same percentages occur for the measures of 1993–2012. With regard to data analysis methods, Table 3.11 shows that qualitative data have also played a significant role—again there is no notable change from 1993 to 2012. Interestingly, descriptive and classical inferential statistics have been used predominantly in the quantitative studies carried out. Only a few studies draw on nonparametric methods. Studies using Rasch modeling are not listed.

The authors summarize their analyses using a number of claims that address similar issues as briefly mentioned before. What is missing however are attempts to explicitly link the findings of their analyses of publications in the Taiwan journal CJSE with the issues discussed in the chapter on the role of the Taiwan National Science Council (NSC). As national science foundations are powerful institutions, it is quite likely that their favourite view of educational research that may be well suited for educational research in general terms may be less suited for science education research. In addition, it would be interesting to find comments in the concluding remarks of the chapter; in which way the science education research may or should be further developed.

[5] http://www.springer.com/education+%26+language/science+education/journal/40573

[6] http://www.journals.uio.no/index.php/nordina

## 4.7 Concluding Remarks

The two chapters under inspection here, namely, role of the NSC and content analysis of science education research in Taiwan as published in CJSE revealed the following. Over the past decades, Taiwan has developed into a well-respected international player in science education—despite the problems non-native English speaking countries face in the "international market" as described earlier. The present volume presents the major research work that has been done. The reviews of the two chapters on the role of the Taiwan National Research Council in the development of science education research and the content analysis of articles published in the national CJSE show a rather impressive development of Taiwan becoming a major international player in the past decades towards a major international player. However, the analysis also reveals that the research profile is somewhat restricted to the empirical research on teaching and learning science concepts and principles. Hence, a somewhat restricted profile of science education research predominates. It will be interesting in which direction science education in Taiwan will develop in the future—concerning the research questions addressed and the research methods applied.

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# Part II
# Science Learning and Assessment

Science learning and assessment has been one of the research emphases of science education research (Driver et al. 1994; Gabel 1994). Over the past three decades, research on students' learning has moved from behaviorism to constructivism as well as to social constructivism (Duit and Treagust 1998). These changes also influenced the sub-domain of students' learning, namely conceptual change, which has moved from epistemological aspects dominated by Posner et al. (1982) and motivational aspects by Pintrich et al. (e.g., Pintrich et al. 1993; Sinatra and Pintrich 2003) to multidimensional aspects by Duit and Treagust (2003) and Treagust and Duit (2008). Chiu et al. (Chap. 5) analyzed 383 articles that appeared in the four major science education journals and 86 articles from *Chinese Journal of Science Education* (CJSE) (discussed in Chap. 3 in this book). The analyses showed that there were more publications on developing and implementing pedagogical instruction in school practice than on exploring or empowering theoretical frameworks for research in the science learning processes and products in both international journals and CJSE. Approximately 30% of the studies on conceptual change were in physics education, followed by biology and chemistry in the international journals. Meanwhile, in CJSE, about one-third of the research was in the area of physics, followed by earth science, chemistry, and biology. Taiwan, a non-English speaking country, was ranked third as a contributing country by first or correspondence authors for the period of 1982–2012. Following up on the content analysis by Chiu et al. discussed earlier, Yang (Chap. 6) analyzed 106 articles published in the area of learners' epistemic beliefs and their effects on science learning. Specifically, it was shown that students' epistemic beliefs were influenced differently based on the cultural context types of their country. Comparing data from three countries, namely, Taiwan, the USA, and Turkey, it was found that in lower context culture countries, such as Taiwan and the USA, students were more easily influenced by instructional interventions than were students from higher context culture countries such as Turkey. Interestingly, lower context countries were also more likely to believe in one's innate ability than higher context countries. A deeper look into the differences seems like a worthy topic for further research.

In Chap. 7, Tam elaborates on how and why the two-tier item design, that were used to diagnose elementary, middle, and secondary students' conceptual understanding in science, can serve the purpose of diagnosing students' conceptions, and what limitations this research method might have.

Finally, Lien and Lu (Chap. 8) uncovered the factors that attributed to the outstanding performance in science on TIMSS by Taiwan's fourth graders. Traits such as adequate school infrastructure, emphasis on physical sciences in the textbooks, and focus on carrying out experiments were found to be key features in Taiwanese elementary school science lessons. Additional features such as less emphasis on memorization were also listed for further research.

Treagust commented on the four chapters in this section with different perspective on the issues related to science learning. He drew some conclusions and made suggestions for future direction of science education for each chapter.

# Chapter 5
# Content Analysis of Conceptual Change Research and Practice in Science Education: From Localization to Globalization

**Mei-Hung Chiu, Jing-Wen Lin and Chin-Cheng Chou**

**Abstract** This chapter reviews the current research on conceptual change in science education. The review includes research located in the DoRise system (Database of Research in Science Education) in Taiwan and articles published in selected international science education journals *(Journal of Research in Science Teaching, Science Education, International Journal of Science Education, Research in Science Education, and International Journal of Science and Mathematics Education)* between 1982 and 2012. Three hundred and eighty-three articles in the international journals (including 26 English papers from researchers in Taiwan) and eighty-six articles from Taiwan were analyzed (60 and 26 articles from Taiwanese and international journals, respectively). There are five major findings. First, most of the research follows the empirical approach, regardless of it being an international or national article. Second, physics was the main discipline examined both in the international and national studies. Third, about two thirds of the studies from outside of Taiwan used epistemological perspective to frame and present their study. A similar percentage of articles investigated the instructional perspective whereas nearly two thirds of the Taiwanese articles investigated the instructional perspective and only 28 % followed the epistemological perspective. Fourth, as for the research method, we found that qualitative data analysis was ranked first among all the methods we investigated whereas Taiwan appeared to integrate both quantitative and qualitative methods. Fifth, as expected, high percentages of published researchers were from English-speaking countries (i.e., the USA, Australia, and the UK). Taiwan was ranked third out of 31 countries with respect to the number of publications in this study from 1982 to 2012 but was the first non-English-speaking country. Recommendations for researchers and educators are provided.

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## 5.1 Introduction

For the past three decades, there have been studies investigating learners' pre-instruction conceptions and their impact on learners' understanding of scientific phenomenon. Consistent findings regarding the difficulties involved in changing conceptions that learners hold prior to and even after formal instruction were revealed across genders, grades, and cultures. This research showed that learners tend to hold their intuitive knowledge across years and tend to revert to original conceptions even after formal instruction. The robust nature of prior knowledge is believed to be the result of the difficulties inherent in developing true scientific knowledge. Scientific concepts are often abstract, complex, and counterintuitive, and as a result are commonly perceived as not aligned with learners' daily life experiences. To face this challenge, science education researchers proposed different frameworks and theories on conceptual change to explain why naïve conceptions are difficult to refine, restructure, or even remove. The most cited reference on conceptual change is Posner et al. (1982) who advocated that a learner has to feel dissatisfied and conflicted about one's conception before one can accept the scientific concept. They provided conditions that must be met during instruction to successfully promote conceptual change in science learning. These include (1) dissatisfaction with existing conceptions, (2) new conception must be intelligible, (3) new conception must appear plausible, and (4) new conception should suggest the possibility of a fruitful program. This theory on changing learners' intuitive conceptions to scientific concepts has been challenged (Gunstone 1990; West and Pines 1983) for its view of learning as a merely rational activity. It has also been modified to take into account the interaction between scientific conceptions and misconceptions, learners' motivation, and social interaction among learners (Strike and Posner 1992).

The research field on conceptual change is inspiring and pioneer work gradually received the attention of researchers from various fields. To conduct this study, we searched "conceptual change" as a keyword on Web of Science (WOS) (http://www.isi-thomsonreuters.org/), and we found 1788 articles from 1970 to 2013 (through 10 October 2013). In other words, as far as the WOS list is concerned, we found that the earliest article was dated 1970. According to the results from the WOS, there was a dramatic increase in the number of articles in the area of conceptual change published from 1992, about 10 years after Posner et al. (1982) published their pioneer work and then continuously increased (see Fig. 5.1).

As a tribute to the 30th anniversary of Posner and his colleague's influential article on conceptual change in science education, being first published in 1982 (Posner et al. 1982), we selected 1982 as the starting year for our literature review, going on till 2013. Figure 5.2 shows the gradual growth in the number of publications on conceptual change. Dramatic increases are not evidenced during the first 10 years following Posner et al.'s seminal publication. The three years, 1998, 2007, and 2010, represent peaks in the number of publications.

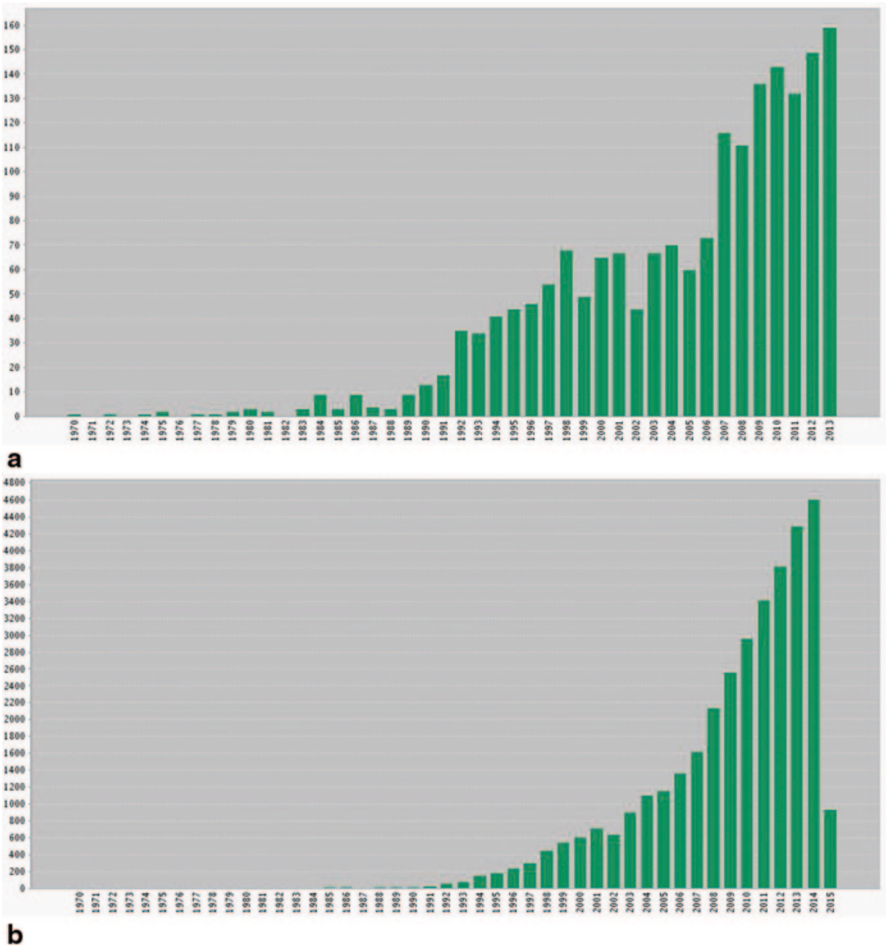


**Fig. 5.1** Number of publications and citations in the area of conceptual change **a** published articles with conceptual change as a keyword from 1970 to 2013, **b** published articles on conceptual change cited from 1970 to 2013

While investigating articles published in Chinese in Taiwan, the earliest article appeared in 1992, 10 years after the Posner et al. (1982) article. This number continued to increase with peaks in 2000 and 2005. With the only exception being 1994, every year between 1992 and 2012 saw at least one article on conceptual change being published by Taiwanese scholars.

Although there is a great deal of research in the area of conceptual change, there is little consensus as to the definition of conceptual change. Some of the more widely used definitions involve: (a) reassignment of a concept to a different (within or across) ontological category or generation of a new distinct ontological category (Chi 2008), (b) additions or deletions from an existing network or the radical shift

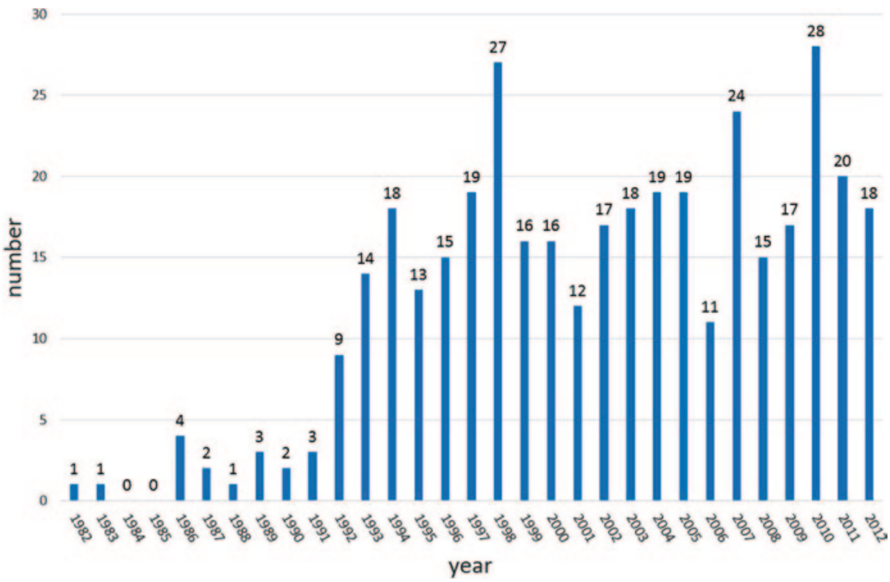


**Fig. 5.2** Number of published articles per year in international journals from 1982 to 2012

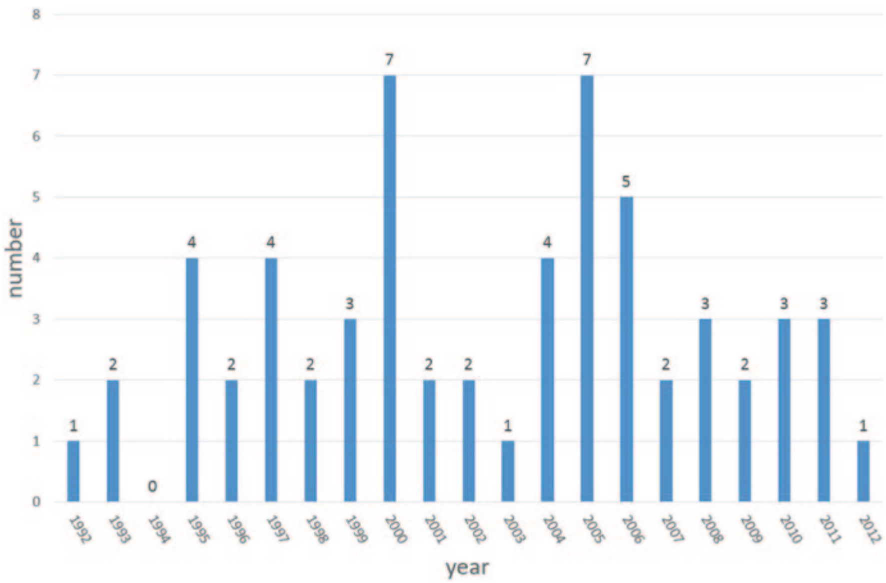


**Fig. 5.3** Articles on conceptual change published each year in local journals in Taiwan (1992–2012)

to different branches or trees, (c) change in the ontological and epistemological presupposition of the learner's internally coherent explanatory system, (d) "individual's lifelong trajectory of understanding of a given topic or discipline" (Linn 2008, p. 694), or (e) "knowledge-in-pieces" involving incoherent and inconsistent structures that gradually develop into coordinator structure (diSessa 2008). In the three special handbooks on conceptual change (Schnotz et al. 1999; Vosniadou 2008, 2013), there seems to be no consensus about the nature of knowledge structures that a learner owns, namely, consistent or inconsistent, coherent or piecemeal, and mental models or p-prims (e.g., Vosniadou 1994, 2008; diSessa 1993, 2008). Researchers continue to debate over the universal definition of each of these elements.

The multiple frameworks that attempt to explain how conceptual change occurs and the research for investigating conceptual change have their origins in science education (i.e., Chiu 2007; Chiu and Lin 2008; Duit and Treagust 2003; Treagust and Duit 2008). These evolutions of conceptual change theories move research from a singular perspective to a multi-perspective paradigm that provides powerful interpretations and predictions of conceptual change.

The authors of this chapter have been long engaged in research on conceptual change involving different science topics and adopted a conceptual framework more recently via the use of the research and instructional based/oriented work (RAINBOW) framework that the first author developed to investigate issues related to science learning (see Chiu 2007; Chiu and Lin 2008). The RAINBOW framework includes multiple perspectives, namely ontological, epistemological, developmental, evolutionary, instructional, affective/social, and integrative approaches, to describe how conceptual change might be investigated. We published several articles related to each of these perspectives, namely, ontological (Chiu et al. 2002; Chiu and Chung 2013), epistemological (Chiu et al. 2002; Chiu and Lin 2005; Wang et al. 2013), developmental (Chiu and Chung 2013; Chiu and Wu 2013; Liang et al. 2011), evolutionary (Lin 2008; Lin and Chiu 2009; Chiu and Wu 2013), instructional (Chiu et al. 2002; Chiu and Chung 2013; Chiu and Lin 2005), affective/social (Chiu and Chung 2013), and integrative (Chiu and Lin 2008; Chiu et al. 2002; Chiu and Lin 2005; Chiu and Chung 2013) approaches to describe students' performance in learning different topics in sciences.

Conceptual change has guided much science education research over the past 30+years. Taiwan also showed its interest in conceptual change. The first article to come out of Taiwan that involved conceptual change was published in a local journal in 1992 (Hsu, 1992) in which the article discussed more about the nature and evaluation modes in measuring hypotheses and process skills in inquiry practice. Little was dealt with contemporary conceptual change theories or empirical work. The first article to discuss Posner et al. (1982)'s four conditions of conceptual change model was by Chiu (1993) in which introduced the nature of CCM, Chi's ontological categories of scientific concepts in conceptual change, and the relation between conceptual change and textbooks for meaningful learning. An article introducing researchers in the area of conceptual change including Chi, Vosniadou, Thagard, and Nersessian was published in Taiwan in 2000 (Chiu 2000) and was selected as one of the eight most cited papers between 1993 and 2002. In this review chapter, we would like to explore the rankings of countries that contributed to the field of conceptual change as well. It will show the efforts the researchers in Taiwan and other countries invested.

Possible influences on the research on conceptual change in Taiwan were the presentations provided by leading researchers in the area of conceptual change who were invited to give lectures at workshops or/and conferences, including Michelene T.H. Chi, Reinders Duit, Dedre Gentner, Ken Forbus, John Gilbert, Peter Hewson, David Treagust, and Stella Vosniadou. But other researchers in this field (such as Paul Thagard and Nancy Nersessian) also influenced the research trend on conceptual change in other ways. These researchers, as well as others, provided a valuable foundation to the theories of cognitive learning and inspired interactions between local and international science educators conducting research on conceptual change in science education.

With long-term research interest and experience in the area of conceptual change, in this chapter, we analyze the contents of local and international articles on conceptual change to uncover the journey that many researchers took over the past 30 years and then provide some evidence-based pedagogical suggestions for future research in science education.

### *5.1.1 Research Purposes and Questions*

This chapter fulfills two purposes. First, it shows the research trends in conceptual change in science education over the past 30 years. Second, it compares the similarities and differences between national and international publications on conceptual change.

The following research questions are answered in this chapter:

1. How many empirical and nonempirical studies on conceptual change were published from 1982 to 2012?
2. What were the theoretical perspectives presented in the literature on conceptual change from 1982 to 2012?
3. What were the science disciplines examined in these studies?
4. What were the research methods and instruments used in these studies?
5. What were the teaching strategies used to investigate conceptual change in these studies?
6. What were the rankings of countries that contributed to the field of conceptual change from 1982 to 2012?

## 5.2 Method

### *5.2.1 Identifying Papers for This Review*

Identification of journal articles included two parts. Journal articles published from 1982 through 2012 in the top five international science education journals (i.e., *Journal of Research in Science Teaching, Science Education, International Journal of Science Education (European Journal of Science Education), Research in Science Education, and International Journal of Science and Mathematics Education*) were searched for the keywords “conceptual change.” This process yielded 383 articles. Among them, there were 26 articles whose first author or corresponding author was from Taiwan. For the Taiwanese articles, the authors used the index to Taiwan periodical literature system (http://readopac.ncl.edu.tw/nclJournal/) to identify conceptual change related journal articles. This free database contained an exhaustive list of article citations of Chinese and Western language periodicals published in Taiwan (including some in Hong Kong and Macau) since 1970. This database was searched using the same keyword, i.e., conceptual change, and 70 articles were displayed. However, this included some nonacademic journal articles. As a result, we performed a second search on the DoRise (Database of Research in Science Education, http://w1.dorise.info/JCSE/) database to cross check and delete nonacademic journals from our search. This database was supported by the National Science Council and was the most representative database of research in science education in Taiwan. Of the original 70 Taiwanese articles, 60 were from academic journals and these 60 were selected for inclusion in our analyses.

### 5.2.2 *Formation of an Analytical Framework*

In this chapter, to provide support for implementation and make policies for promoting scientific literacy and support educational reform, we used the content analysis method to analyze the selected journal articles with special interest in the following topics: research theoretical framework, methodological issues, research intervention, and authorship (See Fig. 5.4).

Based on the framework and our previous research, we constructed a preliminary coding scheme for analyzing the selected articles. As for the categories of teaching strategies, they were expanded from another collaborative study (Chiu 2012) that had a panel of 12 experts with different background knowledge and experiences in science education. Sixteen out of 60 Taiwanese journal articles were systematically selected to pilot the feasibility of the analytical framework. The final coding scheme is shown in Table 5.1.

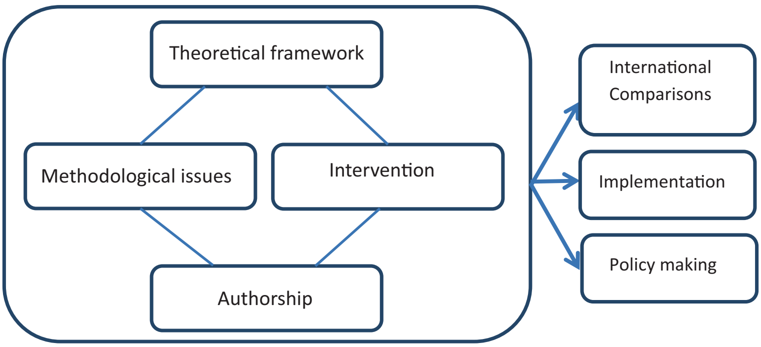


**Fig. 5.4** The framework for content analysis of this study

**Table 5.1** Coding scheme of the study

| Research question | Category | Subcategory |
|---|---|---|
| RQ 1 | Empirical and nonempirical | 1. Empirical<br>2. Nonempirical |
| RQ 2 | Theoretical perspectives | 1. Epistemology<br>2. Ontology<br>3. Affection/social<br>4. Development<br>5. Evolution<br>6. Instruction<br>7. Multiple dimensions<br>8. Others |
| RQ 3 | Discipline | 1. Physics<br>2. Chemistry<br>3. Biology<br>4. Earth science<br>5. Cross-domain<br>6. Others (such as decision-making, modeling)<br>7. NA (such as nature of science, motivation) |
| RQ 4 | Research methods | 1. Qualitative<br>2. Quantitative<br>3. Mixed methods<br>4. Quantify qualitative data analysis |
| | Instruments | 1. Paper-and-pencil test<br>2. Interview<br>3. Drawing<br>4. Online data<br>5. Questionnaire<br>6. Online questionnaire<br>7. Rubric or coding sheet of classroom observation<br>8. Biological data<br>9. Others |
| RQ 5 | Teaching strategies | 1. Analogy, model, and modeling<br>2. Multimedia<br>3. Conceptual conflict<br>4. Inquiry<br>5. Cooperative learning<br>6. Experiment<br>7. Text<br>8. Multiple representations<br>9. Argumentation<br>10. Concept map<br>11. Science history<br>12. Metacognitive approach<br>13. Constructivist approach<br>14. Self-explanation<br>15. Others |

**Table 5.1** (continued)

| Research question | Category | Subcategory |
|---|---|---|
| RQ 6 | The nationality of authors | 1. The first author or corresponding author was from Taiwan<br>2. At least one author was from Taiwan but not the first author or corresponding author<br>3. No scholars from Taiwan involved |
| | The nationality of participants | – |

*NA* Not applicable

### *5.2.3 Data Analysis*

Each of the 443 studies (383 in English and 60 in Chinese) was analyzed based on the coding scheme in Table 5.1. At first, 383 international articles and 60 Chinese articles were ordered by year and author names, respectively. And then, all Chinese journal articles were coded by one of the authors of this article and then double-checked by a second person to validate the feasibility of the coding rubric. Once all the consistencies were confirmed and possible queries solved, 16 Chinese journal articles were systematically selected for coding exercises and establishing the preliminary inter-rater reliability. The inter-rater reliability was 87.5%, and following training, the rest of the articles were independently coded by the three authors. Due to the large number of international journal articles, 70 international journal articles were selected (one out of every 5–7 articles) for double-checking and calculating the inter-rater reliability. The inter-rater reliability was 70.0%. Due to the difficulty associated with extrapolating the theoretical background of some of the studies, inter-rater reliability excluding the theoretical background category increased to 74.3%. Disagreements between the two examiners were resolved by revisiting and discussing specific segments of the article or by adding opinions of a third member. Details of categorical comparisons between articles written by Taiwanese scholars in international journals (TIJ) and in Taiwanese journals (TJ) are listed in the appendices.

## 5.3 Results and Discussions

The results start with the analysis of the articles on conceptual change from international scholars ($n=383$, including 26 articles from Taiwan as a whole) and articles from scholars in Taiwan ($n=86$; 60 articles in national and 26 in international journals), separately. Then comparisons are drawn between the articles from national and international researchers to show trends in the research on conceptual change in science learning. To refer to the articles from different sources, we categorized them as follows. For the 383 articles from international journals, we used the code

IJ. In other words, it appeared in an international journal regardless of the scholar's country of origin. For the 60 articles published in Taiwanese journals, we used the code TJ. For the 26 articles written by Taiwanese scholars but published in international journals, we used the code TIJ. The total articles published by scholars in Taiwan (TJ + TIJ = 86) was coded as T. The detailed statistics from the analyses are presented in the appendices.

### 5.3.1 RQ1: Empirical and Nonempirical Studies

The 10 years after Posner et al. (1982) proposed the first conceptual change model (CCM) served as an induction period with few studies published on the topic. During this period (1982–1992), about 40% of the published studies both inside and outside of Taiwan (10 out of 26) were nonempirical. These studies mainly supported the philosophy of conceptual change in science (e.g., Stenhouse 1986; Terry and Jones 1986) and suggested other factors of conceptual change. For example, Stenhouse suggested Wittgenstein's concept of the "language-game," and Hewson and Thorley (1989) added the idea of conceptual ecology. During the years 1993–1997, studies of conceptual change grew rapidly and this trend continues today. The number of nonempirical studies ($n=22$, 5.7% of the total) was also the highest at this stage. However, after this stage, the number decreased by year. In other words, there were more empirical studies accepted for publication in international journals, whereas fewer and fewer nonempirical studies (such as position articles) that described the issues surrounding conceptual change were published.

As for the TJ ($n=60$) articles published in Taiwan, the first conceptual change study appeared in 1992. This article was an empirical study that explained the relationship between formulating hypotheses and conceptual change (Hsu 1992). However, the first one introduced contemporary theories of conceptual change (such as Chi, Duit, Hewson, Treagust, and Vosniadou) was by Chiu (1993). In the early stages, nonempirical studies outnumbered empirical studies from 1988 to 1997. These studies mainly introduced the trend of cognitive psychology and theories of knowledge restructuring to Taiwanese researchers. After 1997, the number of empirical studies increased abruptly, and some Taiwanese articles on conceptual change began to be published in international journals. All of the articles written by Taiwanese scholars and published in the international journals were empirical studies. The first TIJ ($n=26$) appeared in the *International Journal of Science and Education* in 1999. This study mainly examined the effects of a problem-solving-based instructional model on earth science students' alternative frameworks and achievement (Chang and Barufaldi 1999). From 1998 to date, the publication rate for Taiwanese authors stabilized, and the research came to focus on the application of conceptual change theories on science education research (i.e., Chiu et al. 2002; Tsai 2000). There were five articles published in TJ on average per year.

Generally speaking, the growth of conceptual change studies in Taiwan fell behind the international trend starting around 5–10 years. The research in Taiwan on conceptual change was started by introducing important conceptual change theories to the science education research community. Therefore, the nonempirical studies outnumbered the empirical studies between 1993 and 1997. The biggest growth period in Taiwan was between 1998 and 2002. During this period, there were many empirical studies published. After 2002, the number of conceptual change research stabilized. However, the number of articles published in TIJ increased whereas TJ decreased (Table 5.2).

### *5.3.2 RQ 2: Theoretical Framework*

We used the RAINBOW (Chiu 2007; Chiu and Lin 2008) approach to analyze each article. The order of the perspectives from most frequent to least frequent were epistemology, instruction, other (including self-naming theories), affection/social interaction, development, ontology, multiple dimensions, and evolution. Among these, 66.1 % of epistemology and 61.1 % of instruction perspectives were revealed in the international journals. The ontology (6.0 %, such as Chiu et al. 2002), multiple dimensions (3.1 %, such as Chiu and Lin 2005), and evolution (0.5 %, such as Alzate and Puig 2007) approaches were quite low. Affection and development (i.e., Margel et al. 2008) were ranked in the middle. However, the order of the approaches was instruction, epistemology, multiple dimensions, ontology, other (including self-naming theories), development, affection/social, and evolution, for the international and national journals in Taiwan. Among them, about 70 % of the articles were related to the instructional perspective and 33.7 % were related to the epistemological perspective which differed from the international studies. Because science educators try to understand how students construct their knowledge and then how they use explanations of scientific phenomena (Vosniadou and Ioannides 1998), it was understandable that relatively high percentages of studies in the area of epistemological approach occurred.

In addition, we found that the number of articles published in epistemology and ontology perspectives started to increase in 1993 whereas the number of articles published in the affection perspective started to increase in 1998 after Pintrich et al. (1993) published their influential article on “hot” conceptual change for 5 years. With some reflections on the possible explanations for these trends found in Table 5.3, we notice that, other than Posner’s influential 1982 article, several other theories on conceptual change, such as Chi (1992), Thagard (1992), and Vosniadou and Brewer (1992), emerged in 1992. The 1992 theories might have also influenced the development of research in this area.

In addition, we found more studies investigating the impact of affection on conceptual change in the international journals as opposed to studies by Taiwanese scholars. However, there were more studies related to ontological issues by Tai-

**Table 5.2** The distribution of empirical and nonempirical publications during 1982–2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n=383$ | 1. Empirical | 5 | (1.3) | 11 | (2.9) | 57 | (14.9) | 75 | (19.6) | 78 | (20.4) | 90 | (23.5) | 316 | (82.5) |
| | 2. Nonempirical | 3 | (0.8) | 7 | (1.8) | 22 | (5.7) | 14 | (3.7) | 13 | (3.4) | 8 | (2.1) | 67 | (17.5) |
| | Total | 8 | (2.1) | 18 | (4.7) | 79 | (20.6) | 89 | (23.2) | 91 | (23.8) | 98 | (25.6) | 383 | (100.0) |
| Taiwan $n=86$ | 1. Empirical | 0 | (0.0) | 1 | (1.2) | 5 | (5.8) | 19 | (22.1) | 24 | (27.9) | 20 | (23.3) | 69 | (80.2) |
| | 2. Nonempirical | 0 | (0.0) | 0 | (0.0) | 7 | (8.1) | 4 | (4.7) | 3 | (3.5) | 3 | (3.5) | 17 | (19.8) |
| | Total | 0 | (0.0) | 1 | (1.2) | 12 | (14.0) | 23 | (26.7) | 27 | (31.4) | 23 | (26.7) | 86 | (100.0) |

**Table 5.3** The distribution of conceptual framework of articles from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n=383$ | 1. Epistemology | 8 | (2.1) | 15 | (3.9) | 56 | (14.6) | 66 | (17.2) | 52 | (13.6) | 56 | (14.6) | 253 | (66.1) |
| | 2. Ontology | 0 | (0.0) | 0 | (0.0) | 4 | (1.0) | 9 | (2.3) | 6 | (1.6) | 4 | (1.0) | 23 | (6.0) |
| | 3. Affection/social | 1 | (0.3) | 0 | (0.0) | 4 | (1.0) | 10 | (2.6) | 10 | (2.6) | 8 | (2.1) | 33 | (8.6) |
| | 4. Development | 0 | (0.0) | 3 | (0.8) | 5 | (1.3) | 6 | (1.6) | 7 | (1.8) | 12 | (3.1) | 33 | (8.6) |
| | 5. Evolution | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) | 0 | (0.0) | 2 | (0.5) |
| | 6. Instruction | 5 | (1.3) | 14 | (3.7) | 46 | (12.0) | 52 | (13.6) | 65 | (17.0) | 52 | (13.6) | 234 | (61.1) |
| | 7. Multiple dimensions | 0 | (0.0) | 2 | (0.5) | 3 | (0.8) | 2 | (0.5) | 2 | (0.5) | 3 | (0.8) | 12 | (3.1) |
| | 8. Others | 1 | (0.3) | 2 | (0.5) | 6 | (1.6) | 8 | (2.1) | 17 | (4.4) | 19 | (5.0) | 53 | (13.8) |
| | Subtotal | 15 | (3.9) | 36 | (9.4) | 124 | (32.4) | 154 | (40.2) | 160 | (41.8) | 154 | (40.2) | | |
| Taiwan $n=86$ | 1. Epistemology | | | 1 | (1.2) | 6 | (7.0) | 6 | (7.0) | 8 | (9.3) | 8 | (9.3) | 29 | (33.7) |
| | 2. Ontology | | | 0 | (0.0) | 1 | (1.2) | 3 | (3.5) | 3 | (3.5) | 2 | (2.3) | 9 | (10.5) |
| | 3. Affection/social | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 1 | (1.2) | 1 | (1.2) | 3 | (3.5) |
| | 4. Development | | | 0 | (0.0) | 0 | (0.0) | 2 | (2.3) | 1 | (1.2) | 1 | (1.2) | 4 | (4.7) |
| | 5. Evolution | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 1 | (1.2) |
| | 6. Instruction | | | 0 | (0.0) | 8 | (9.3) | 20 | (23.3) | 16 | (18.6) | 16 | (18.6) | 60 | (69.8) |
| | 7. Multiple dimensions | | | 0 | (0.0) | 1 | (1.2) | 2 | (2.3) | 1 | (1.2) | 0 | (0.0) | 4 | (4.7) |
| | 8. Others | | | 0 | (0.0) | 2 | (2.3) | 0 | (0.0) | 4 | (4.7) | 2 | (2.3) | 8 | (9.3) |
| | Subtotal | | | 1 | (1.2) | 18 | (20.9) | 34 | (39.5) | 34 | (39.5) | 31 | (36.0) | | |

wanese scholars compared to the international scholars. More effort for a diverse approach to face difficulties of learning scientific concepts is needed.

### *5.3.3 RQ 3: Science Disciplines*

During the period 1982–2012, we found that among the four science disciplines the highest percentage of research was completed in physics (29.2 %), followed by biology (18.8 %) and then chemistry (15.9 %) in the international journals. The publications in the area of earth science had the lowest percentage (8.6 %) among the four subjects. In general, physics is considered a difficult science discipline to be learned in elementary and secondary school because it involves a lot of abstract and complex concepts. Because this subject causes students a great deal of difficulty, many researchers in science education chose physics as their research topic to investigate students' alternative conceptions about physics (Akerson et al. 2000; Chiu and Lin 2005; Hewson and Hewson 1983; Tsai 2003; Zembal-Saul et al. 2002).

A similar finding resulted from the publications by Taiwanese authors with the highest percentage of studies involving physics (34.9 %), followed by chemistry (17.4 %; see Table 5.4). Internationally, studies in the area of conceptual change have grown rapidly in 1993. However, the growth in publishing of articles by Taiwanese authors in international journals was not evident until 1998.

From the results, it is evident that physics was the top science discipline to be explored and examined among all the science disciplines (see Table 5.4). From the analysis of the trend every 5 years, we found that publications by Taiwanese researchers mirrored the trend of international journals except for biology and earth science. According to our analysis, biology education researchers did not publish any international articles on conceptual change. However, there were many earth science conceptual change articles and there were more international articles on conceptual change in chemistry than in physics from Taiwan.

### *5.3.4 RQ 4: Methodology*

#### 5.3.4.1 Research Methods

As for the method of data analysis, namely quantitative, qualitative, both methods, or quantifying qualitative data, we found that over the past 31 years, one third of the articles were qualitative (e.g., Venville et al. 2012), followed by integration of quantitative and qualitative (19.8 %; e.g., Tsui and Treagust 2010), and quantifying qualitative data (19.8 %; e.g., Beerenwinkel et al. 2011) in the international journals. Also, we found that there was an increasing rate of publications emphasizing qualitative data analysis, up from 0.3 % in the first period of 1982–1987 to 11.5 % in the last period of 2008–2012.

**Table 5.4** Science disciplines represented in the published articles on conceptual change from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n=383$ | 1. Physics | 5 | (1.3) | 8 | (2.1) | 25 | (6.5) | 19 | (5.0) | 29 | (7.6) | 26 | (6.8) | 112 | (29.2) |
| | 2. Chemistry | 0 | (0.0) | 1 | (0.3) | 11 | (2.9) | 15 | (3.9) | 14 | (3.7) | 20 | (5.2) | 61 | (15.9) |
| | 3. Biology | 0 | (0.0) | 4 | (1.0) | 17 | (4.4) | 18 | (4.7) | 17 | (4.4) | 16 | (4.2) | 72 | (18.8) |
| | 4. Earth science | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 11 | (2.9) | 7 | (1.8) | 14 | (3.7) | 33 | (8.6) |
| | 5. Cross-domain | 0 | (0.0) | 0 | (0.0) | 4 | (1.0) | 4 | (1.0) | 5 | (1.3) | 1 | (0.3) | 14 | (3.7) |
| | 6. Other | 0 | (0.0) | 2 | (0.5) | 11 | (2.9) | 19 | (5.0) | 16 | (4.2) | 18 | (4.7) | 66 | (17.2) |
| | 7. NA | 3 | (0.8) | 3 | (0.8) | 12 | (3.1) | 5 | (1.3) | 5 | (1.3) | 3 | (0.8) | 31 | (8.1) |
| | Subtotal | 8 | (2.1) | 18 | (4.7) | 81 | (21.1) | 91 | (23.8) | 93 | (24.3) | 98 | (25.6) | | |
| Taiwan $n=86$ | 1. Physics | | | 0 | (0.0) | 4 | (4.7) | 8 | (9.3) | 8 | (9.3) | 10 | (11.6) | 30 | (34.9) |
| | 2. Chemistry | | | 0 | (0.0) | 0 | (0.0) | 2 | (2.3) | 8 | (9.3) | 5 | (5.8) | 15 | (17.4) |
| | 3. Biology | | | 0 | (0.0) | 0 | (0.0) | 3 | (3.5) | 2 | (2.3) | 1 | (1.2) | 6 | (7.0) |
| | 4. Earth science | | | 0 | (0.0) | 3 | (3.5) | 4 | (4.7) | 3 | (3.5) | 3 | (3.5) | 13 | (15.1) |
| | 5. Cross-domain | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 2 | (2.3) | 0 | (0.0) | 3 | (3.5) |
| | 6. Other | | | 0 | (0.0) | 0 | (0.0) | 4 | (4.7) | 4 | (4.7) | 4 | (4.7) | 12 | (14.0) |
| | 7. NA | | | 1 | (1.2) | 5 | (5.8) | 3 | (3.5) | 0 | (0.0) | 0 | (0.0) | 9 | (10.5) |
| | Subtotal | | | 1 | (1.2) | 12 | (14.0) | 25 | (29.1) | 27 | (31.4) | 23 | (26.7) | | |

However, as for research done by scholars from Taiwan, 34.9 % of the articles contained both qualitative and quantitative data methods. This was followed by the quantitative approach (23.3 %). This trend kept steady over the past two decades even though the total number of articles in the area of conceptual change decreased by scholars from Taiwan. When we took into account the articles published by Taiwanese scholars in the international journals (see Table 5.5), the highest percentage was still on the integration of quantitative and qualitative research methods (34.9 %), followed by the quantitative approach (17.4 %).

In sum, compared to the international articles, we found that Taiwanese scholars tended to make good use of quantitative and qualitative research methods more than the either research method alone. Also, Taiwanese scholars tended to have more quantitative research articles than qualitative research articles as shown in Table 5.5.

#### 5.3.4.2 Research Instruments

There were nine categories for analyzing the research instruments, namely paper-and-pencil test, interview, drawing, online data collection, paper-and-pencil and online questionnaires, classroom observation rubric, biological data, and others. Among these categories, 51.2 % of the articles used interviews to collect data, and 41.3 % of the articles used paper-and-pencil tests to assess students' and teachers' performance on their conceptual change. In addition, although 83 articles (21.7 %) were considered empirical studies, they did not use the instruments discussed above to collect data. Based upon Table 5.6, to our surprise, there was only one paper that used an online questionnaire to investigate conceptual change. Also, there was only one paper that used biological data to investigate conceptual change. It is likely that these types of research have been published in other research journals which fit much better than the journals we selected for analysis.

Both paper-and-pencil tests (53.5 %) and interviews (54.7 %) were the most commonly used instruments in the studies conducted in Taiwan. Taking the papers published in the international journals by science researchers from Taiwan into account (TIJ), we found similar trends in the use of paper-and-pencil tests and interviews for data collection. For the rest of the methods, very low percentages of papers used them to collect research data.

The data collection methods varied in the articles between IJ and TIJ. Although articles in the areas of conceptual change tended to use the first two types of instruments to conduct conceptual change research, we found that articles in the international journals tended to have a wider range of research instruments, in particular, drawing, questionnaires, online data, and the observation rubric, which were regularly used. Taking into account the papers published in international journals by scholars from Taiwan (TIJ), the majority of research collected data either by paper-and-pencil tests or interview techniques.

**Table 5.5** The distribution of research methods of articles from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n=383$ | 1. Qualitative | 1 | (0.3) | 5 | (1.3) | 18 | (4.7) | 34 | (8.9) | 42 | (11.0) | 44 | (11.5) | 144 | (37.6) |
| | 2. Quantitative | 1 | (0.3) | 3 | (0.8) | 17 | (4.4) | 12 | (3.1) | 15 | (3.9) | 18 | (4.7) | 66 | (17.2) |
| | 3. Both (1) & (2) | 2 | (0.5) | 3 | (0.8) | 13 | (3.4) | 21 | (5.5) | 16 | (4.2) | 21 | (5.5) | 76 | (19.8) |
| | 4. Quantifying the qualitative data | 1 | (0.3) | 4 | (1.0) | 14 | (3.7) | 15 | (3.9) | 18 | (4.7) | 24 | (6.3) | 76 | (19.8) |
| | 5. NA[a] | 3 | (0.8) | 7 | (1.8) | 22 | (5.7) | 14 | (3.7) | 13 | (3.4) | 8 | (2.1) | 67 | (17.5) |
| | Subtotal | 8 | (2.1) | 22 | (5.7) | 84 | (21.9) | 96 | (25.1) | 104 | (27.2) | 115 | (30.0) | | |
| Taiwan $n=86$ | 1. Qualitative | | | 0 | (0.0) | 1 | (1.2) | 5 | (5.8) | 5 | (5.8) | 4 | (4.7) | 15 | (17.4) |
| | 2. Quantitative | | | 1 | (1.2) | 0 | (0.0) | 7 | (8.1) | 8 | (9.3) | 4 | (4.7) | 20 | (23.3) |
| | 3. Both (1) & (2) | | | 0 | (0.0) | 4 | (4.7) | 7 | (8.1) | 10 | (11.6) | 9 | (10.5) | 30 | (34.9) |
| | 4. Quantifying the qualitative data | | | 0 | (0.0) | 1 | (1.2) | 0 | (0.0) | 8 | (9.3) | 7 | (8.1) | 16 | (18.6) |
| | 5. NA[a] | | | 0 | (0.0) | 7 | (8.1) | 4 | (4.7) | 3 | (3.5) | 3 | (3.5) | 17 | (19.8) |
| | Subtotal | | | 1 | (1.2) | 13 | (15.1) | 23 | (26.7) | 34 | (39.5) | 27 | (31.4) | | |

[a] *NA* stands for nonempirical studies for coding methods

**Table 5.6** The distribution of data collection methods of articles from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n = 383$ | 1. Paper and pencil test | 3 | (0.8) | 7 | (1.8) | 29 | (7.6) | 35 | (9.1) | 34 | (8.9) | 50 | (13.1) | 158 | (41.3) |
| | 2. Interview | 4 | (1.0) | 6 | (1.6) | 32 | (8.4) | 44 | (11.5) | 58 | (15.1) | 52 | (13.6) | 196 | (51.2) |
| | 3. Drawing | 0 | (0.0) | 1 | (0.3) | 6 | (1.6) | 9 | (2.3) | 8 | (2.1) | 13 | (3.4) | 37 | (9.7) |
| | 4. Online data | 0 | (0.0) | 0 | (0.0) | 3 | (0.8) | 1 | (0.3) | 3 | (0.8) | 2 | (0.5) | 9 | (2.3) |
| | 5. Questionnaire | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 8 | (2.1) | 3 | (0.8) | 4 | (1.0) | 16 | (4.2) |
| | 6. Online questionnaire | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) |
| | 7. Rubric or coding sheet of classroom observation | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 3 | (0.8) | 3 | (0.8) | 3 | (0.8) | 10 | (2.6) |
| | 8. Biological data | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) |
| | 9. Other | 1 | (0.3) | 3 | (0.8) | 17 | (4.4) | 25 | (6.5) | 16 | (4.2) | 21 | (5.5) | 83 | (21.7) |
| | 10. NA | 3 | (0.8) | 7 | (1.8) | 22 | (5.7) | 14 | (3.7) | 13 | (3.4) | 8 | (2.1) | 67 | (17.5) |
| | Subtotal | 11 | (2.9) | 25 | (6.5) | 109 | (28.5) | 140 | (36.6) | 138 | (36.0) | 154 | (40.2) | | |
| Taiwan $n = 86$ | 1. Paper and pencil test | | | 1 | (1.2) | 4 | (4.7) | 12 | (14.0) | 17 | (19.8) | 12 | (14.0) | 46 | (53.5) |
| | 2. Interview | | | 0 | (0.0) | 4 | (4.7) | 11 | (12.8) | 20 | (23.3) | 12 | (14.0) | 47 | (54.7) |
| | 3. Drawing | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 1 | (1.2) | 3 | (3.5) | 5 | (5.8) |
| | 4. Online data | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 1 | (1.2) | 1 | (1.2) | 3 | (3.5) |
| | 5. Questionnaire | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) |
| | 6. Online questionnaire | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.2) | 1 | (1.2) |
| | 7. Rubric or coding sheet of classroom observation | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 8. Biological data | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 9. Other | | | 0 | (0.0) | 1 | (1.2) | 5 | (5.8) | 4 | (4.7) | 6 | (7.0) | 16 | (18.6) |
| | 10. NA | | | 0 | (0.0) | 7 | (8.1) | 4 | (4.7) | 3 | (3.5) | 3 | (3.5) | 17 | (19.8) |
| | Subtotal | | | 1 | (1.2) | 16 | (18.6) | 35 | (40.7) | 46 | (53.5) | 38 | (44.2) | | |

In row number 9, Others refers to documents, content analysis of literature, or videotapes, etc.

*NA* Not applicable

### 5.3.5 RQ 5: Teaching Strategies

For the international part, from the 383 articles, 240 articles were related to conceptual change teaching strategies (62.7 %). From the TJ, 58 articles (67.4 %, excluding articles that were not applicable) out of total 86 were related to conceptual change teaching strategies (67.4 %). It seems that science educators in Taiwan focus more on the application of teaching strategies (Table 5.7).

From 1982 to 1992, the teaching strategy of conceptual conflict was the top method researchers adopted in IJ. The percentages were 1.3 and 2.1 % in total, respectively. Without doubt, Posner et al.'s (1982) study was the first article to apply the teaching strategy of conceptual conflict. Besides, they also integrated experiments and group discussion to foster students' science learning. However, from 1993 to 2002, the top strategy changed to "analogy, model and modeling." The percentages were 5.0 and 5.0 %, respectively. Actually, the first article about this teaching strategy appeared in 1992. Brown (1992) questioned the effectiveness of a traditional teaching-by-example technique, and presented several principles to design effective analogies in a constructive way. After this article, this strategy increased abruptly. There were various teaching strategies related to "analogy, model and modeling," such as bridging analogies (Brown 1994, Bryce and MacMillan 2005), multiple analogies (Chiu and Lin 2005), transformative modeling (Shen and Confrey 2007), and so on. Recently (2003–2012), the instruction of multimedia became the mainstream to help students overcome their alternative conceptions. The percentages were 5.4 (2003–2007) and 4.6 % (2008–2012), respectively. However, early in 1986, Zietsman and Hewson had already adopted microcomputer simulations to diagnose and remediate an alternative conception of velocity. With regard to the whole sample, the most popular methods were analogy, model/modeling (19.6 %), followed by multimedia (16.3 %) and conceptual conflict (15.8 %). The trend in conceptual change instruction was from conceptual conflict to analogy, model/modeling, and then to instruction of multimedia.

As for the TJ, on the whole, "multimedia" (20.7 %), "conceptual conflict" (20.7 %), "analogy, model/modeling" (15.5 %), "inquiry" (12.1 %), and "concept map" (10.3 %) were the teaching strategies most adopted. In the initiation stage (1982–1997), there were fewer journal articles related to teaching strategies. In the years 1993–1997, text was the most popular teaching strategy (3.4 %). Then, the teaching strategies of multimedia, conceptual conflict, and concept map (6.9, 6.9, 6.9 %, respectively) became popular between 1998 and 2002. At the last stage, teaching strategy of multimedia (10.3 %) was the most popular teaching method between 2008 and 2012.

The researchers in Taiwan invested more effort than international researchers in developing teaching strategies using multimedia (Taiwan: International = 20.7 %: 16.3 %) and improving the strategy of conceptual conflict (Taiwan: International = 20.7 %: 15.8 %). The importance of these two instructional strategies is still evident. Unlike the trend of the changes of teaching strategies across the globe, there was no obvious trend of changing in Taiwan. Besides, the total percentage showed Taiwanese researchers (125.9 %) adopted more multiple teaching strategies in a study than international researchers (117.1 %) (see Table 5.8).

**Table 5.7** The distribution of teaching or nonteaching studies from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International *n*=383 | Articles related to teaching | 4 | (1.0) | 10 | (2.6) | 46 | (12.0) | 56 | (14.6) | 63 | (16.4) | 61 | (15.9) | 240 | (62.7) |
| | NA | 4 | (1.0) | 8 | (2.1) | 33 | (8.6) | 33 | (8.6) | 28 | (7.3) | 37 | (9.7) | 143 | (37.3) |
| | Total | 8 | (2.1) | 18 | (4.7) | 79 | (20.6) | 89 | (23.2) | 91 | (23) | 98 | (25.6) | 383 | (100.0) |
| Taiwan *n*=86 | Articles related to teaching | 0 | (0.0) | 0 | (0.0) | 2 | (2.3) | 19 | (22.1) | 22 | (25.6) | 15 | (17.4) | 58 | (67.4) |
| | NA | 0 | (0.0) | 1 | (1.2) | 8 | (9.3) | 6 | (7.0) | 5 | (5.8) | 8 | (9.3) | 28 | (32.6) |
| | Total | 0 | (0.0) | 1 | (1.2) | 10 | (11.6) | 25 | (29.1) | 27 | (31.4) | 23 | (26.7) | 86 | (100.0) |

*NA* not applicable, articles are not related to teaching

**Table 5.8** The distribution of teaching strategies between 1982 and 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n=240$ | 1. Analogy, model and modeling | 0 | (0.0) | 1 | (0.4) | 12 | (5.0) | 12 | (5.0) | 13 | (5.4) | 9 | (3.8) | 47 | (19.6) |
| | 2. Multimedia | 1 | (0.4) | 0 | (0.0) | 6 | (2.5) | 8 | (3.3) | 13 | (5.4) | 11 | (4.6) | 39 | (16.3) |
| | 3. Conceptual conflict | 3 | (1.3) | 5 | (2.1) | 7 | (2.9) | 6 | (2.5) | 9 | (3.8) | 8 | (3.3) | 38 | (15.8) |
| | 4. Inquiry | 0 | (0.0) | 0 | (0.0) | 2 | (0.8) | 4 | (1.7) | 9 | (3.8) | 8 | (3.3) | 23 | (9.6) |
| | 5. Cooperative learning | 1 | (0.4) | 0 | (0.0) | 2 | (0.8) | 4 | (1.7) | 6 | (2.5) | 2 | (0.8) | 15 | (6.3) |
| | 6. Experiment | 1 | (0.4) | 0 | (0.0) | 1 | (0.4) | 3 | (1.3) | 3 | (1.3) | 4 | (1.7) | 12 | (5.0) |
| | 7. Text | 0 | (0.0) | 0 | (0.0) | 5 | (2.1) | 1 | (0.4) | 4 | (1.7) | 1 | (0.4) | 11 | (4.6) |
| | 8. Multiple representation | 0 | (0.0) | 0 | (0.0) | 1 | (0.4) | 2 | (0.8) | 3 | (1.3) | 3 | (1.3) | 9 | (3.8) |
| | 9. Argumentation | 0 | (0.0) | 0 | (0.0) | 1 | (0.4) | 1 | (0.4) | 0 | (0.0) | 3 | (1.3) | 5 | (2.1) |
| | 10. Concept map | 0 | (0.0) | 1 | (0.4) | 3 | (1.3) | 0 | (0.0) | 1 | (0.4) | 0 | (0.0) | 5 | (2.1) |
| | 11. Science history | 0 | (0.0) | 1 | (0.4) | 1 | (0.4) | 0 | (0.0) | 2 | (0.8) | 0 | (0.0) | 4 | (1.7) |
| | 12. Metacognitive approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (0.8) | 0 | (0.0) | 2 | (0.8) | 4 | (1.7) |
| | 13. Constructivist approach | 0 | (0.0) | 1 | (0.4) | 1 | (0.4) | 0 | (0.0) | 1 | (0.4) | 0 | (0.0) | 3 | (1.3) |
| | 14. Self-explanation | 0 | (0.0) | 0 | (0.0) | 1 | (0.4) | 2 | (0.8) | 0 | (0.0) | 0 | (0.0) | 3 | (1.3) |
| | 15. Other | 1 | (0.4) | 1 | (0.4) | 9 | (3.4) | 18 | (7.5) | 13 | (5.4) | 21 | (8.8) | 63 | (26.3) |
| | Total | 7 | (2.9) | 10 | (4.2) | 52 | (21.7) | 63 | (26.3) | 77 | (32.1) | 72 | (30.0) | 281 | (117.1) |

**Table 5.8** (continued)

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taiwan $n = 58$ | 1. Analogy, model and modeling | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 3 | (5.2) | 3 | (5.2) | 2 | (3.4) | 9 | (15.5) |
| | 2. Multimedia | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 4 | (6.9) | 2 | (3.4) | 6 | (10.3) | 12 | (20.7) |
| | 3. Conceptual conflict | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 4 | (6.9) | 6 | (10.3) | 2 | (1.7) | 12 | (20.7) |
| | 4. Inquiry | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (3.4) | 4 | (6.9) | 1 | (1.7) | 7 | (12.1) |
| | 5. Cooperative learning | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 1 | (1.7) | 0 | (0.0) | 2 | (3.4) |
| | 6. Experiment | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 2 | (3.4) | 0 | (0.0) | 3 | (5.2) |
| | 7. Text | 0 | (0.0) | 0 | (0.0) | 2 | (3.4) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (3.4) |
| | 8. Multiple representation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 9. Argumentation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (3.4) | 0 | (0.0) | 0 | (0.0) | 2 | (3.4) |
| | 10. Concept map | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 4 | (6.9) | 1 | (1.7) | 1 | (1.7) | 6 | (10.3) |
| | 11. Science history | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (3.4) | 2 | (3.4) |
| | 12. Metacognitive approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 13. Constructivist approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) |
| | 14. Self-explanation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 15. Other | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 4 | (6.9) | 7 | (12.1) | 4 | (6.9) | 16 | (27.6) |
| | Total | 0 | (0.0) | 0 | (0.0) | 4 | (6.9) | 26 | (44.8) | 26 | (44.8) | 17 | (29.3) | 73 | (125.9) |

## 5.3.6 RQ 6: Authorship and Participants

### 5.3.6.1 Authorship

Among the 383 articles published in the international journals from 1982 to 2012, we found that 38.1% ($n=146$) of the authors were from the USA, followed by 9.9% ($n=38$) from Australia (see Table 5.9). The first two countries were mainly English-speaking countries with a population of 320 and 24 million, respectively (World Population Review 2014). Taiwan, with 6.8% ($n=26$), was ranked third; Taiwan is the first non-English-speaking country in the list and has a population of 23 million only. In particular, the papers published by scholars in Taiwan were only during the last 15 years (1998–2012) unlike the USA, Australia, and the UK who started publishing as early as the 1980s. As a non-English-speaking country, this provides evidence that the efforts of researchers in Taiwan contributed to the conceptual change community worldwide. In addition to this, we also noted that South Korea (with a population of 50 million), Turkey (with a population of 76 million), and Germany (with a population of 80 million) showed their active involvement in publishing research papers during the period 2003–2012. In addition, we found that several countries had started publishing papers in the five major science education journals during the period 1998–2002. Although this phenomenon was not foreseen and it is difficult to attribute causes for the increase, we hypothesized that the international trend of research on students' understanding of science switched from the alternative conception paradigm, which accumulated a great number of research results, to the conceptual change paradigm to improve school science learning, which may have been a factor. A great number of studies have been produced that address the difficulties of learning science at different levels, by different genders, and within different cultures. The results of these studies have guided science education researchers to consider possible meaningful strategies for promoting students' knowledge reconstruction of scientific phenomenon. Therefore, after Posner et al. (1982) and other researchers published conceptual change articles, this area gained more attention from science educators and researchers. We also noticed that the number of articles from the USA started to increase in 1993. Several other countries also showed their interest in conducting research on conceptual change (e.g., Australia, the UK, Israel, Canada, and Spain) whereas Taiwan joined the research trend in 1999 and stably increased its visibility. As for Turkey, it was quite impressive to see eight international articles published from 2008 to 2012, putting Turkey at number four among the 32 countries.

### 5.3.6.2 Participating Countries

An analysis was conducted on the participating countries, and we found that 34.2% ($n=131$) of the articles were published in the USA, and that this dropped dramatically to 7.8% ($n=30$) in Australia, 6.0% ($n=23$) in Taiwan, and then 3.9% ($n=15$) each from the UK and Israel. Also, there were five articles that involved

**Table 5.9** The distribution of the first or correspondence authors' countries from 1982 to 2012

| | | | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International $n=383$ | 1. | USA | 2 | (0.5) | 9 | (2.3) | 41 | (10.7) | 45 | (11.7) | 20 | (5.2) | 29 | (7.6) | 146 | (38.1) |
| | 2. | Australia | 1 | (0.3) | 3 | (0.8) | 7 | (1.8) | 5 | (1.3) | 12 | (3.1) | 10 | (2.6) | 38 | (9.9) |
| | 3. | Taiwan | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 7 | (1.8) | 8 | (2.1) | 11 | (2.9) | 26 | (6.8) |
| | 4. | UK | 1 | (0.3) | 0 | (0.0) | 5 | (1.3) | 4 | (1.0) | 8 | (2.1) | 3 | (0.8) | 21 | (5.5) |
| | 5. | Israel | 1 | (0.3) | 2 | (0.5) | 5 | (1.3) | 3 | (0.8) | 3 | (0.8) | 3 | (0.8) | 17 | (4.4) |
| | 6. | Canada | 0 | (0.0) | 1 | (0.3) | 5 | (1.3) | 4 | (1.0) | 3 | (0.8) | 2 | (0.5) | 15 | (3.9) |
| | 7. | Spain | 0 | (0.0) | 1 | (0.3) | 3 | (0.8) | 4 | (1.0) | 6 | (1.6) | 0 | (0.0) | 14 | (3.7) |
| | 8. | Korea | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 6 | (1.6) | 4 | (1.0) | 11 | (2.9) |
| | 9. | Turkey | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) | 8 | (2.1) | 10 | (2.6) |
| | 10. | Germany | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 4 | (1.0) | 4 | (1.0) | 9 | (2.3) |
| | 11. | Greece | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (0.5) | 2 | (0.5) | 4 | (1.0) | 8 | (2.1) |
| | 12. | South Africa | 2 | (0.5) | 0 | (0.0) | 4 | (1.0) | 1 | (0.3) | 0 | (0.0) | 1 | (0.3) | 8 | (2.1) |
| | 13. | China | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 5 | (1.3) | 1 | (0.3) | 0 | (0.0) | 6 | (1.6) |
| | 14. | France | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 4 | (1.0) | 2 | (0.5) | 6 | (1.6) |
| | 15. | Sweden | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (0.5) | 4 | (1.0) | 6 | (1.6) |
| | 16. | Brazil | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) | 2 | (0.5) | 5 | (1.3) |
| | 17. | The Netherlands | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) | 2 | (0.5) | 1 | (0.3) | 0 | (0.0) | 5 | (1.3) |
| | 18. | Finland | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (0.5) | 2 | (0.5) | 4 | (1.0) |
| | 19. | Italy | 0 | (0.0) | 0 | (0.0) | 4 | (1.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 4 | (1.0) |
| | 20. | Lebanon | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 0 | (0.0) | 3 | (0.8) | 4 | (1.0) |
| | 21. | Venezuela | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 2 | (0.5) | 0 | (0.0) | 1 | (0.3) | 4 | (1.0) |
| | 22. | Cyprus | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (0.5) | 1 | (0.3) | 3 | (0.8) |
| | 23. | New Zealand | 1 | (0.3) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 2 | (0.5) |
| | 24. | Nigeria | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 2 | (0.5) |

**Table 5.9** (continued)

| | | | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25. | Singapore | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) | 2 | (0.5) |
| | 26. | Argentina | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 1 | (0.3) |
| | 27. | Bangladesh | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) |
| | 28. | Northern Ireland | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) |
| | 29. | Norway | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) |
| | 30. | Scotland | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 0 | (0.0) | 1 | (0.3) |
| | 31. | Switzerland | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (0.3) | 1 | (0.3) |
| | | Subtotal | 8 | (2.1) | 18 | (4.7) | 79 | (20.6) | 89 | (23.2) | 91 | (23.8) | 98 | (25.6) | 383 | (100.0) |

collaboration between countries, namely, one article involving Australia and Korea, one involving Australia and the USA, two with New Zealand and China, and one for Spain and the UK (see Table 5.10).

## 5.4 Concluding Remarks

Based upon our careful analysis of the contents of the identified articles both from international and national journals, we have the following claims to make.

### *5.4.1 Claim 1: Studies on Conceptual Change in International Journals Are at a Reasonable Stable Status but in TJ the Numbers Appear to Be Limited*

Conceptual change is important for science education, and its importance is still being unraveled. In our analysis, most of the studies follow the empirical approach to explore this domain whether it is an international or a national article. This is supported by the trend that publications on conceptual change in international journals are at a reasonably stable status (see Figs. 5.2 and 5.3). The research on conceptual change in Taiwan fell behind the international trend around 5–10 years back, but it has since risen and the number of published studies now rival Western countries. However, the rate of publication on conceptual change in Taiwan seems to be leveling off. The research trend of science education in Taiwan recently is quite consistent with the international research trend in three main science education journals *(Journal of Research in Science Teaching, Science Education, and International Journal of Science Education)*. That is, the context of students' learning replaced students' conceptual learning, which was the most published research topic from 1998 to 2002 (Lin et al. 2014). We speculate this might be the reason for the limited number of Taiwanese conceptual change studies lately.

### *5.4.2 Claim 2: Most of the Published Research on Conceptual Change Investigated the Effectiveness of Instructional Strategies and Materials*

Based upon our analysis, we found that more studies were related to epistemology and instruction compared to other perspectives (See Table 5.3). Since most of instructions originated from epistemological perspective, it is not surprising to have high percentages of publications in these two areas. However, Taiwan tended to solve the problems in school practice by conducting more studies on designing instructional materials to improve science teaching, therefore, a high percent-

**Table 5.10** The distribution of participants by country from 1982 to 2012

| | Country | *n* | % |
|---|---|---|---|
| 1. | USA | 131 | 34.2 |
| 2. | Australia | 30 | 7.8 |
| 3. | Taiwan | 23 | 6.0 |
| 4. | UK | 15 | 3.9 |
| 5. | Israel | 15 | 3.9 |
| 6. | Canada | 11 | 2.9 |
| 7. | Spain | 11 | 2.9 |
| 8. | Korea | 11 | 2.9 |
| 9. | Germany | 9 | 2.3 |
| 10. | France | 6 | 1.6 |
| 11. | Greece | 6 | 1.6 |
| 12. | Sweden | 6 | 1.6 |
| 13. | Turkey | 6 | 1.6 |
| 14. | China | 5 | 1.3 |
| 15. | South Africa | 5 | 1.3 |
| 16. | Brazil | 4 | 1.0 |
| 17. | Lebanon | 4 | 1.0 |
| 18. | The Netherlands | 4 | 1.0 |
| 19. | Finland | 3 | 0.8 |
| 20. | Italy | 3 | 0.8 |
| 21. | Venezuela | 3 | 0.8 |
| 22. | Cyprus | 2 | 0.5 |
| 23. | Nigeria | 2 | 0.5 |
| 24. | Singapore | 2 | 0.5 |
| 25. | Argentina | 1 | 0.3 |
| 26. | India | 1 | 0.3 |
| 27. | Latin America | 1 | 0.3 |
| 28. | Maldives | 1 | 0.3 |
| 29. | Northern Ireland | 1 | 0.3 |
| 30. | Scotland | 1 | 0.3 |
| 31. | Thailand | 1 | 0.3 |
| 32. | Uganda | 1 | 0.3 |
| | Dual | 5 | 1.3 |
| | Australia & Korea | 1 | 0.3 |
| | Australia & USA | 1 | 0.3 |
| | New Zealand & China | 2 | 0.5 |
| | Spain and UK | 1 | 0.3 |
| | NA | 53 | 13.8 |
| | Total (*n*) | 383 | 100.0 |

age of instructional studies in Taiwan compared to the international studies that emphasized more on the epistemological perspective on teaching and learning. We also found the low percentage of the amount of research on evolutionary perspective. We speculate one of the possible explanations is the difficulty of conducting long duration research in schools due to the pressure to cover a large number of science topics for the sake of high school and university entrance examinations. Furthermore, compared to international articles, it was found that Taiwan has more articles on the ontology perspective and a lower number of articles on affection/social. As researchers in this area advocated multiple-dimension approaches in uncovering the challenges of conceptual change in teachers' and students' beliefs and conceptions about science, this result shed some light on the research outcomes and directions for empowerment.

### 5.4.3 Claim 3: More Research on Conceptual Change Is in the Area of Physics Compared to Chemistry, Biology, and Earth Science

Not surprisingly, there were more studies completed in the area of physics compared to the other science disciplines because of its long history in science education research and the complex, counterintuitive, and abstract nature of its concepts. However, as one of the major science disciplines in elementary and secondary schools, relatively low percentage of studies were carried out for improving school biology instruction and developing teachers' expertise in knowing students' knowledge of biology in Taiwan which might need more attention from science educators (See Table 5.4). In addition, we noticed that there seems to be more physics education researchers than researchers of any other subjects. Although we do not have the exact number of researchers in physics education, we suspect that there are many current research investigating students' misconceptions and developing instructional materials and assessment items for physics (such as mechanics, light, and electricity), so the results can be easily compared across different cultures and countries. That might be one of the possible reasons why we found research in physics education dominating science education research.

### 5.4.4 Claim 4: Most Published Studies on Conceptual Change Relied on Multiple Data Collection Methods for Triangulation Purposes

As expected, most of the research used paper-and-pencil and interview methods to collect research data from 1982 to 2012 regardless of where the research took place. We also found that higher percentages of qualitative studies appeared in the international journals whereas higher percentages of studies using both qualitative and quantitative methods were found in the articles by Taiwanese authors. The use of the triangulation approach allows researchers to provide better quality, more richness, and fuller explanations of students' complex learning processes than is afforded by single methods alone (Cohen and Manion 2000).

### 5.4.5 Claim 5: Major Teaching Strategy Changes from Conceptual Conflict, Analogy to Multimedia

The change of the trend of teaching strategy in international journals is obvious. Conceptual conflict was the main teaching strategy early on, and it changed to "analogy, model and modeling," and then to multimedia. The trend in Taiwan was not as clear. It seems that researchers in Taiwan preferred the teaching methods of conceptual conflict and multimedia. One of the reasons might be that the Taiwanese government continuously allocated a considerable budget to support the development of e-learning via both scholarly and industrial research (Chang et al. 2009). There also appeared to be ample evidence from numerous studies that conceptual change instruction was more efficient than traditional instruction (Duit and Treagust 2012). However, is any teaching strategy more efficient than the other? Why is the trend of teaching strategy in Taiwan different from the international trend? These questions should be further examined by considering the nature of learners' conceptions, the theoretical backgrounds adopted, and cultural differences. Large-scale programs for improving the quality of science instruction should also be implemented in the near future.

### 5.4.6 Claim 6: Continuous Effort on Research on Conceptual Change in Science Learning

As a non-English-speaking country, Taiwan outperformed other countries in terms of research produced and published on conceptual change. Researchers in Taiwan should be continuously making contributions to this field and not only investigating theoretical frameworks but also taking sociocultural perspectives into account when conducting research in Taiwan. As Chiu and Duit (2011) pointed out, globalization is not a new movement. However, there is the danger of just exchanging local (indigenous) ideas for science conceptions; as a result, one may lose one's cultural identity and become alienated from one's indigenous culture. On the one hand, we concur that the perspective of globalization provides new insights into how science should be taught and what should be emphasized (Chiu and Duit 2011). On the other hand, we present the caveat that cultural and historical perspectives, which have not been taken into account in general thus far, should be considered as a way to guide us to conduct and implement the studies into practices.

### *5.4.7 Claim 7: Two Stages of Conceptual Change Research Trend*

Based on our analysis of international and national articles on conceptual change, two stages of conceptual change research were identified: Stage 1 is *incubation* and Stage 2 is *development* in terms of quantity of publications during a specific period of time. For international articles, the period of Stage 1 was from 1982 to 1992 and Stage 2 from 1993 to 2012. For articles from science education researchers in Taiwan, the period of Stage 1 was from 1992 to 1997 and Stage 2 from 1998 to 2012. Taiwan started research on conceptual change 10 years later than the international research trend. However, starting in 1999, researchers in Taiwan generated quality publications that showed a high interest in this area. The special issue in *International Journal of Science Education* (Chiu et al. 2007) described the background and the process that the researchers in Taiwan spend our time, effort, and human and financial resources to conduct the National Science Concept Learning Study to catch up with the international studies on conceptual change.

## 5.5 Implications for Science Education Research on Conceptual Change

It was not a surprise to find the disparities of distributions of research types to be in favor of empirical studies that were published internationally and nationally. Due to the major findings shown above, we have the following suggestions for research on conceptual change.

### *5.5.1 Suggestion 1: Increasing Nonempirical Studies for Informing Conceptual Change Theory*

After a period of the first 10 years (1982–1992), the percentage of nonempirical studies became less and less starting from 1993 to 1997 and then stayed low afterwards. Most researchers conducted empirical studies, in particular in the innovation of teaching strategies. It might be that science education researchers tried to accumulate more findings from empirical studies to evolve new theories (or paradigm) on conceptual change. Although the early Taiwanese conceptual change studies focused more on the nonempirical studies, they mainly introduced other scholars' important conceptual change theories for the Taiwanese science education community. In other words, no matter whether it is from the global perspective or the local perspective, science educators paid less attention to the formation or supplementation of conceptual change theories. We have accumulated considerable results from these empirical studies. The next step is to synthesize these results and increase the number of nonempirical studies for renewing or reconstructing conceptual change theories for global or local needs. In particular, Taiwan's educational system has its own unique culture (such as high-stakes testing) that may shed light on the conceptual change research challenges and the emerging need for developing local learning theories.

### 5.5.2 Suggestion 2: Encouraging More Research in Diverse and Cross-Science Disciplines

The imparity of distribution of studies in science disciplines shows an emerging need for putting more effort across different subjects. Although we did not analyze what topics in physics were investigated, our speculation is that topics in the area of electric circuits, light, mechanics, and weight and density are the most commonly found in the articles. Therefore, spreading out the research interests to other science disciplines and new scientific concepts (such as nanotechnology) would be valuable to explore.

### 5.5.3 Suggestion 3: Strengthening the Implementation of Multiple Perspectives of Approaches for Research

As early as 1997, Tyson et al. had already proposed the multidimensional approach for conceptual change studies; other researchers (Chiu 2007; Chiu and Lin 2008; Duit and Treagust 2003, Treagust and Duit 2008) have advocated for the multiple perspectives approach. Table 5.3 shows that besides epistemological perspectives, instructional perspectives received relatively more attention by researchers than the others. The other perspectives, individual or joint, need to be explored in the future. There is still room to improve our use of multiple approaches to answer crucial questions that remain in the area of conceptual change.

### 5.5.4 Suggestion 4: Using Multiple Research Methods to Increase Reliability of Studies as Evidence-Based Sources for Educational Reforms

Science education researchers need to seriously consider how to increase the reliability of their research methods, outcomes, and implications via multiple sources of data collection. Such evidence is necessary for making reliable and relevant judgments, conclusive claims, and convincing implications. It is the challenge before us to develop new research methods that can open new avenues to effective research on conceptual change in science learning. In addition, with advanced research methods, profound theories of students' construction and change of their epistemological beliefs will likely be developed. More importantly, it is evident that research outcomes currently have very little impact on science educational reform (such as science curriculum standards). By increasing the reliability of research outcomes, decisions made for science educational reforms can be more trustworthy, and as a result, more influential in school science practice reform policy-making.

### *5.5.5 Suggestion 5: Strengthening the Relationships Among Science Disciplines, Multimedia, and Instructional Theory, Followed by Conveying Them to School Teachers to Promote Quality Teaching in School Science Practice*

From this literature review, we found the teaching strategy of multimedia is the most mainstream. In particular, Taiwan showed its advantage in terms of technology, science educators in Taiwan dominate in the development of innovative strategy with multimedia. However, multimedia is only a tool. We must strengthen the relationships among disciplines, multimedia, and conceptual change theory to change the teaching materials and then implement them in schools. Of course, teachers should be well informed about the innovative teaching opportunities and change their pedagogical content knowledge on science accordingly to provide higher quality instruction.

### *5.5.6 Suggestion 6: Increasing the Interaction Between Local Scholars and International Scholars*

The research published in international journals and collaborated with international scholars should serve the following functions:

- To share research findings and experiences with the global community.
- To increase the researchers' awareness of the current trends in theoretical framework and methodological issues in different contexts.
- To show the uniqueness of cultural and social impacts on science learning.
- To build a culture of sharing and to cultivate research competence.

Based upon our results, linking local research with the international research community should be emphasized. Not only do local researchers have expertise and experiences in conducting research locally and publishing in international journals, but Taiwan researchers also have the obligation to increase international scholars' awareness of the cultural and historical impact of non-English-speaking countries on science as a human enterprise. More importantly, we should link research with school practice not only to change school teaching but also to promote quality professional development for preservice and in-service teachers.

### 5.5.7 Suggestion 7: Advocating New and Revolutionary Theories and Research Methods on Conceptual Change for Promoting Research Quality and Quantity to the Next Stage

Without insightful theories, empirical research cannot be easily developed or designed. Analyses of the current chapter showed that empirical studies, especially those with instructional design, dominated the field. To strengthen the impact of research on conceptual change in school science practice, revolutionary theories, innovative research methods, and systematic assessment tools on conceptual change in science education should be further developed and advanced. We concur that the "Acquisition of a paradigm and of the more esoteric type of research it permits is a sign of maturity in the development of any given scientific field" (Kuhn 1970, p. 55). The spirit of research maturity might also be applied to research on conceptual change in learning science.

# Appendices

Appendix A. The distribution of empirical and nonempirical international and national publications by science education researchers in Taiwan from 1982 to 2012

| | | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ ($n$=26) | Empirical | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 7 | (26.9) | 8 | (30.8) | 11 | (42.3) | 26 | (100.0) |
| | Nonempirical | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| TJ ($n$=60) | Empirical | 0 | (0.0) | 1 | (1.7) | 5 | (8.3) | 12 | (20.0) | 16 | (26.7) | 9 | (15.0) | 43 | (71.7) |
| | Nonempirical | 0 | (0.0) | 0 | (0.0) | 7 | (11.7) | 4 | (6.7) | 3 | (5.0) | 3 | (5.0) | 17 | (28.3) |
| Total ($n$=86) | Empirical | 0 | (0.0) | 1 | (1.2) | 5 | (5.8) | 19 | (22.1) | 24 | (27.9) | 20 | (23.3) | 69 | (80.2) |
| | Nonempirical | 0 | (0.0) | 0 | (0.0) | 7 | (8.1) | 4 | (4.7) | 3 | (3.5) | 3 | (3.5) | 17 | (19.8) |

Appendix B. The distribution of science disciplines of articles by science education researchers in Taiwan from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ ($n$=26) | 1. Physics | | | | | | | 1 | (3.8) | 3 | (11.5) | 2 | (7.7) | 6 | (23.1) |
| | 2. Chemistry | | | | | | | 1 | (3.8) | 3 | (11.5) | 5 | (19.2) | 9 | (34.6) |
| | 3. Biology | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 4. Earth science | | | | | | | 2 | (7.7) | 0 | (0.0) | 2 | (7.7) | 4 | (15.4) |
| | 5. Cross-domain | | | | | | | 1 | (3.8) | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) |
| | 6. Others | | | | | | | 2 | (7.7) | 2 | (7.7) | 2 | (7.7) | 6 | (23.1) |
| | 7. NA | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | Subtotal | | | | | | | 7 | (26.9) | 8 | (30.8) | 11 | (42.3) | | |

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TJ ($n=60$) | 1. Physics | | | 0 | (0.0) | 4 | (6.7) | 7 | (11.7) | 5 | (8.3) | 8 | (13.3) | 24 | (40.0) |
| | 2. Chemistry | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 5 | (8.3) | 0 | (0.0) | 6 | (10.0) |
| | 3. Biology | | | 0 | (0.0) | 0 | (0.0) | 3 | (5.0) | 2 | (3.3) | 1 | (1.7) | 6 | (10.0) |
| | 4. Earth science | | | 0 | (0.0) | 3 | (5.0) | 2 | (3.3) | 3 | (5.0) | 1 | (1.7) | 9 | (15.0) |
| | 5. Cross-domain | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (3.3) | 0 | (0.0) | 2 | (3.3) |
| | 6. Others | | | 0 | (0.0) | 0 | (0.0) | 2 | (3.3) | 2 | (3.3) | 2 | (3.3) | 6 | (10.0) |
| | 7. NA | | | 1 | (1.7) | 5 | (8.3) | 3 | (5.0) | 0 | (0.0) | 0 | (0.0) | 9 | (15.0) |
| | Subtotal | | | 1 | (1.7) | 12 | (20.0) | 18 | (30.0) | 19 | (31.7) | 12 | (20.0) | | |

Appendix C. The distribution of conceptual framework of articles by science education researchers in Taiwan from 1982 to 2012

| | Time Interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ ($n=26$) | 1. Epistemology | | | | | | | 3 | (11.5) | 3 | (11.5) | 5 | (19.2) | 11 | (42.3) |
| | 2. Ontology | | | | | | | 3 | (11.5) | 0 | (0.0) | 1 | (3.8) | 4 | (15.4) |
| | 3. Affection/social | | | | | | | 0 | (0.0) | 1 | (3.8) | 1 | (3.8) | 2 | (7.7) |
| | 4. Development | | | | | | | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) | 1 | (3.8) |
| | 5. Evolution | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 6. Instruction | | | | | | | 6 | (23.1) | 4 | (15.4) | 7 | (26.9) | 17 | (65.4) |
| | 7. Multiple dimensions | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 8. Others | | | | | | | 0 | (0.0) | 3 | (11.5) | 1 | (3.8) | 4 | (15.4) |
| | Subtotal | | | | | | | 12 | (46.2) | 11 | (42.3) | 16 | (61.5) | | |

| | Time Interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TJ ($n=60$) | 1. Epistemology | | | 1 | (1.7) | 6 | (10.0) | 3 | (5.0) | 5 | (8.3) | 3 | (5.0) | 18 | (30.0) |
| | 2. Ontology | | | 0 | (0.0) | 1 | (1.7) | 0 | (0.0) | 3 | (5.0) | 1 | (1.7) | 5 | (8.3) |
| | 3. Affection/social | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) |
| | 4. Development | | | 0 | (0.0) | 0 | (0.0) | 2 | (3.3) | 1 | (1.7) | 0 | (0.0) | 3 | (5.0) |
| | 5. Evolution | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 1 | (1.7) |
| | 6. Instruction | | | 0 | (0.0) | 8 | (13.3) | 14 | (23.3) | 12 | (20.0) | 9 | (15.0) | 43 | (71.7) |
| | 7. Multiple dimensions | | | 0 | (0.0) | 1 | (1.7) | 2 | (3.3) | 1 | (1.7) | 0 | (0.0) | 4 | (6.7) |
| | 8. Others | | | 0 | (0.0) | 2 | (3.3) | 0 | (0.0) | 1 | (1.7) | 1 | (1.7) | 4 | (6.7) |
| | Subtotal | | | 1 | (1.7) | 18 | (30.0) | 22 | (36.7) | 23 | (38.3) | 15 | (25.0) | | |

Appendix D. The distribution of data collection methods of articles by science education researchers from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ ($n=26$) | 1. Qualitative | | | | | | | 0 | (0.0) | 2 | (7.7) | 3 | (11.5) | 5 | (19.2) |
| | 2. Quantitative | | | | | | | 3 | (11.5) | 2 | (7.7) | 3 | (11.5) | 8 | (30.8) |
| | 3. Both (1) and (2) | | | | | | | 4 | (15.4) | 2 | (7.7) | 2 | (7.7) | 8 | (30.8) |
| | 4. Quantifying the qualitative data | | | | | | | 0 | (0.0) | 3 | (11.5) | 5 | (19.2) | 8 | (30.8) |
| | 5. NA | | | | | | | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) | 1 | (3.8) |
| | Subtotal | | | | | | | 7 | (26.9) | 9 | (34.6) | 14 | (53.8) | | |

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TJ ($n=60$) | 1. Qualitative | | | 0 | (0.0) | 1 | (1.7) | 5 | (8.3) | 3 | (5.0) | 1 | (1.7) | 10 | (16.7) |
| | 2. Quantitative | | | 1 | (1.7) | 0 | (0.0) | 4 | (6.7) | 6 | (10.0) | 1 | (1.7) | 12 | (20.0) |
| | 3. Both (1) and (2) | | | 0 | (0.0) | 4 | (6.7) | 3 | (5.0) | 8 | (13.3) | 7 | (11.7) | 22 | (36.7) |
| | 4. Quantifying the qualitative data | | | 0 | (0.0) | 1 | (1.7) | 0 | (0.0) | 5 | (8.3) | 2 | (3.3) | 8 | (13.3) |
| | 5. NA | | | 0 | (0.0) | 7 | (11.7) | 4 | (6.7) | 3 | (5.0) | 2 | (3.3) | 16 | (26.7) |
| | Subtotal | | | 1 | (1.7) | 13 | (21.7) | 16 | (26.7) | 25 | (41.7) | 13 | (21.7) | | |

Appendix E. The distribution of data collection methods of articles by science education researchers from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ ($n=26$) | 1. Paper and pencil test | | | | | | | 5 | (19.2) | 4 | (15.4) | 4 | (15.4) | 13 | (50.0) |
| | 2. Interview | | | | | | | 5 | (19.2) | 5 | (19.2) | 6 | (23.1) | 16 | (61.5) |
| | 3. Drawing | | | | | | | 1 | (3.8) | 0 | (0.0) | 1 | (3.8) | 2 | (7.7) |
| | 4. Online data | | | | | | | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) | 1 | (3.8) |
| | 5. Questionnaire | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 6. Online questionnaire | | | | | | | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) | 1 | (3.8) |
| | 7. Rubric or coding sheet of classroom observation | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 8. Biological data | | | | | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 9. Others | | | | | | | 3 | (11.5) | 2 | (7.7) | 4 | (15.4) | 9 | (34.6) |
| | 10. NA | | | | | | | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) | 1 | (3.8) |
| | Subtotal | | | | | | | 14 | (53.8) | 11 | (42.3) | 18 | (69.2) | | |

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TJ (*n*=60) | 1. Paper and pencil test | | | 1 | (1.7) | 4 | (6.7) | 7 | (11.7) | 13 | (21.7) | 8 | (13.3) | 33 | (55.0) |
| | 2. Interview | | | 0 | (0.0) | 4 | (6.7) | 6 | (10.0) | 15 | (25.0) | 6 | (10.0) | 31 | (51.7) |
| | 3. Drawing | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 2 | (3.3) | 3 | (5.0) |
| | 4. Online data | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 1 | (1.7) | 0 | (0.0) | 2 | (3.3) |
| | 5. Questionnaire | | | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) | 0 | (0.0) | 0 | (0.0) | 1 | (1.7) |
| | 6. Online questionnaire | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 7. Rubric or coding sheet of classroom observation | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 8. Biological data | | | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 9. Others | | | 0 | (0.0) | 1 | (1.7) | 2 | (3.3) | 2 | (3.3) | 2 | (3.3) | 7 | (11.7) |
| | 10. NA | | | 0 | (0.0) | 7 | (11.7) | 4 | (6.7) | 3 | (5.0) | 2 | (3.3) | 16 | (26.7) |
| | Subtotal | | | 1 | (1.7) | 16 | (26.7) | 21 | (35.0) | 35 | (58.3) | 20 | (33.3) | | |

Appendix F. The distribution of teaching or nonteaching studies by science education researchers in Taiwan from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ (*n*=26) | Articles related to teaching | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 6 | (23.1) | 6 | (23.1) | 7 | (26.9) | 19 | (73.1) |
| | NA | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (3.8) | 2 | (7.7) | 4 | (15.4) | 7 | (26.9) |
| | Total | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 7 | (26.9) | 8 | (30.8) | 11 | (42.3) | 26 | (100.0) |
| TJ (*n*=60) | Articles related to teaching | 0 | (0.0) | 0 | (0.0) | 2 | (3.3) | 13 | (21.7) | 16 | (26.7) | 8 | (13.3) | 39 | (65.0) |
| | NA | 0 | (0.0) | 1 | (1.7) | 8 | (13.3) | 5 | (8.3) | 3 | (5.0) | 4 | (6.7) | 21 | (35.0) |
| | Total | 0 | (0.0) | 1 | (1.7) | 10 | (16.7) | 18 | (30.0) | 19 | (31.7) | 12 | (20.0) | 60 | (100.0) |

Appendix G. The distribution of teaching strategies of articles by science education researchers in Taiwan from 1982 to 2012

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TIJ ($n=19$) | 1. Analogy, model and modeling | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (5.3) | 1 | (5.3) | 2 | (10.5) |
| | 2. Multimedia | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (5.3) | 0 | (0.0) | 5 | (26.3) | 6 | (31.6) |
| | 3. Conceptual conflict | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (10.5) | 3 | (15.8) | 2 | (10.5) | 7 | (36.8) |
| | 4. Inquiry | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (5.3) | 1 | (5.3) | 0 | (0.0) | 2 | (10.5) |
| | 5. Cooperative learning | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 6. Experiment | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (5.3) | 0 | (0.0) | 1 | (5.3) |
| | 7. Text | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 8. Multiple representation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 9. Argumentation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 10. Concept map | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (5.3) | 0 | (0.0) | 0 | (0.0) | 1 | (0.0) |
| | 11. Science history | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 12. Metacognitive approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 13. Writing | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 14. Constructivist approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 15. Self-explanation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 16. Motivation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (5.3) | 1 | (5.3) |
| | 17. Others | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (10.5) | 0 | (0.0) | 1 | (5.3) | 3 | (15.8) |
| | Total | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 7 | (36.8) | 6 | (31.6) | 10 | (52.6) | 23 | (121.1) |

| | Time interval | 1982–1987 | | 1988–1992 | | 1993–1997 | | 1998–2002 | | 2003–2007 | | 2008–2012 | | Subtotal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TJ ($n=39$) | 1. Analogy, model and modeling | 0 | (0.0) | 0 | (0.0) | 1 | (2.6 ) | 3 | (7.7) | 2 | (5.1) | 1 | (2.6) | 7 | (17.9) |
| | 2. Multimedia | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 3 | (7.7) | 2 | (5.1) | 1 | (2.6) | 6 | (15.4) |
| | 3. Conceptual conflict | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (5.1) | 3 | (7.7) | 0 | (0.0) | 5 | (12.8) |
| | 4. Inquiry | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (2.6) | 3 | (7.7) | 1 | (0.0) | 5 | (12.8) |
| | 5. Cooperative learning | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (2.6) | 1 | (2.6) | 0 | (0.0) | 2 | (5.1) |
| | 6. Experiment | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (2.6) | 1 | (2.6) | 0 | (0.0) | 2 | (5.1) |
| | 7. Text | 0 | (0.0) | 0 | (0.0) | 2 | (5.1) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (5.1) |
| | 8. Multiple representation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 9. Argumentation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (5.1) | 0 | (0.0) | 0 | (0.0) | 2 | (5.1) |
| | 10. Concept map | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 3 | (7.7) | 1 | (2.6) | 1 | (2.6) | 5 | (12.8) |
| | 11. Science history | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 2 | (5.1) | 2 | (5.1) |
| | 12. Metacognitive approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 13. Writing | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 14. Constructivist approach | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 1 | (2.6) | 0 | (0.0) | 0 | (0.0) | 1 | (2.6) |
| | 15. Self-explanation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 16. Motivation | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| | 17. Others | 0 | (0.0) | 0 | (0.0) | 1 | (2.6) | 2 | (5.1) | 7 | (17.9) | 2 | (5.1) | 12 | (30.8) |
| | Total | 0 | (0.0) | 0 | (0.0) | 4 | (10.3) | 19 | (48.7) | 20 | (51.3) | 8 | (20.5) | 51 | (130.8) |

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# Chapter 6
# Learners' Epistemic Beliefs and Their Relations with Science Learning—Exploring the Cultural Differences

**Fang-Ying Yang**

**Abstract** This chapter discusses the cultural differences in learners' epistemic beliefs (EBs) and the relations with science learning by cross comparing empirical studies from different countries in the recent 10 years. The reviewed papers were collected from the Social Science Citation Index (SSCI) database on the research platform, *Web of Knowledge,* from 2004 to 2013. A total of 106 papers were included in the review. Comparisons of the research purposes, questions, and findings were made across different countries to reveal possible cultural differences. The analysis shows that among the eight issues abstracted from the 106 papers, the four which received the most attention were the status of students' EBs (or conceptions of learning, COL), the role or effects of EBs (or COL) in science learning, the effects of instructional intervention on changes in EBs, and the relations between EBs and study approaches. Since most studies were conducted in Taiwan, Turkey, and the USA, the cultural comparisons were made mainly across these three countries. It was found that learners from Taiwan and the USA, which were identified as having lower context cultures, seemed to have developed more sophisticated beliefs about knowledge, but they tended to believe more in the innate ability of learning. On the contrary, learners from Turkey as well as China, which were recognized as having high-context cultures, tended to believe more in authority knowledge while relying more on the value of effort. While not much difference in the relations between learners' EBs and science learning could be found across Taiwan, Turkey, and the USA, it was much easier for the EBs of learners with low-context cultures to be affected by instructional interventions.

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## 6.1 Introduction

In the research of psychology, personal epistemology has been identified as the highest level cognition mediating human activities, including thinking and problem solving. Many psychologists argue that personal epistemology undergoes a developmental process which is highly related to an individual's educational experiences. A considerable number of educational studies exploring learners' personal epistemic beliefs (EBs) and their roles in learning have been accumulating over the recent 10 years. Although, in general, these studies agree that personal EBs play a significant role in the process of learning, how these beliefs affect students' learning behaviors might not be universally the same. It is certain that there should be social or cultural influences on the development and the actions of EBs. However, such an issue has not been extensively explored.

In this chapter, an attempt is made to discuss the cultural differences in EBs and their relations to science learning. To this end, we first review educational studies involving investigations of learners' personal EBs and the effects of these beliefs on science learning in the past 10 years (from 2004 to 2013). Then, by cross comparing the research themes and findings of each study conducted in different countries, we hope to reveal cultural differences in the role of EBs in science learning.

### *6.1.1 EBs in the Context of Science Learning*

The study of personal epistemology originating from Perry's studies of intellectual development (Perry 1998) concerns an individual's beliefs about the nature of knowledge and knowing. Psychological studies have shown that personal epistemology as the highest level of cognition mediates human cognitive behaviors (e.g., Hofer and Pintrich 1997; Hofer and Pintrich 2002; Perry 1998). In later years, Schommer (1990; Schommer-Aikins 2004) used the term personal epistemological beliefs to specify learners' beliefs about the nature of knowledge and learning. Many subsequent studies, especially in the field of education, have explored learners' personal epistemic theories in accordance with such a definition. Although some scholars argue that aspects of personal epistemology include only the nature of knowledge and knowing (Sandoval 2009), the conceptual overlap between the nature of knowing and learning is evident. As a matter of fact, Perry's structure of personal epistemology was generalized from students' educational experiences in their college years (Perry 1998). Accordingly, personal beliefs or theories about learning reflect to a certain extent one's beliefs about the nature of knowing.

In the context of education, it has been recognized that teachers' as well as students' beliefs about knowledge taught in school, and their ideas about teaching and learning have been recognized as a crucial determinant affecting classroom practice. As far as science learning is concerned, considerable studies have suggested that students' personal epistemological beliefs mediate concept learning, the uses of learning strategies, and the practices of argument skills (see a recent review by Yang and Tsai 2012). Also, as will be shown in this review work, in the context of science education, beliefs or conceptions about the nature of teaching and learning are found to be associated with teachers' educational decisions, students' school performance, and the study approaches. Accordingly, to understand students' science learning behaviors, an in-depth investigation on learners' EBs will be informative.

To avoid the confusion of theoretical definition for personal epistemology, researchers in the fields of psychology and education nowadays use the term personal "epistemic beliefs" instead to indicate the wider range of beliefs about knowledge, knowing, teaching, and learning. In this chapter, we focus on analyzing learners' personal EBs in science and their relations to science learning.

### *6.1.2 Cultural Differences and Science Learning*

The effects of culture have been identified in various areas of research, such as business management, anthropology, psychology, education, and online commercial advertising (e.g., Chan 1999; Enz 1986; Hall 1976; Korac-Kakabadse et al. 2001; Marcus and Gould 2000; Triandis 1989; Würtz 2006). Basically, these studies pointed out that cultural rituals and values are reflected in communication styles and social behaviors. As far as learning is concerned, cultural differences have been identified in learning styles, school performance, study approaches and so forth (e.g., Ogbu 1992; Irvine and York 1995). Recent research about web-based learning reports that cultural differences are apparent in perceptions of online discussions, expectations about instructors and students, and styles of interaction and information approaches (Cifuentes and Shih 2001; Hannon and D'Netto 2007; Morse 2003).

In the literature, studies about cultural differences in science education mainly discuss the differences between students and science teachers in the same classroom (e.g., Erickson 1986; Cobern and Aikenhead 1998; Hammond and Brandt 2004). Few studies have examined the cultural differences across different nations. A recent "Organization For Economic Co-Operation And Development" (OECD) report about the PISA 2006 test shows that although numerous Asian students in certain countries demonstrated high science and mathematics abilities, their interest and motivation in learning science as well as their tendencies to pursue future careers in science were not as high as their performance would suggest (OECD 2007). The situation differs from prior educational studies which found that the higher students' interest and motivation, the better their school performance will be (Pintrich and Schunk 2002). It is apparent that there are cultural factors giving rise to such an outcome, which are worthy of further exploration.

## 6.2 Objective of the Study

The main purpose of this study is to examine whether differences from cultural perspectives can be found in the empirical studies about EBs and science learning in the past 10 years. By reviewing relevant papers published in SSCI journals from 2004 to 2013, we hope to gain insights into the effects of cultural entities on learners' EBs and how beliefs developed under different cultures could lead to different outcomes of science learning.

## 6.3 Method

### *6.3.1 Paper Selection*

The papers selected for review came from the Social Science Citation Index (SSCI) database included in the research platform, Web of Knowledge, developed by Thomas Reuters (http://apps.webofknowledge.com). Topic keywords such as "personal epistemology," "epistemological beliefs," and "epistemic beliefs" were combined with "science learning" using the Boolean operator, AND, to find papers of interest. Each combination was then put together using the history tracking tool provided by the search platform to locate all relevant papers from 2004 to 2013. A total of 168 papers were abstracted from the selection. Subsequently, an inspection of the abstract of each paper was carried out to confirm that each paper had objectives related to studies about learners' EBs (including the terms of EBs, personal epistemology, and epistemological beliefs) and science learning. Additionally, book chapters, review papers, and those papers written in languages other than English were excluded from the review. A final total of 106 papers were identified for the review.

### *6.3.2 Paper Analysis*

To present the cultural differences, we focus majorly on analyzing the participants, the study purposes, research questions, and the study findings of each collected paper. Descriptive analysis and cross-country comparisons are then conducted to capture the cultural differences.

## 6.4 Result

1. *Distribution of countries*

Among the 106 studies, about 35 % were conducted in Taiwan, 25 % in the USA, and 11 % in Turkey. The remaining 29 % were distributed among 18 countries. Figure 6.1 shows the paper distribution across 21 countries.

2. *Study issues*

In all, eight issues were abstracted from the 106 papers as indicated in Fig. 6.2. By analyzing the study purposes and research questions, it was found that the majority of the collected papers (77 %) focused on issues concerning the status of students'

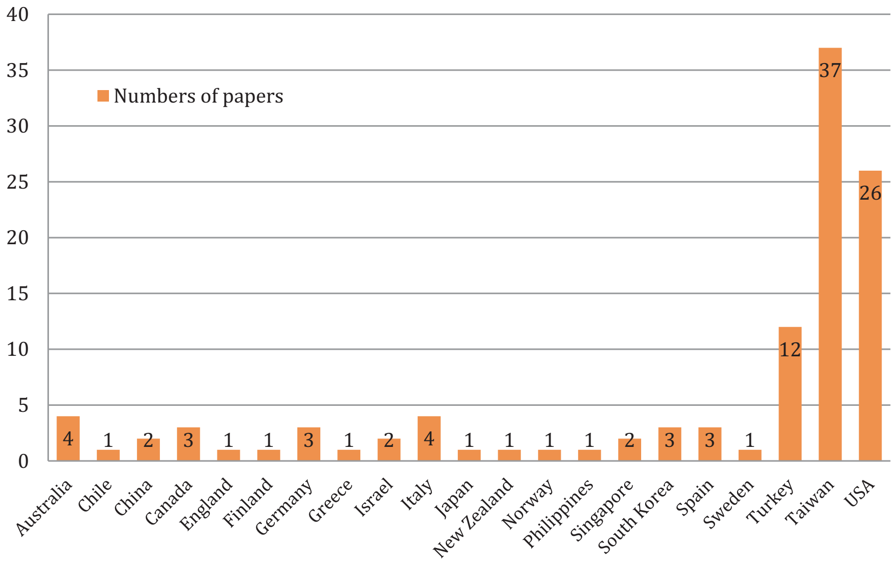


**Fig. 6.1** Numbers of papers by different countries from 2004 to 2013

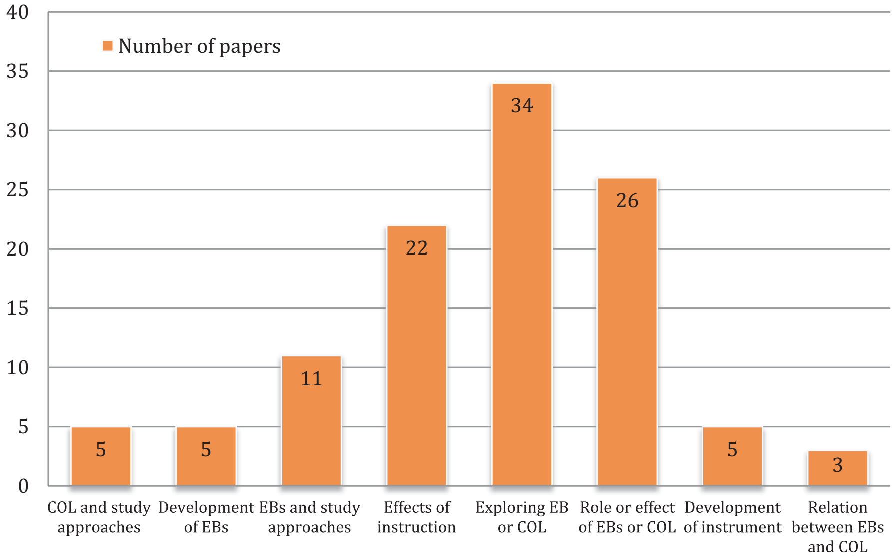


**Fig. 6.2** Distribution of study issues (Note: *EBs* epistemic beliefs; *COL* conceptions of learning)

EBs or COL, the roles or effects of EBs or COL in science learning, the effects of instructional intervention on the changes in EBs, and the relation between EBs and study approaches. It should be noted that some studies involve the discussion of two issues.

3. *Subjects*

Among the 106 papers, 37 dealt with university students, 34 involved high school students, 15 studied student teachers, and 10 explored elementary learners. Meanwhile, there are ten studies investigating in-service teachers' EBs. The rest involved adult subjects or faculty members. Overall, adults were the main subjects under investigation.

4. *Cultural difference*

Figure 6.2 shows that the majority of the collected papers (90 papers, about 85 %) focus on issues concerning the status of students' EBs and/or COL, the effects of instructional intervention on changes in EBs, the roles or effects of EBs and/or COL in science learning, and the relations between EBs and study approaches. Accordingly, the main analyses of cultural differences involve these issues. Moreover, due to the fact that most of these papers are distributed across three countries, namely Taiwan, the USA, and Turkey, the comparisons mostly concern the differences across these three countries.

(1) Status of learners' EBs

Among the 34 papers related to the status of students' EBs about knowledge in science and learning, 9 are from Taiwan, 6 were conducted in Turkey, and 5 in the USA. The studies from Taiwan showed that university students and in-service teachers held from moderate to advanced EBs in scientific knowledge (e.g., Yang et al. 2008; Liu and Liu 2011; Lee et al. 2012), but their beliefs about learning were rather simple, that is, they seemed to believe more in innate and fixed ability (e.g., Yang et al. 2008; Lee et al. 2012). A large-scale survey showed that high school students expressed different EBs about different science subject matters (Tsai 2006). A similar result was found for university students (Lee and Tsai 2012). Gender difference was reported in some investigations where male students showed more advanced EBs in knowledge (e.g., Tsai 2006, 2008).

In Turkey, the study findings are less than conclusive. In one study, university students were found to have moderate EBs in knowledge and learning (Er 2013), while another reported constructivist views about learning (Kabapinar 2012). Gender and background discipline were found to contribute to the variety in EBs (Er 2013; Ertekin et al. 2009). Meanwhile, domain-specific EBs in scientific knowledge were found among high school students (Ogan-Bekiroglu and Sengul-Tugut 2011).

Studies from the USA reported that students' beliefs varied across different genders, grade levels, and ethnic groups, and how students think about scientific knowledge depended on the tasks, learning environments, and contextual cues (Watkins and Elby 2013; Chen 2012). A large-scale study (Chen 2012) showed that high-school students in general held sophisticated epistemic views on scientific knowledge, but their beliefs in learning were simple. In other words, they believed more in innate ability. Wheeler and Montgomery (2009) reported in their study that while most college students displayed largely simple to moderate views on math learning, some students were moving toward the sophisticated form.

The study results from Taiwan, Turkey, and the USA as introduced above suggest that learners in Taiwan and the USA might have developed more sophisticated beliefs in scientific knowledge compared to the learners in Turkey. However, in terms of beliefs in learning, students in Taiwan and the USA tend to believe that learning depends on fixed and innate ability. On the other hand, Turkish students seem to be more diverse in terms of their beliefs in learning. These comparisons imply that students from Taiwan and the USA are similar in their EBs in knowledge and learning, which differ evidently from those held by Turkish students. Studies of the three countries indicate that displays of EBs are largely affected by educational experiences, problem contexts, and knowledge domains.

While the above comparisons are made indirectly, there are three papers providing direct cultural comparisons of students' EBs (Lin et al. 2013; Lee et al. 2012; Chai et al. 2012). These three studies compared students from Taiwan, Singapore, and China. The results showed that students in Taiwan possessed more advanced beliefs in knowledge than did Chinese students, but their beliefs in innate and fixed ability were stronger. The authors of these studies argued that although these three countries share the same Chinese culture, the different educational philosophies might have asserted an influence on the development of their EBs.

(2) The role or effects of EBs in science learning

Four studies in Taiwan discuss the role of EBs in the process of science learning. It was found that sophisticated EBs promote the development of inquiry skills (Wu 2011), guide the use of evaluation standards for online information (Lin and Tsai 2008), and affect views on the nature of science (Yang 2005). One study showed that teachers' EBs drove their pedagogical attention (Tsai 2007). The only study from Turkey demonstrated that advanced EBs were associated with higher levels of learning and performance goals, while six studies from the USA showed that students' EBs were associated with their academic achievement (Beghetto 2012; Nussbaum et al. 2008), academic motivations (Ricco et al. 2010) and learning as well as problem-solving behaviors (Gupta and Elby 2011; Lising and Elby 2005; Ravindran et al. 2005). In addition, three studies from the USA indicated that teachers' instructional goals and decisions were affected by their EBs (Knobloch 2008; Benett and Park 2011; Kang 2008), which would then give rise to different learning environments.

In sum, the role or effects of EBs in science learning seem to be universally the same across different countries. Evidently, the more sophisticated form of EBs, the better development in academic-related cognitive processes and higher motivations for learning. Although most of the studies listed above provide findings indicating correlational rather than causal relationships, since the development of EBs take time and they are at the highest level of cognition, it is reasonable to infer that EBs are the major underlying determinants for students' (as well as teachers') performance.

(3) The effects of instructional interventions

Among the 22 papers that discuss the effects of instructional intervention, only one study was conducted in Taiwan. This study (She 2004) describes an instructional approach that challenges high school students' EBs. The results showed that such an approach fostered radical conceptual change. On the other hand, four studies from Turkey explore whether inquiry or problem-based instruction are able to change students' epistemic status; their findings are inconclusive. For university students, instructional interventions seemed to provide no effect in terms of belief change (Coban 2013; Smith 2010), but for elementary and high school subjects, their EBs were much more easily influenced (Cam and Geban 2011; Kizilgunes et al. 2009). All ten studies from the USA showed that students' EBs were changeable, regardless of their age or educational level. Some important features of the effective curriculum include the presence of inquiry or problem solving activities (e.g., Lindsey et al. 2012; Sandi-Urena et al. 2011), the inclusion of dialogic or argumentative interactions (e.g., Walker et al. 2013; Reznitskaya and Gregory 2013), and the involvement of reasoning or critical thinking processes during learning (e.g., Gottesman and Hoskins 2013; Gill et al. 2004).

In sum, while adult students in Turkey tended to maintain their EBs after inquiry-based instructional interventions, the USA students, regardless of their age or educational level, seemed to be more flexible in terms of adjusting their EBs. Although the disparity between the two countries might come from different instructional approaches, the possibility of cultural difference could not be ruled out.

(4) Relations between EBs and study approaches

As shown in Fig. 6.2, 11 papers discuss the relationship between EBs and study approaches. Rather than originating from just a few countries, these papers are distributed across nine countries, and have a similar finding, namely that sophisticated EBs are associated more with deep study approaches, while simple or naive beliefs are related to surface approaches (e.g., Nieminen et al. 2004; Watters and Watters 2007).

(5) Other issues

Other than the abovementioned study issues, five papers conducted in five different countries discussed the development of EBs. A general progressive trend related to age and educational experience was shown (e.g., Thomas 2008; Rivero et al. 2011). Another five studies aimed to develop valid instruments for assessing EBs (e.g., Suzuki 2005; Colbeck 2007). Finally, the issues related to learners' COL and their relations with EBs and other learning behaviors were only examined by researchers in Taiwan (e.g., Tsai 2004; Lee et al. 2008). These papers show consistent results, but no cultural difference can be drawn.

## 6.5 Discussion

Culture is a complex set of basic assumptions, values, life orientations, politics, social habits, beliefs, customs, laws and more, which are shared by a particular group of people (Spencer-Oatey 2008). For anthropologists, culture is itself a series of situational models for behavior and thought (Hall 1976). Hall proposed that culture could be referred to as a continuum of contexts from high to low. In a high-context culture, many things are left unsaid, letting the culture explain. Word choice becomes very important because a few words can communicate a complex message. On the other hand, in a low-context culture, the communicator needs to be much more explicit, and the value of a single word is less important. For example, Chinese writers often use some indirect stories or expressions to reflect a certain problem or issue while English writers usually pinpoint the problem or issue to be discussed explicitly in the beginning of their articles.

As mentioned before, issues related to EBs and science learning were examined mostly by researchers from Taiwan, Turkey, and the USA in the past 10 years. Taking into consideration the cultural entities, these three countries just represent different cultural contexts. Based on Hall's definition, the USA is a representative of a low-context culture while Turkey, with its rich ancient history and strong religious influences, is a country with a high-context culture. Meanwhile, since Taiwan, although with its deep Chinese cultural roots, has been westernized and developed into a democratic society, its cultural tendencies could fall somewhere between the high and low contexts. These different cultural contexts might help to explain more of the differences in learners' EBs.

It has been shown that students from Taiwan and the USA with relatively lower cultural contexts seem to have more sophisticated beliefs in scientific knowledge, but they tend to believe more in fixed and innate ability in learning. On the contrary, students from Turkey and China, which are identified as having high-context cultures, are more likely to believe that scientific knowledge is certain and experts warrant the validity of knowledge, but they believe less in fixed ability. As far as the role or the effects of EBs in learning are concerned, no distinct cultural differences can be drawn from the collected studies. Regarding the change in EBs, it has been found that the USA learners compared to those from Turkey have more flexible EBs which seem to be much easier to influence by instruction incorporating inquiry activities with dialogic or argument events.

If, as proposed by Hall, we see culture as a continuum spectrum ranging from low to high contexts, based on the analyses discussed in this chapter, it is concluded that culture plays a role in securing learners' beliefs in knowledge and learning. High-context cultures with a strong emphasis on collectivism might promote conformity that results in a simpler form of beliefs in scientific knowledge while cherishing more the importance of efforts. Low-context cultures on the other hand, focusing more on individualism, value personal development, which as a result promotes sophisticated thoughts on the nature of knowledge but gives higher weight to innate ability. However, it is seemingly the low-context cultures that allow more room for self-improvement and adjustment in EBs. As mentioned in the introduction section, studies in various fields have found that cultural rituals and values are reflected in communication styles and social behaviors. In educational research, cultural differences have also been identified in learning styles, school performance, study approaches, and perceptions of elements of learning environments. Given that EBs mediate learning, by considering the cultural difference in EBs, educators may understand more of learners' learning behaviors and performance in different cultural contexts.

## 6.6 Limitation of the Study

In this chapter, we made an attempt to examine the cultural differences in the status and development of the EBs in science by cross analyzing relevant studies conducted in different countries. The analysis made in the study supports that culture plays a role in shaping learners' EBs which in turn mediate the process of school science learning. A genuine social-cultural comparison study requires the direct and empirical investigation and the information about the contexts of classrooms, the social–cultural–historical backgrounds of the participants and so forth is needed to make thorough discussions. Given that the study reported in the chapter is basically a work of literature review, conclusions drawn from the review analysis may suffer from being rather broad and superficial. For example, the USA is a nation consisted of large heterogeneous societies. Our study findings might reflect only a small portion of the reality.

As a matter of fact, the chapter is written in the hope to raise the attention from educators and educational researchers in Taiwan on the cultural differences regarding learners' epistemic development. Very often when educators in Taiwan tried to launch a new instructional reform, the new ways of teaching and learning encountered strong resistance or ineffective result that were not found in other countries which had successful reform practices. We believe that the major problem lies in the lack of understanding of the cultural differences. It was likely that students in Taiwan had not developed proper EBs that could guide their reasoning and learning in a new learning environment. We thus advocate that before starting a new educational reform, a careful investigation on the cultural differences in learners' epistemic theories will help local educators to develop the adaptive curriculum that gradually promote the desired learning goals and performances.

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# Chapter 7
# On the Identification of Students' Misconceptions in a Two-Tier Item

**Hak Ping Tam**

**Abstract** The two-tier item format has gained some popularity in use by science educators worldwide, including those from Taiwan. Despite its broad applications, there are relatively few studies that focused themselves on extending the present methodology in analyzing this particular item format. As a result, there are still uncertainties concerning how the result in the data table from a two-tier item should be analyzed and interpreted, especially with respect to the identification of potential misconceptions held by the participating students. The usual practice in this area of research is to assume that if more than 10% of the respondents picked a wrong combination of options across the two tiers, then that combination can be regarded as reflecting the presence of a misconception of some sort. This study argues against the use of the 10% rule, on the ground that it is, among other reasons, subjective and lacks substantive support based on the subject matters. Instead, it is suggested that correspondence analysis can be performed in a three-stage manner. Potential types of misconceptions as held by the participating students could then be identified by means of interpreting the clusters of categories across the two tiers in the correspondence plot. This study reflects the kind of interest from local researchers on methodological issues surrounding the two-tier item format.

## 7.1 Introduction

The study of students' misconceptions as an area of science and mathematics education research has been popular for many years. As early as in 1940, evaluation of certain science misconceptions among students had already formed the subject of study in a journal article (Hancock 1940; Blosser 1987). Interest in this area was heightened in the 1980s and 1990s, when three international conferences on misconceptions in science and mathematics were organized by researchers from the Cornell University (1983, 1987, 1993). Nowadays, there exists a vast literature on various kinds of science and mathematics misconceptions that were held by primary, secondary, or tertiary students (e.g., Pfundt and Duit 2006). Thus far, research in this area has already

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covered most of the major school science concepts, thereby, amassing a huge resource of information about students' learning that can be of potential use by frontline science teachers (Garnett et al. 1993; Smith et al. 1993). According to the compilation by Pfundt and Duit (2006), which started out as a bibliography of studies on students' pre-instructional or alternative conceptions in science, there were, by 2006, over 7000 papers related to various students' and teachers' conceptions on learning and teaching science published in the literature. The bibliography was updated in 2009 in which some 700 references were added (Duit 2009). Furthermore, according to Guo (2001), there were at least 400 papers published in Taiwan by 2001 on students' science misconception or alternative conception. In their study that traced the trend of research topics by papers published in the *International Journal of Science Education*, *Science Education,* and *Journal of Research in Science Teaching* from 1998 to 2002, Tsai and Wen (2005) indicated that research on *Learning—students' conceptions and conceptual change*, including those pertaining to misconceptions of students, had a higher rate of being published with an average of 24.7 % among all research articles. Though the average publishing rate on this topic was reported to have shrunken to 15.3 % for the period from 2003 to 2007 (Lee et al. 2009), all the information above unquestionably reflects that there exists a high interest of research in this area, and there is important contribution from the study on misconception or alternative conception in the realm of science education. Since misconceptions would, in many cases, result in barriers that hinder or even prevent students from learning key concepts, it is natural to expect that science education researchers have been interested all along to devote time and energy to do research in this important area.

Hancock (1940) originally contended that misconception referred to any unfounded belief that originated from faulty reasoning and was not associated to such factors as fear, good luck, faith, or supernatural intervention (Blosser 1987). However, researchers from the later era began to look at the issue in a broader scope which resulted in a slightly diverse view on the topic. This change of viewpoint has brought about different descriptors, such as, alternative views, alternative framework, preconceptions, alternative conception, or naive knowledge (e.g., Cobern 1993; Driver 1981; Osborne and Freyberg 1985; Perkins 1992). Moreover, there are researchers who may simply regard the wrong answers provided by students on test items related to science concepts as being misconceptions (e.g., Barrass 1984). According to this point of view, a misconception is but another term for misunderstanding. In order to simplify the discussion below, this study regards misconception as an umbrella name that refers to the science concepts held by students, but are at variance with the notions commonly accepted by the scientific community, regardless of whether they are from prior knowledge, self-construction, or from interaction with external sources. Misconception is further regarded as being somehow meaningful to students and is not merely a response made up by them on the spot to answer a given probe. The word as it is used in the context herein carries no implication of degradation of any sort on the part of the students.

Despite much scholarly efforts, research on science misconceptions is not without its critiques. The present author vividly recalled on one occasion around the turn of the century, when he accidentally overheard in a semipublic environment a comment made by a local well-known chemistry professor to one of the managers of a funding agency for science educational research. This professor asserted that even though studies related to misconceptions had been conducted in Taiwan for many years, misconceptions were, nevertheless, continuously identified with every new generation of science students. Accordingly, he questioned the worthiness of this direction of research. Not too long ago, Tao and Gunstone (1999) expressed the view that "(t)he field of study has now reached a stage where it is perhaps no longer fruitful to continue to survey students' conceptions in more domains." They asserted that by merely identifying the existence of misconceptions would not directly lend a hand in the delivery of science instruction that could alleviate those problems. Instead, they suggested that a more productive approach would be to investigate into the nature as well as the process of conceptual change (Thagard 1992).

## 7.2 Purpose of Study

We are perhaps more optimistic than Tao and Gunstone in this regard. We certainly agree that conceptual change is not only an important but a promising area of research. The study of misconceptions is, nevertheless, a vast research field that is still growing (Guo 2001; Pfundt and Duit 2006). We believe that there are still enough rooms for research in this area. There are at least two, among several others, useful and interesting directions of research in misconception, namely, the clarification of the sources of misconceptions, as well as advances in the methodology of detecting coupled with subsequent confirmation of the existence of students' misconceptions regarding various science topics. In this chapter, we will briefly touch on the first line of research, but spend most of the effort discussing the latter issue by limiting our attention on the usage of the two-tier item format. We will start out by elaborating on the problems embedded in the current practice by science education researchers when they interpret the result from a two-tier item. In order to handle these problems, we will next turn our attention to discussing a systematic approach to detect potential misconceptions from the data table of a two-tier item. An empirical example will be provided afterward to illustrate the plausible types of misconceptions that can be identified as held by students with respect to the concept being tested. The validity and the reliability of this approach of analysis will also be briefly discussed at the end of the chapter.

## 7.3 Sources of Misconceptions

One useful area of research in science education is in the clarification of the sources of students' misconceptions. Consider the case when a person is being suspected to be affected by a certain virus, laboratory tests must first be carried out to identify the kind of virus that the person is being afflicted with. In addition, sanitary inspection must be conducted in order to determine the sources of the infection, so that antiseptic procedures can be adopted. These measures are necessary if corrective procedures are intended to cure the afflicted person and to curb the spread of infection into a potential epidemic. A similar argument can also be applied to the issue of students' misconception in science. Currently, such factors as the daily life experiences of students, intuitions, interaction with teachers or textbooks, social interaction, cultural language of use, experiential gestalt of causation, functional reduction, and functional fixedness have been claimed to be possible sources of misconceptions on various topics of science (Duit 2009; Pfundt and Duit 2006). The actual mechanism by which such factors could have shaped a misconception in the mind of a student about a science concept is worthy of deeper investigation.

## 7.4 Methods for the Identification of Misconceptions

Another promising area of research is in the development of suitable methods that can be used to identify the kinds of misconceptions that some students may possess. Many techniques have already been reported in the literature, including multiple choice test, diagnostic test, clinical interviews, concept map, and free sorting (Novak and Gowin 1984; Novak 1996; Osborne and Cosgrove 1983; Ross and Munby 1991; White and Gunstone 1992). In fact, Wandersee et al. (1994) collected at least 14 methods that could be used in the study of students' misconceptions.

Though the conventional paper-and-pencil multiple-choice test format is easy to administer and can hence facilitate a massive collection of data within a short period of time, it has its own limitations. For example, item writers without extensive training may tend to compose a multiple-choice test that caters toward testing students' memory of factual knowledge rather than higher order thinking. Furthermore, it is not easy for the traditional multiple-choice test to collect directly the reason why a respondent chooses a certain option rather than the others. In order to overcome these limitations, Treagust and Haslan (1987) launched the two-tier item format that can collect more in-depth information about how students have understood science concepts. In most practices, a typical two-tier item contains a common item stem followed by two portions, usually the factual and the reason portions, that are both framed in a multiple-choice format (e.g., Treagust 1995; Tan and Treagust 2002; Tan et al. 2002). The purpose of the first portion is to assess whether students can provide factual or declarative knowledge regarding a certain phenomenon stated in the item stem. The purpose of the second portion is to assess whether students can demonstrate understanding regarding the reason behind the given phenomenon presented in the item stem and/or other relevant procedural knowledge. Treagust (1988) regarded the two-tier item format as a useful approach to diagnose students' understanding of science concepts.

The use of the two-tier item format has since gained some popularity worldwide in its use within the realm of science education, let alone in Taiwan. The local interest in adopting this particular item format was highest in the years 2000–2003, when the National Science Council (now Ministry of Science and Technology) in Taiwan sponsored the National Science Concept Learning Study (or NSCLS), which was a large-scale assessment project aimed at identifying misconceptions among students in physics, chemistry and biological science from primary to senior high schools. All items used in the NSCLS were casted in the two-tier item format. Various findings concerning students of Taiwan were eventually gathered into a special issue of the *International Journal of Science Education* in 2007 (see, for example Chiu et al. 2007; Tam and Li 2007). More information about this study together with its study design can be found in a subsequent section of this chapter. The interest in using two-tier items in science education research among researchers of Taiwan continues unto these days. Other than the push of using two-tier items in NSCLS and spin-off studies, it is generally considered to be a convenient diagnostic item format by many local researchers. Most of the published studies were on the development of instruments that identified students' misconceptions of various sorts, for example, with respect to dynamics and electricity in physics (Lee et al. 2005; Lin et al. 2009; Lin et al. 2011), particle theory, combustion and the classification of metals in chemistry (Hsu 2003; Lin 2006; Lin and Lin 2003; Chang and Chang 2007), genetics and the use of microscope in biological science (Lu 2003; Yang and Changlai 2004), as well as in the development of nanotechnology curriculum (Lu and Sung 2010).

Unfortunately, there were very few studies that investigated into how the data collected in a two-tier item should be analyzed, either in local journals or worldwide (see, for example, Ho and Koa 2006; Tam et al. 2012). Most of the published studies employed traditional statistical approaches, such as proportion and chi-square test, as their means to analyze the data. As a result, there still remains several methodological issues that are associated with this relatively new item format. For example, Peterson et al. (1989) originally regarded only those who could answer both portions correctly to be considered as having proper understanding of the underlying concept. Respondents who chose any other combination would reflect their holding of some kinds of misconception. Moreover, if the percentage of respondents choosing a certain combination of options across the two tiers reached 20 % or more, then it could be considered as a significant alternative conception. However, later researchers, for example, Tan et al. (2002), contended that a high cutoff percentage might have eliminated some valid alternative conceptions from the results. Tan and Treagust (2002) used 10 % as the cutoff for a combination of options to be regarded as constituting a substantial alternative conception. This practice certainly resonated with that of Gilbert (1977), who suggested that attention should be given to those responses selected by more than 10 % of the respondents.

However, technically speaking, a wrong answer does not necessarily imply a misconception. There are many possible reasons for a respondent to get a wrong answer, especially with respect to the multiple-choice format. For example, a student with no misconception can accidentally pick the wrong answer due to carelessness, distraction, fatigue, or an incidental slip of the mind. In addition, there are those, for example, foreign students, who have misinterpreted the item due to, say, unfamiliar terminology or a particular usage of grammar and thus arrived at the wrong answer. On the other hand, the 10 % rule is very subjective and lack any substantive reason to serve as its basis. For example, it suffered the same kind of argument against the setting of statistical level of test significance at 0.05 that is commonly used in the null hypothesis testing environment in applied research. Here, we face a similar dispute in relation to the special yet arbitrary status of the 10 % criterion. Why, for example, a 9.9 %, or some other figures, could not be adopted as the convention even though it may be equally well justified as the 10 % criterion. Moreover, from a pedagogical and pragmatic point of view, a misconception held by only 4 % of the respondents could have important consequences that science educators should pay attention at more than another misconception held by over 10 % of the respondents. Whereas, 10 % may indicate the prevalence of some form of misunderstanding by the students, a misconception held by 4 % of the respondents may err more seriously in terms of the substantive matters of the concept being tested. The small proportion of such students with alternative perception may put them in the unfortunate situation of being easily overlooked by their teachers, thereby, leaving their misunderstanding intact without receiving any remedial instruction to clear up their misapprehension. The adoption of this kind of threshold may perchance be more misleading than being useful.

There is a further problem with the 10 % criterion that is also somewhat related to those issues discussed above. Even though the 10 % criterion is certainly easy to implement by an applied researcher in identifying the presence of misconception, it should, nevertheless, be put to careful use. More specifically, it must be reminded that many descriptive statistical results are sample-dependent, in the sense that if a new sample of respondents is selected, a different result will very likely be observed. This possibility is certainly susceptible under the institution of the 10 % rule. When a two-tier item is given to two independent groups of students, the distribution of the respondents among the various combinations of options across the two tiers by the former group may differ from the distribution of the latter group. This phenomenon could be due to mere chance or to some other reasons. Without loss of generality, let us assume that 11 % of one group of respondents had chosen a particular combination of options which, under the 10 % rule, would have been regarded as indicating a misconception. Let us further assume that for the other group, only 7 % of the respondents had chosen that particular combination. Thus we may encounter the peculiar situation when a certain combination of options is being regarded as a misconception being held by a group of respondents in one study but not so by a group in another study. Under the prespecified 10 % rule, the interpretation will incline toward arbitrating one group as having a misconception whereas the other group does not. However, should that particular combination be judged conceptually to constitute a misconception, for example, via experts' consensus, a better interpretation is that both groups actually have respondents holding that misconception, with one group having more respondents with that misconception than the other group. It is hence inappropriate to make judgment solely relying on the size of the proportion, which is a sample-dependent statistics, with respect to a fixed threshold. This practice would lead to confusion on the part of the teachers when they subsequently decide whether to set up remedial instructions for the respondents or not.

Furthermore, some students may choose a certain combination of options across the two tiers purely by guessing. It is no surprise that for students who do not know the answer at all, they will resort to random guessing, otherwise they will have to leave the answer blank on the answering sheet. Under this situation, since there is no intellectual engagement involved in this kind of responses, answers that are randomly generated should not be used as a basis for labeling respondents as students with alternative conception. Of course, it is difficult to discern whether an answer given by the respondent is based on his/her personal understanding or whether it is merely an act out of random guessing. Either post hoc interviews or probabilistic models are necessary in order to estimate the proportion of these random guessers. We have previously constructed several probabilistic models for this purpose, but an elaboration of these models will be the subject matter of another report for another occasion (Tam and Yang 2005). Nevertheless, should the choice of a certain combination of options be regarded as a misconception, the observed proportion of respondents who chose that combination would include the random guessers on top of those who really abide by that misconception. Hence, a direct referral to the observed proportion would have overestimated the actual proportion of respondents with the misconception. In this sense, the disposition towards solely relying on a certain numerical threshold as the indicator of the presence of misconception is not very well justifiable. Additionally, the 10 %, or any other numerical threshold, will very much depend on the specific structure of the two-tier item. In sum, it is rather difficult to defend the 10 % criterion.

In the remaining space for this chapter, we will focus on discussing a viable approach concerning how one should interpret the result from a typical two-tier item that was presented in the form of a cross-tabulation table.

## 7.5 Methodology

Instead of an arbitrarily fixed threshold, we would like to suggest the application of correspondence analysis (Greenacre 1984) as a means to analyze the cross-tabulation data table that is compiled from the options chosen by the respondents across the two tiers of the item. Correspondence analysis is a multivariate descriptive statistical technique that can be used to analyze categorical two-way or multi-way data tables. Its main function is to represent the levels of the categorical variables from a data table onto a two-dimensional or even higher-dimensional plot. This is done by way of assigning scale scores to each level of the two variables via the singular value decomposition procedure, a technique frequently used in matrix algebra. When there are only two categorical variables involved, the levels of each variable can be displayed into a joint space which reflects the relative association among the levels. Greenacre referred the simultaneous display of the row and the column variable levels onto the same plot as the symmetric map. Caution, however, must be exercised in interpreting the proximity across the row and the column variable levels. A strict interpretation of the row-to-column distance as an absolute indicator of the strength of the relationship between the two levels must always be avoided. But rather, the interpretation should be performed in a relative sense (see below). Further discussion about correspondence analysis can be found in Greenacre (1984), Weller and Romney (1990), Greenacre and Blasius (2006) and many other good references in the literature.

## 7.6 Data Source

In order to illustrate this method and its use in the context of identifying potential misconceptions, we will use a two-tier item in physics that is taken from a study conducted in Taiwan in 2003. The NSCLS was one of the most extensive surveys on science education that were undertaken in Taiwan in recent years. A total of 36,093 primary, junior high, and senior high school students were selected by way of a two-stage stratified cluster sampling design to participate in the study (Tam and Li 2007). The present study only focused on the 2900 senior high school students that took the physics tests. For the main study, a total of three booklets were developed, each with 15 items. Common items were used for horizontal linkage across the three booklets for each grade level and for each subject. All items were phrased in a two-tier item format, with each portion being dichotomously scored.

## 7.7 Procedures

In order to identify misconceptions in a way that can safeguard a high degree of validity via the two-tier item format, this study proposes a three-step procedure as an alternative to the single-step threshold-comparison approach. Firstly, it is suggested that various combinations of options across the two tiers should be carefully judged by a group of experts to determine if they constitute misconceptions from a conceptual standpoint. Consensus should be attained among these experts. In other words, what counts as a misconception must have a meaningful and substantive basis, rather than being purely determined by statistical information. Secondly, the combination of fact and reason that constitute a misconception should be consistently identified from independent samples of respondents. In other words, the findings must be repeatable through replications. One possible way of achieving this is to construct multiple booklets with the two-tier item embedded within each booklet. The booklets can subsequently be distributed to random equivalent groups of respondents by spirally arranging the booklets as is commonly discussed in the test equating literature. If a specific combination of fact and reason can be consistently identified to be associated with each other and, above all, matches with the pattern as agreed upon by the experts in the first step, then there are good reasons to suspect that the combination may constitute a misconception. Thirdly, the identification of associations between the options across the two tiers can be facilitated by inspecting the various correspondence plots.

## 7.8 Data Analysis

As an illustration, a particular physics item was chosen from the NSCLS for analysis. It is included in the appendix and the readers are strongly encouraged to examine the item together with the options that are available to both tiers. The following discussion will refer directly to the options provided therein. In short, the item asked what the resulting image of a flat triangular plate would look like on the film that was placed inside a camera, of which the upper half of its circular aperture was completely blocked. The first tier contained six options that pertained to the possible shape of the image that would be exposed on the film. All six options are presented in a diagrammatic format with a brief caption listed below. As for the second tier, it had four options that inquired into the reason behind the respondent's option of choice in the first tier.

As part of the data analysis process, we had asked three physics experts who were not involved in the project to inspect the item on separate occasions. They essentially agreed that the options may be meaningfully clustered into the following three groups of answers given by the respondents. The other combinations were judged as not being meaningful combinations and might have been results from random guessing.

- The meaning of the cluster 1D:

The cluster 1D refers to those respondents who chose the first option from the first tier and the D option from the second tier. This combination of options is the scientifically correct answer. Compared with the whole lens, half of the lens will works exactly the same in forming an image of the object both in terms of its size and shape. The only difference between the two situations rests on the fact that there is less amount of light being converged onto the film.

- The meaning of the cluster 2A:

The cluster 2A refers to those respondents who chose the second option from the first tier and the A option from the second tier. Here, the students misunderstand that masking half of the lens would block off part of the light from passing through the lens, thereby resulting in a reduction of the size of the image on the film.

- The meaning of the clusters 3,4,5,6, B & C:

These clusters refer to those respondents who chose the third, fourth, fifth, or sixth option from the first tier and the B or C option from the second tier. The clusters that fall in this category share a common misconception that masking half of the lens would result in the disappearing of half of the object. There are, however, some differences among them concerning which half of the image would disappear and whether the corresponding half of the film would also be illuminated or not. Nevertheless, they all share the common view that the image was transmitted from the object and entered the lens where it might be inverted onto the film. Therefore, if half of the lens is masked, the image would reduce to only half of the original form of the object.

This particular item was selected to be included on all three booklets and was taken by a total of 2900 11th graders that were sampled via a two-stage stratified

**Table 7.1** The number of 11th graders who chose various combinations of options across the two tiers of the illustrated item

| 2nd tier / 1st tier | A | B | C | D |
|---|---|---|---|---|
| 1 | 10 | 10 | 8 | 644 |
| 2 | 162 | 11 | 29 | 62 |
| 3 | 19 | 55 | 69 | 18 |
| 4 | 13 | 235 | 315 | 48 |
| 5 | 6 | 53 | 86 | 17 |
| 6 | 21 | 417 | 501 | 81 |

sampling design. After deleting the invalid responses, a total of 2890 responses remained. The aggregated data is listed in Table 7.1 for handy reference.

Correspondence analysis on this two-way table was performed by using the PROC CORRESP procedure that was implemented in SAS version 9.3. It turned out that the first axis accounted for 62.46 % of the total inertia, whereas the second axis accounted for another 36.40 %. Apparently, a two-dimension solution would suffice, since together they already accounted for 99.86 % of the total inertia in the data. The resultant correspondence plot is shown in Fig. 7.1 below.

Since the main purpose is to identify possible misconceptions among the respondents in relation to science concepts, it is the combination of options across

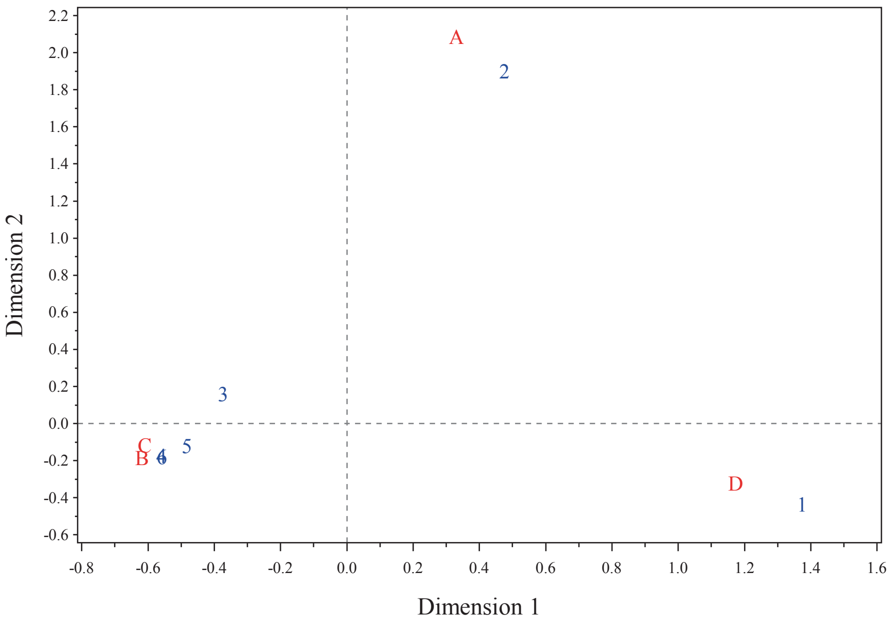


**Fig. 7.1** Correspondence plot for the problem on light entering the camera with a blocked lens

the two tiers that are at stakes in the interpretation. Hence the identification of the axes in the correspondence plots is of relatively less importance and can apparently be skipped for the present purpose. In Fig. 7.1, it is noticed that of the six options listed in the first tier, the option "D" of the second tier is relatively close to option "1" in comparison to the other options in the first tier. It is further noticed that option "A" of the second tier is relatively close to option "2" in comparison to the other options in the first tier. In contrast, the options "B" and "C" are relatively close to options "3", "4", "5", and "6" rather than to options "1" or "2". Hence, it indicates that for those who chose option "1" in the first tier, they were prone to justify their choice with option "D" in the second tier rather than other reasons provided in the second tier. Similar interpretation can be extended to the other clusters as seen in Fig. 7.1. For this study, we have also performed correspondence analysis on each set of data from the other two booklets. Since the patterns identified in each booklet are very similar to the one shown in Fig. 7.1, they are not displayed in the present report for the sake of simplicity. As for detailed substantive interpretation and the implication of this plot in relation to the actual options across the two tiers, interested readers are referred to the explanation suggested by the experts that was presented at the beginning of the data analysis section.

## 7.9 Discussion

In this chapter, we have proposed a more comprehensive approach to identify misconception in a two-tier item context that consists of the following three steps:

1. Particular combinations of options across the two tiers should be conceptually judged by subject matter experts to determine if they constitute a misconception. Consensus should be attained among the experts.
2. Multiple booklets that contain the same two-tier items as common items should be constructed and distributed to random equivalent groups of respondents to work on. An alternative approach is to pursue replications by administering the items to different groups of respondents at different time periods.
3. Proximity of specific configurations of fact and reason options should be carefully inspected for consistency in patterns formation among the various correspondence plots, one for each booklet.

What is emphasized in the three-step approach is the coherence among the various types of findings. First of all, coherence should be attained among the experts' opinions. Furthermore, coherence should also be attained among the correspondence plots that are based on the various test booklets. Finally, coherence should also be achieved between the clusters identified by the experts based on theoretical ground and from the various correspondence plots based on empirical ground. The first and the third kind of coherence can be regarded as part of the evidence for establishing the validity of the method proposed in this study. The stability and replicability of the patterns identified in the correspondence plots from different samples of respondents in the second kind of coherence can be regarded as contributing to the evidence of reliability for the method proposed.

One of the main advantages of the correspondence analysis approach lies in its visual feature, which is both appealing and can lend itself more easily to direct interpretation of information on the part of the teachers. Another advantage is that it can alleviate the need to set up subjective threshold rate (for example the 10 % criterion) to designate a certain combination of options as constituting the dominating misconceptions among the respondents to the item. Thus, this study argues that potential misconceptions of students should be identified in terms of the clusters as seen in the correspondence plots, rather than using the arbitrary 10 % criterion.

The technique presented in this chapter is still based on a multivariate descriptive statistical technique. Currently, we are contemplating if inferential statistical technique can be established in the identification of misconceived combination of facts and reasons by the respondents across the two tiers.

## 7.10 Conclusion

In this chapter, it is pointed out that the 10 % criterion which is commonly used in the identification of misconception in the two-tier item format is not well justified. We introduce a three-step approach as a better alternative in this regard. An example has been furnished to illustrate this procedure. If subject matter experts' identification of potential misconceptions can be consulted before they are allowed to look at the results from the correspondence analysis, and that their identification is consistent with those derived from the correspondence plots, then the findings can be regarded as having been triangulated from different sources. Future direction of research can further explore other kinds of statistical approaches for the identification of students' misconceptions. In sum, this study promotes the use of correspondence analysis in the context of identifying potential types of misconceptions within a two-tier item context. Furthermore, future research can also explore the derivation of an agreement index among the patterns identified across various correspondence plots.

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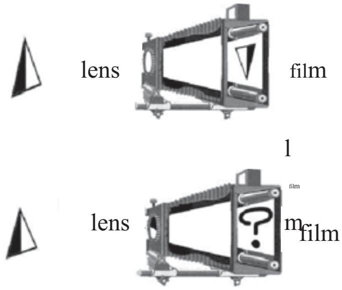
# Appendix

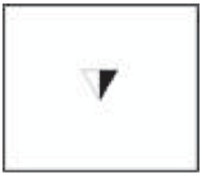
2. As shown in the figure, a camera is focused on a triangular object so that a clear picture is obtained on the film. If the upper half of the lens is masked by a black tape (as shown in the following figure), what happens to the picture on the film?




(1) Which of the following pictures will appear on the film?

1.


☐ The picture remains the same except it becomes dimmer.

2.


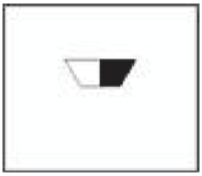
☐ The image shrinks.

3.


☐ Upper half of the image disappears.

4.


☐ No light arrives at the upper half of film.

5.


☐ Lower half of the image disappears.

6.


☐ No light arrives at the lower half of film.

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(2) Which of the following statements can best explain your answer in (1)?

☐ (A) Decreasing the light passing through the lens changes the shape and/or size of the image.

☐ (B) Since the light rays from the upper half of the object is blocked off, no image of upper half remained on the film.

☐ (C) All light rays from various parts of the object head toward the center of the lens. Since those rays coming from the lower half the object were blocked off by the mask, therefore no image of lower half remained on the film.

☐ (D) Half of the lens works as same as the whole one in forming the image of same object. The shape and size of the image remains the same when half of the lens is masked except the amount of light passing through the lens decreases.

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# Chapter 8
# Elementary Science Education in Taiwan—From the Perspective of International Comparison

**Yu-ling Lu and Chi-jui Lien**

**Abstract** The East Asia region has often won excellent remarks from international evaluation institutions such as the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA). As a result, science education in the East Asia region is closely focused on by the global community. Taiwan is considered as a key geographical center in this region, where elementary science education, due to its special backgrounds, has its own appearance and features. In this chapter, drawing from literature and secondary data analysis of TIMSS, we have provided a close description of Taiwan's special characteristics in elementary science education. Three sections are outlined in this chapter to introduce Taiwan's: (1) schools' resources and environment; (2) science curriculum and text-books; (3) teaching and learning. In order to emphasize Taiwan's uniqueness in comparison to other important parts of the world, our chapter compares Taiwan's performance with other countries within the TIMSS and Korea, Singapore, Japan, USA, and the Russian Federation in particular, due to its excellent performance in the TIMSS. As a result, this study found that Taiwan's elementary science education has many features versus these top-ranking countries/regions. These include: (1) relatively adequate facilities, in terms of laboratory and book resources (e.g., almost all schools have a laboratory(ies), etc.), (2) vital family and parent support, and (3) emphasizing experiments in science teaching, etc. Some other issues, such as: (1) schools' strong opinions on asking for more resources for science teaching, (2) the content of the fourth grade textbooks being emphasized physical science, (3) the relative low correlation between Taiwan's curriculum and TIMSS examination, (4) science textbooks are much thinner than those of some other countries, (5) science class hours are relatively lower, and (6) less emphases on "read," "memorize," and "explanation," etc., were also pointed out for further research while formulating the next innovations in science education.

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## 8.1 Introduction

Confucian thoughts have widely affected the East Asia region. With their doctrine, it affects many scopes in our society, such as ideas, politics, and economics. Among these, it influences education the most. It is these genuine ideas that affect families and encourage their descendants to be proactive in learning. Perhaps it is because of these influences and historical background that science education in East Asia has excelled greatly and received a certain level of global attention (Martin et al. 2012, p. 6).

Taiwan, being a key geographical center within the East Asia region, has its unique cultural aspects in oceanic pioneering and thereby rendezvous closely with its neighboring regions. While being modernized in the trend of sciences and industries, Taiwan has developed its own pathway of science education that embraces both the traditional and the modern. Over the past decade, Taiwan's publications in top journals have been ranked number one in Asia and are among the top-ranked at the international level (Tsai et al. 2010). In elementary science education, the performance rankings of Taiwanese students in 2003, 2007, and 2011 by TIMSS, were second, second, and sixth place, respectively. Although, these achievements are still considered as top-performers, along with statistically equivalent scores in 2011 and 2007, it is an undeniable fact that there has been a decline in the standings. In other words, other countries are improving. This is the time for us to explore our advantages and maybe deficiencies, so that the development of science education can continue.

## 8.2 Objectives

The purpose of this chapter is to describe Taiwan's current status in elementary science education from a perspective of international comparison. In order to achieve this, the examined information, which includes: (1) TIMSS 2011 dataset, (2) TIMSS 2011 final report (Martin et al. 2012), and (3) periodicals and theses in Taiwan and other countries, was collected and analyzed.

In the data reanalysis using TIMSS 2011 dataset, our chapter referred to the top seven ranked countries: (1) Korea (average score 587), (2) Singapore (583), (3) Finland (570), (4) Japan (559), (5) the Russian Federation (552), (6) Taiwan (Chinese Taipei in TIMSS report, 552), and (7) USA (544). For simplicity and clarity of comparison among countries, we utilized modified formats different from the TIMSS and other references. In our chapter, we especially highlighted the top-ranked countries including: the USA and the Russian Federation, due to their major populations and influence in the global community. We have also placed Korea, Singapore, and Japan (abbreviated as KSJ) as a combined group, where their economics, cultural background, technological advancements, and science education performances are similar to some extent. This will shape Taiwan's status in Asia and in the global community more clearly and will in turn emphasize its uniqueness in science education, potential problems, and direction for improvements.

Within the following analysis, the global averages were derived from the TIMSS database that includes 52 countries/regions with about 400,000 students and teachers (Trends in International Mathematics and Science Study 2011). For the comparison among Taiwan, USA/Russian Federation, and KSJ, this study utilized data from 1142 school staffs and administrators with 36,135 students. In addition to increase readability, this study reversed opposite-directional TIMSS data (e.g., in TIMSS dataset, "Existing science Laboratory?" used "1" for "Yes," and "2" for "No"; here, were re-coded as "1" for "No," and "2" for "Yes"). In this chapter, sets of radar charts were used to:

1. Contrast Taiwan with the global community to help readers clearly see the similarities and differences.
2. Contrast Taiwan with the USA, the Russian Federation, and KSJ for showing the similarities and differences among these top-ranking countries/regions.

This descriptive research aims to answer the following research questions: (1) What is the status quo of the elementary science education in Taiwan? (2) What are the similarities and differences when comparing with some other top-ranking countries/regions? This study may also help readers residing inside or outside these regions to see the contrast and perhaps to formulate new ideas or viewpoints for their purposes. This is something that was not seen in the TIMSS 2011 report (Martin et al. 2012).

## 8.3 Results and Discussion

Our chapter will focus on three dimensions: (1) schools' resources and their environments, (2) science curriculum and text-books, and (3) teaching and learning.

**(1) Schools' Resources and Environment**

In Taiwan, "the Compilation and Administration of Education Expenditures Act" was promulgated in 1990. It required the aggregated education expenditures of governments of all levels, which would be no less than 22.5 % of average net annual revenue over the previous 3 years of the budgeting year. Practically, school budget was affected by the financial condition of their local government. This created, to some extent, the inequality of educational resources. To compensate the shortage, the Ministry of Education (MOE) initiated Educational Priority Areas Projects, to minimize schools' deficiencies. However, schools and teachers have stronger concerns about unstable resources in these years.

As to the social status of school teachers and principals, the traditional culture's values have maintained those as highly respectable ones. They play a role in cultivating youth to strive upward and are highly recognized by society. Currently, almost all elementary school teachers in Taiwan have a bachelor's degree (99.5 %), which included 42.1 % with a master's degree and 0.8 % with a doctoral degree. As for science teachers, some of them hold a degree in sciences, while the other portion holds a degree in other specialties. At the moment, the student-to-teacher ratio is

14.08, with an average class size of 24.38 students (M.O.E. 2013, pp. 97–99). Most teachers serving at the primary level have a positive attitude towards their job satisfaction and their school (Hung 2012). In addition, due to the phenomenon of low-birth rates, the number of teaching positions has vastly decreased along with many talented young individuals with teaching certificates looking for an opportunity in teaching (M.O.E. 2012, p. 112). Moreover, a large portion of science classes were taught by non-science-majored teachers, and many science-majored teachers had to teach other subjects such as language, mathematics, social studies, etc. Some teachers majored in science and education but due to curriculum arrangements, science-majored teachers in schools were not able to contribute to their specialty at a full level.(Wu et al. 2011) The above factors indicated that elementary science education in Taiwan still has lots of potential for growth and improvement (Ministry of Education 2012, 2013; Lu and Lien 2009).

For the purpose of better understanding the schools' resources and environment, further data were extracted from the TIMSS 2011 database to acquire information from the schools' perspective about the status and environment of elementary science education in Taiwan and other countries/regions. To depict this, the TIMSS data related to the existing science laboratories, schools' perceptions of shortage of teaching resources, and parental support were recollected, analyzed, and shown in Table 8.1 and Fig. 8.1a, b.

In Table 8.1 and Fig. 8.1, we depicted Taiwan's science education in the following areas: (1) school facilities, (2) school opinions on teaching resources, and (3) family support.

1. Laboratory and book resources are relatively adequate
   From the surveyed data shown in Table 8.1, most schools in Taiwan are equipped with science laboratories for students (Mean: 1.89; 1 for "No"; 2 for "Yes." This represented about 90 % of schools), which is far better than the international average (1.37) and is contrasted as shown in Fig. 8.1a. Also, room for improvements can be seen when Taiwan's average is compared to KSJ's average of 2.00. However, it is worth mentioning that the USA's and the Russian Federation's averages (1.25, 1.23 respectively) are far lower than Taiwan's (as Fig. 8.1b). Besides, the abundance of library resources located within Taiwan's schools can also be noticed from the data in Table 8.1. Therefore, Taiwan's schools are fairly replete with teaching facilities, in terms of laboratory and book resources.
2. Schools' opinions on resources for science teaching still yet to be fulfilled
   The results of our secondary analysis of the TIMSS database on the schools' own opinion on "whether there is a shortage of teaching resources" were depicted in Fig. 8.1a. It showed that Taiwan's schools expressed relatively strong feelings of concern regarding the shortage of resources for science teaching, when compared with international average, in the following areas: (a) teaching materials, (b) science teachers, (c) information software, (d) library resources, (e) audio/video resources, and (f) scientific equipment. From Table 8.1, it shows that Taiwan's average feeling of shortages in these areas are far higher than the international averages (Taiwan 2.66–3.06, International 2.11–2.44; range 1–4, 1 = none, 2 = a little, 3 = somewhat, 4 = very much). Especially, when compared

**Table 8.1** Schools' resources and their environments (4th Grade, TIMSS)

| | Taiwan | Japan | Korea | Singapore | KSJ[a] | USA | Russian federation | Global | Range |
|---|---|---|---|---|---|---|---|---|---|
| | Mean(Std) | Mean(Std) | Mean(Std) | Mean(Std) | Mean | Mean(Std) | Mean(Std) | Mean(Std) | |
| 1.a Existing science laboratory | 1.89 (0.32) | 1.99 (0.08) | 2.00 (0.00) | 2.00 (0.00) | 2.00 | 1.25 (0.44) | 1.23 (0.42) | 1.37 (0.48) | 1–2 |
| b Books with different titles | 5.63 (0.68) | 5.13 (0.79) | 5.65 (0.70) | 5.15 (1.07) | 5.31 | 4.77 (1.15) | 4.86 (1.15) | 3.80 (1.56) | 1–6 |
| 2. Shortage\ a. instructional material | 2.66 (1.23) | 1.53 (0.91) | 1.28 (0.66) | 1.65 (1.07) | 1.49 | 1.56 (0.83) | 1.99 (1.09) | 2.11 (1.15) | 1–4 |
| b. Teach. spec. science | 2.93 (0.99) | 2.13 (0.90) | 1.59 (0.83) | 2.53 (0.88) | 2.08 | 2.30 (1.00) | 1.67 (1.00) | 2.22 (1.12) | 1–4 |
| c. Computer software | 2.60 (0.82) | 2.30 (0.80) | 1.61 (0.75) | 2.01 (0.87) | 1.97 | 2.27 (0.97) | 2.55 (0.92) | 2.31 (0.98) | 1–4 |
| d. Library materials | 2.66 (0.82) | 2.23 (0.77) | 1.66 (0.75) | 1.91 (0.87) | 1.93 | 2.02 (0.92) | 2.25 (0.92) | 2.17 (0.96) | 1–4 |
| e. Audio-visual resource | 2.68 (0.87) | 2.29 (0.77) | 1.70 (0.76) | 2.06 (0.95) | 2.02 | 2.06 (0.97) | 2.53 (0.90) | 2.30 (0.98) | 1–4 |
| f. Science equipment | 3.06 (0.99) | 2.30 (0.94) | 1.67 (0.87) | 2.00 (1.08) | 1.99 | 2.23 (1.00) | 2.77 (0.98) | 2.44 (1.02) | 1–4 |
| 3.Home possess\ a. computer | 1.95 (0.23) | 1.83 (0.38) | 1.98 (0.13) | 1.96 (0.19) | 1.92 | 1.93 (0.25) | 1.85 (0.36) | 1.82 (0.38) | 1–2 |
| b. Internet | 1.87 (0.34) | 1.77 (0.42) | 1.89 (0.31) | 1.92 (0.27) | 1.86 | 1.85 (0.35) | 1.71 (0.45) | 1.73 (0.45) | 1–2 |
| 4.Parental a. support | 3.95 (0.76) | 3.11 (0.78) | 3.51 (0.97) | 3.40 (0.77) | 3.34 | 3.55 (0.98) | 2.98 (0.56) | 3.20 (0.90) | 1–5 |
| b. Involvement | 3.62 (0.73) | 3.42 (0.91) | 3.45 (0.99) | 3.18 (0.76) | 3.35 | 3.34 (1.06) | 3.11 (0.66) | 3.07 (0.96) | 1–5 |

[a] *KSJ* Mean value of Korea, Japan, and Singapore

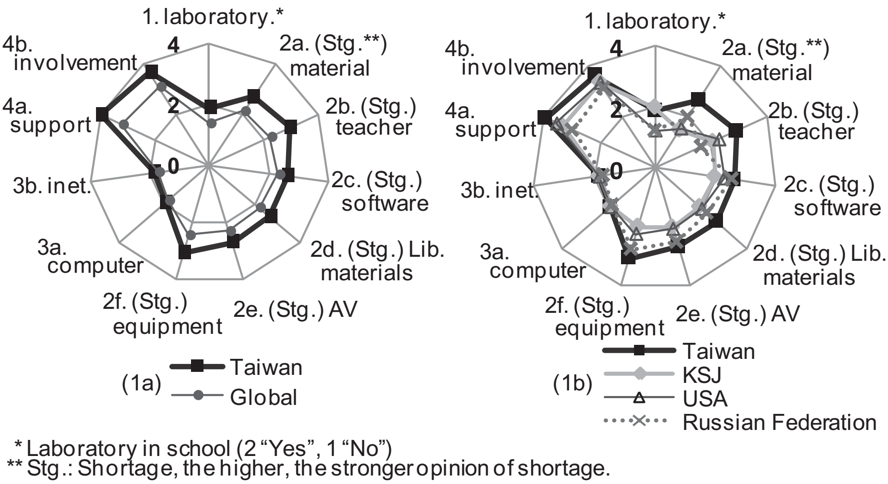


**Fig. 8.1** Educational institutions' resources and their environment (4th Grade, TIMSS)

to the USA, the Russian Federation, and KSJ, Taiwan showed a higher average of shortages. On the other hand, in comparison with KSJ (1.49–2.08), Taiwan's sense of resource shortage is far higher (Fig. 8.1b). This phenomenon is probably due to competition among schools. In Taiwan, a low-birth rate has caused a decline in enrolled students in various school districts along with increased competition among schools, and pressure on the faculties (Hung 2011). As a result, schools tended to express stronger expectations of more resources to create a better educational environment, and indeed there is an inadequacy of various resources in fulfilling the needs of science teaching (Chen 2005). These are factors worth further investigation and seeking changes for improvement.

3. Family- and parent-support systems are vital in educational development
   In the area of family and parental support, the number of families in Taiwan with computers and Internet (1.95 and 1.87; range: 1–2, 1 for "no," 2 for "yes") as in Table 8.1 and Fig. 8.1a, are higher than the global average (1.82 and 1.73), while relatively even in comparison to the USA, the Russian Federation, and KSJ ( Fig. 8.1b). Besides, Fig. 8.1a, b shows clearly the support of Taiwanese parents towards their children's education and school, which is far greater than other countries/regions. Recently, a survey study investigated science teachers' opinions of the application of community resources to science teaching, from which science teachers also expressed that strong parental support contributes much towards science teaching (Shen 2011). Ping and Lin (2010) used PISA data and conducted a study to see how economic assets (equipments/spaces that support children's learning, such as desk, study space, computer, Internet, etc.) and cultural assets (resources related to humanity and arts, such as classical literature books, encyclopedias, dictionaries, musical instruments, etc.) affect Taiwanese students' learning achievements. It found that both have significantly positive effects. This suggests that family assets and parental support are vital

components and are potent driving forces for the further development of Taiwan's elementary science education.

**(2) Science Curriculum and Textbooks**

Before 1998, curriculum and textbook policy in Taiwan was centrally based. A unified textbook editorial system with the national curriculum guideline was the only official source of science textbooks.

In these early years, textbook publishing had been known as the country's core ingredient to national educational development. Therefore, in Taiwan, there existed a special task group particularly geared towards textbook publishing and conducting a curriculum experimental project on science curriculum called the "Ban-Chiao Model" (due to the location of the task group in Ban-Chiao City). It is widely believed that this model paved the foundation for the development of science education in Taiwan. Forty years later, a recent research on the Ban–Chiao model interviewed elderly scholars of the time and reviewed documents. The study discussed special characteristics of Taiwan's Ban–Chiao Model, which included: (1) establishing a solid foundation of philosophy for the science curriculum and its development, (2) the well-structured process of curriculum innovation, including research, application, and evaluation, and (3) large-scale curriculum experimentation on the newly developed curriculum (Wu 2011). These are important experiences for the future development of science curriculums in Taiwan.

In 1998, the General Guideline of Grade 1–9 Curriculum, a new National Curriculum Guideline, was promulgated by MOE of Taiwan and the core competence-oriented curriculum stage began. Grade 1–9 Curriculum encompasses "Science and Technology Learning Areas," instead of "Science Subject." The reforms provided elementary teachers with professional independence, dynamic teaching, using school-based curriculum, integrated curriculum, and multiple assessment opportunities. In addition to the innovation of the curriculum, the textbook policy has tremendously shifted to an open appraisal mechanism (Liu and Chiu 2012).

Under the textbook liberalization policy, commercial publishers wrote their textbooks based on the National Curriculum Guideline. Once the textbook was approved by a review committee, it was ready for school's selection. There are some main commercial publishers of elementary science and technology textbooks offering elementary schools free choices. Most of these commercial publishers are equipped with a systematic and organized team that edits, evaluates, develops, and markets textbooks and teaching aids. To help readers more fully understand Taiwan's elementary textbooks, we have attached a partial list of commercial publishers' websites as extra references (Han Lin Publishing 2013; Kang Hsuan Publishing 2013; Nani Publishing 2013).

A little over a decade, after the implementation of the new curriculum and textbooks, the TIMSS 2011 data provided some relevant information, as shown in Table 8.2 and Fig. 8.2a, b. These may be used as references for further consideration of the current curriculum.

In accordance with Table 8.2 and its relevant references, four sections are outlined below: (1) the content distribution of science curriculum, (2) the connection

**Table 8.2** Content distribution and textbook reliance (4th Grade, TIMSS 2011)

| Item | Taiwan | Japan | Korea | Singapore | KSJ[a] | USA | Russian federation | Global | Range |
|---|---|---|---|---|---|---|---|---|---|
| | Mean(Std) | Mean(Std) | Mean(Std) | Mean(Std) | Mean | Mean(Std) | Mean(Std) | Mean(Std) | |
| 1. Cont. Dist.\ a. life science | 33.81 (12.75) | 37.39 (12.89) | 34.93 (13.24) | 36.44 (18.12) | 36.26 | 36.55 (14.27) | 41.39 (19.19) | 43.51 (18.91) | 0–100 |
| b. Physical science | 44.85 (17.22) | 41.67 (13.61) | 32.24 (11.87) | 57.38 (22.32) | 43.76 | 32.05 (14.45) | 16.88 (12.15) | 30.24 (17.25) | 0–100 |
| c. Earth science | 21.34 (11.56) | 20.94 (9.26) | 32.83 (14.15) | 6.18 (9.83) | 19.98 | 31.41 (14.59) | 41.73 (17.47) | 26.25 (15.61) | 0–100 |
| 2. Resourc es\ textbooks | 2.95 (0.22) | 2.81 (0.41) | 2.96 (0.24) | 2.62 (0.57) | 2.80 | 2.30 (0.71) | 2.94 (0.24) | 2.60 (0.64) | 1–3 |

[a] *KSJ* Mean value of Korea, Japan, and Singapore

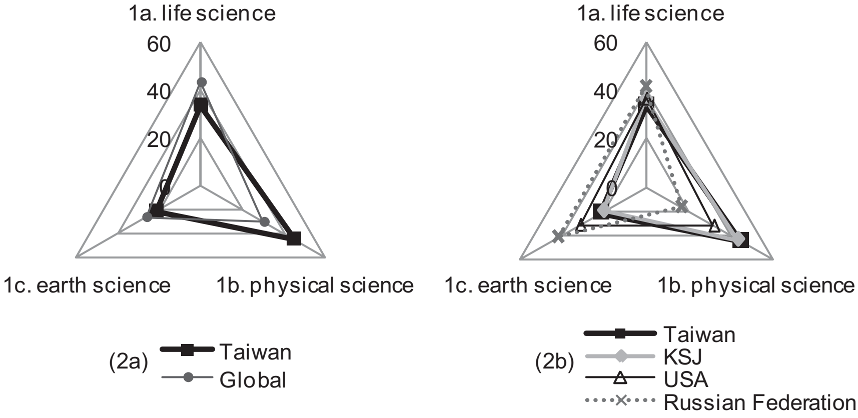


**Fig. 8.2** Curriculum content distribution (TIMSS)

between curriculum and TIMSS examination, (3) the quantity of content, and (4) the level of dependence on textbooks.

1. The content distribution of the fourth grade textbooks was physical science-oriented in Taiwan
   The TIMSS 2011 surveyed the content distribution of fourth graders' curriculum, with the data received from various elementary school teachers around the world according to their syllabus. These data indicated that the percentage of distribution for biology, physical science and life sciences were 29.84 %, 39.08 %, and 18.54 % in Taiwan, while the international averages were 38.11 %, 25.53 %, and 23.09 % (Table 8.2). The comparison between the two groups was shown in Fig. 8.2a. Here, Taiwan's curriculum distribution clearly skewed. In Taiwan, physical science was heavier than earth science and life science, and its physical science is higher than the global average.
   However, further comparison of the curriculum of Taiwan with the USA, the Russian Federation, and KSJ (as in Fig. 8.2b) showed the distribution towards the lower right (physical science) is not unique to Taiwan and is also seen in KSJ, which is nearly the same as that of Taiwan. We can also see the curriculum of the USA is distributed triangularly (33.46 %, 28.58 %, and 28.62 %). A special point is observed in the Russian Federation's curriculum, in which the "earth science" is the heaviest. Science curriculum from Grade 1 to Grade 4 in the Russian Federation was named as "The World Around." Its content primarily is to guide students in observing the weather, agriculture, human body, and natural surroundings (Hassard and Dias 2009) and therefore physical science only received 12.78 % of distribution, along with high emphasis in earth sciences with 31.52 %. Overall, from Fig. 8.2b, we clearly see the typical distribution models for the three kinds of sciences: (1) physical science weighed, e.g., Taiwan and KSJ, (2) equally weighed, e.g., USA, and (3) earth science weighed, e.g., the Russian Federation. Is this phenomenon a result of the diversity of educational

goals and needs? Or, is it just revealing different content—emphases that can happen differently in different grade levels? These still require further study.

2. Science textbooks in Taiwan are much thinner than those of some other countries
The number of pages in Taiwanese science textbook is also an issue, for it is relatively less than that of other countries. For example, science textbook for fourth grade used in whole academic year in the USA has a total of almost 500 pages, and Taiwan's textbook has only 160 pages (another workbook of about 100 pages will be used too). One of the reasons for the thin textbook was that Taiwanese families, except low income or with disable parents/children, needed to purchase textbooks for their children, so that local educational authorities tended to select textbooks with affordable price to maintain the educational equity, and thus, the number of pages and price were naturally controlled. Another factor contributed to the thin textbook was that, students were expected to learn science through inquiry and experiment; thus, most textbooks are mainly to give questions/problems and to guide students' inquiry, rather than to put on a large amount of scientific knowledge. While Taiwanese textbooks were with above features, there were studies suggested that Taiwanese textbooks still have room to increase the amount of content and to improve the ways of structuring textbooks' content (Yang et al. 2012; Yang 2010).
3. The correlation between Taiwan's curriculum and TIMSS examination is low.
Unusual phenomenon also surfaced in regards to relevance between the school curriculum and TIMSS examination contents (Martin et al. 2012, p. 482). Within the TIMSS 2011 report, whether it is Taiwan's or KSJ's curriculum, both showed low overlapping content with the TIMSS examination questions. Of the 181 TIMSS questions, Taiwan's curriculum only covered 69 questions (38 %) and KSJ even fewer, with only 59 questions (33 %). The Russian Federation, on the other hand, showed better relevance at 84 questions (46 %), with the USA ranking at the top with 150 questions (83 %), which is higher than the global average of 130 questions (72 %). Although we think, more evidences are needed to support the validity and reliability of the survey result, however no further study has been found at this stage. Under the circumstances, by assuming these data are accountable, this phenomenon may suggest that the school curriculum of many countries/regions (such as Taiwan and KSJ) did deviate from the "ideal content" of the TIMSS 2011. The inconsistency between the low overlapping of school curriculum and the high ranking of achievement may have resulted from the approach of how Taiwanese textbook organized and how science was taught. In Taiwanese textbook, most of the units have started from questions/problems. Students explore, not only read or remember a large amount of texts or knowledge. The phenomenon of using thin textbook yet gaining high-learning achievement could be a remark for the idea of "less is more," which was addressed in the Project 2061.
4. Reliance on textbooks in classroom instruction is quite heavy
The TIMSS 2011 investigation also indicated a high reliance on textbooks while teaching science in most of these countries (Table 8.2). The data suggested that science textbooks in Taiwan are extremely high (2.95, range 1- 3, as in Table 8.2).

This is higher than those in KSJ (2.80), the USA (2.30), and the Russian Federation (2.94).

Taiwan's National Academy for Educational Research in Taiwan (NAER) is currently conducting and preparing a next- stage reform. Perhaps the above mentioned problems can be further clarified and/or can be helpful for finding a more suitable direction for science curriculum and textbooks in the future.

**(3) Teaching and Learning**

Engaging in science education reform requires substantive change in teaching and learning. In keeping pace with global development, the educational authority in Taiwan is heavily devoted to preparing scientifically and technically literate citizens. The focus on learning core concepts was a key aspect of a coherent science education before 1998. After 1998, the "General Guideline of Grade 1–9 Curriculum" was intended to reflect a new vision for science education in Taiwan (MOE of Taiwan 1998). The concept of curriculum shifted from understanding scientific knowledge to developing scientific core competences. Students are expected to spend more time working on problem solving approaches and scientific inquiry.

The TIMSS 2011 also conducted data collection related to teaching and learning. Our data for this section is secondary data analysis from the TIMSS dataset as well as from related references to describe Taiwan's status versus other countries mentioned earlier. The results are shown in Table 8.3 and Fig. 8.3a, b. This is introduced in three parts: (1) weekly science class hours for science teaching, (2) teachers' teaching activities, and (3) students' learning activities.

1. Taiwan's science class hours are lower in comparison to most countries
   According to Table 8.3, Grade 4 students in Taiwan receive about 2.08 h of science classes weekly (every class period in Taiwan is 40 min, which is about 3 periods; these data currently match the curriculum regulations), which is slightly less than the international average of 4.14 % (2.17) (Fig. 8.3b). Taiwan's data are also lower than KSJ's data, about 6.72 % (2.23) and far fewer than the hours in the USA (2.69) of about 22.68 % (Fig. 8.3b). In particular, the class hour for science in the Russian Federation is only 0.99 h, which is a large deviation from the international norm. However, its students showed excellent learning efficiency with such a low amount of hours allocated. Whether this is due to the Russian Federation's curriculum containing other adjunctive courses to aid students' relevant scientific knowledge (e.g., their "Technology" class in elementary curriculum) or the Russian Federation's science education has some remarkable characteristics, is still pending further exploration. Aside from this, like the special case in the Russian Federation, Taiwan's weekly science class hours are on the lower end versus other countries/regions, which may require more attention and consideration about increasing hours of science class.
2. Teachers' teaching activities need to be reevaluated and improved
   In the TIMSS 2011 survey, teachers were asked, "How often do you do the following in teaching this class?" (Numerical values reversed from the TIMSS survey: 4- Every or almost every lesson, 3- About half the lessons, 2- Some, 1- Never.) The collected data have been helpful in evaluating the status of teach-

**Table 8.3** Teachers' teaching and students' learning activities (4th Grade, TIMSS 2011)

| Item | Taiwan | Japan | Korea | Singapore | KSJ | USA | Russian federation | Global | Range |
|---|---|---|---|---|---|---|---|---|---|
| | Mean(Std) | Mean(Std) | Mean(Std) | Mean(Std) | Mean | Mean(Std) | Mean(Std) | Mean(Std) | |
| 1. Time spent science\hours | 2.08 (0.76) | 2.02 (0.17) | 2.33 (0.64) | 2.35 (1.01) | 2.23 | 2.69 (1.58) | 0.99 (0.31) | 2.17 (1.41) | 1–10 |
| 2. How often\ a. Summarizing | 3.47 (0.71) | 3.71 (0.54) | 3.70 (0.58) | 3.62 (0.66) | 3.68 | 3.78 (0.49) | 3.84 (0.45) | 3.61 (0.69) | 1–4 |
| b. relate to students l ives | 3.32 (0.75) | 3.07 (0.73) | 3.55 (0.67) | 3.35 (0.74) | 3.32 | 3.66 (0.54) | 3.52 (0.70) | 3.47 (0.74) | 1–4 |
| c. elicit reasons | 3.43 (0.72) | 3.72 (0.54) | 3.73 (0.52) | 3.73 (0.55) | 3.73 | 3.88 (0.35) | 3.56 (0.63) | 3.73 (0.57) | 1–4 |
| d. encourage students | 3.40 (0.72) | 3.46 (0.69) | 3.58 (0.66) | 3.72 (0.54) | 3.59 | 3.96 (0.21) | 3.92 (0.29) | 3.79 (0.51) | 1–4 |
| e. praise students | 3.39 (0.72) | 3.65 (0.54) | 3.72 (0.54) | 3.65 (0.62) | 3.67 | 3.96 (0.22) | 3.96 (0.22) | 3.82 (0.48) | 1–4 |
| f. bring i nteresting material | 3.05 (0.82) | 2.56 (0.68) | 3.21 (0.76) | 2.89 (0.71) | 2.89 | 3.22 (0.70) | 3.45 (0.68) | 3.03 (0.81) | 1–4 |
| 3. Ask students\ a. obsei^e phenomena | 2.87 (0.71) | 2.76 (0.74) | 2.41 (0.72) | 2.66 (0.76) | 2.61 | 2.60 (0.84) | 2.63 (0.73) | 2.65 (0.82) | 1–4 |
| b. demonstrate experiment | 2.76 (0.78) | 2.68 (0.78) | 2.59 (0.82) | 2.69 (0.72) | 2.65 | 2.39 (0.71) | 2.28 (0.61) | 2.59 (0.85) | 1–4 |
| c. plan experiments | 2.80 (0.70) | 2.99 (0.79) | 2.85 (0.80) | 2.40 (0.85) | 2.75 | 2.40 (0.79) | 2.09 (0.54) | 2.42 (0.82) | 1–4 |
| d. conduct experiments | 3.10 (0.69) | 3.33 (0.61) | 3.10 (0.73) | 2.94 (0.73) | 3.12 | 2.60 (0.78) | 2.12 (0.53) | 2.56 (0.81) | 1–4 |
| e. read textbooks | 2.90 (0.82) | 3.20 (0.79) | 3.46 (0.79) | 2.84 (0.91) | 3.17 | 2.85 (0.88) | 3.78 (0.49) | 3.12 (0.91) | 1–4 |
| f. memorize facts | 2.30 (0.81) | 3.01 (0.73) | 2.99 (0.82) | 2.66 (0.91) | 2.89 | 2.24 (0.83) | 2.95 (0.87) | 2.76 (1.02) | 1–4 |
| g. give explanation | 3.11 (0.80) | 3.07 (0.72) | 3.57 (0.68) | 3.46 (0.70) | 3.37 | 3.39 (0.80) | 3.88 (0.36) | 3.41 (0.78) | 1–4 |
| h. relate science to l ife | 3.29 (0.75) | 2.84 (0.78) | 3.42 (0.73) | 3.39 (0.74) | 3.22 | 3.30 (0.78) | 3.71 (0.60) | 3.49 (0.74) | 1–4 |
| j. written test or quiza(*) | 2.19 (0.49) | 2.36 (0.72) | 2.57 (0.77) | 2.33 (0.56) | 2.42 | 2.45 (0.81) | 2.50 (0.65) | 2.53 (0.86) | 1–4 |

[a] *KSJ* Mean value of Korea, Japan, and Singapore, * : "i" is neglected

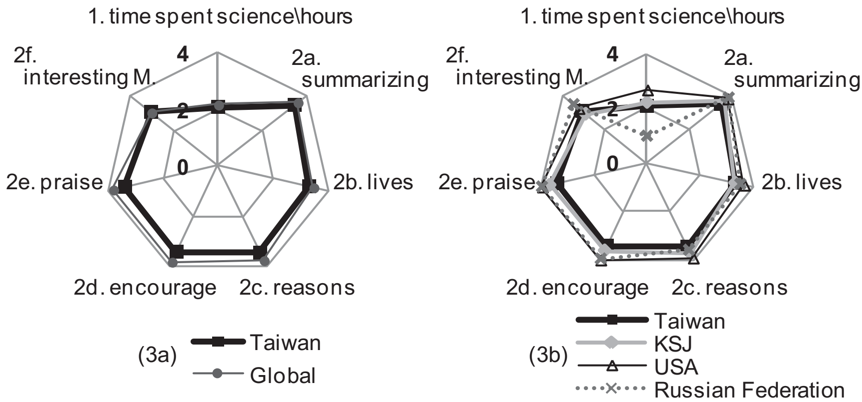


**Fig. 8.3** Teachers' teaching activities (4th Grade, TIMSS)

ers' teaching in Taiwan. The questions included the following phrases listed below:

a. *Summarize* what students should have learned from the lesson
b. Relate the lesson to students' daily *lives*
c. Use questioning to elicit *reasons* and explanations
d. *Encourage* all students to improve their performance
e. *Praise* students for good effort
f. Bring *interesting* materials to class

Fig. 8.3a's (as Table 8.3's data) data of Taiwan versus the global average showed Taiwan as slightly above average in one item, "(f)- Bring interesting materials to class (3.05 versus 3.03)," but below in all other items. In addition, Fig. 8.3b shows that, in comparison to other countries/regions, the averages of Taiwan's teaching activities in terms of the abovementioned (a)–(f) is relatively low, especially in the domain of practicing thinking skills- "(c)- Use questioning to elicit reasons and explanations," which is at the core of scientific learning. In this area, Taiwan's value (3.43) is the lowest among the compared countries/regions, including KSJ (3.54–3.89, please see Table 8. 3 for the listed data). This shows room for strengthening in training elementary school students' reasoning in elementary science education.

3. Emphasis of experiments being a special characteristic of teaching science in Taiwan
   This study used a question set in a teachers' questionnaire to collect information concerning students' science learning activities. The question is, "In teaching science to the students in this class, how often do you *usually* ask them to do the following?" (4- Every or almost every lesson, 3- About half the lessons, 2- Some, 1- Never).These data provide us with information to sketch the status of students' indoor class learning activities. The question included the following items:

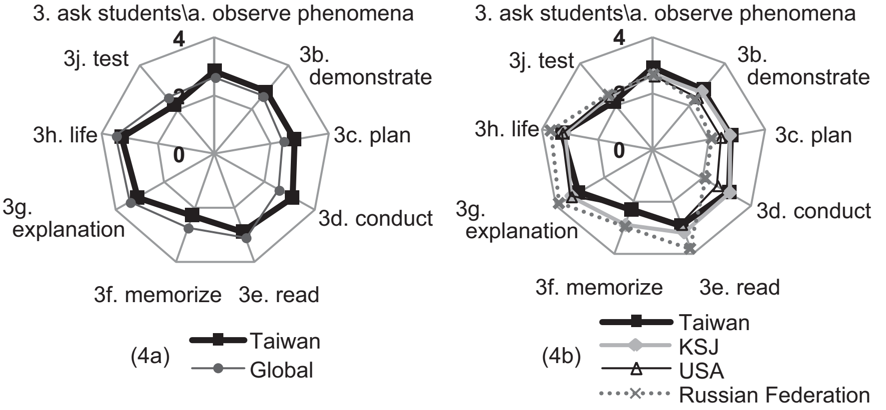


**Fig. 8.4** Student learning activities (4th Grade, TIMSS)

a. *Observe* natural phenomena such as the weather or a plant growing and describe what they see
b. Watch me *demonstrate* an experiment or investigation
c. Design or *plan* experiments or investigations
d. *Conduct* experiments or investigations
e. *Read* their textbooks or other resource materials
f. Have students *memorize* facts and principles
g. Give *explanations* about something they are studying
h. Relate what they are learning in science to their *daily lives*
i. Do field work outside the class
j. Take a written *test* or quiz

From the above, we chose to neglect "i" in our analysis due to its relatively low frequency when compared to other types of activities and for its not happening inside campus. The data is shown in Table 3 and in Figs. 8.4a and 8.4b. In order to better depict the meaning of the nine items above, we hereby interpret the items in the following manner: (1) experiment (including a- observe phenomena, b- demonstrate, c- plan, and d- conduct); (2) read (e- read their textbooks or other resource materials); (3) memorize (f- have students memorize facts and principles); (4) explanation (g- give explanations about something they are studying); (5) life (h- relate what they are learning in science to their daily lives); and (6) test (i- take a written test or quiz). These will be referred to in the following paragraphs.

There is a noticeable difference in the comparison of averages between Taiwan and the world as a whole (Fig. 8.4a). Taiwan, according to our data, focused more on experiments (a, b, c, d-, with averages of 2.86, 2.75, 2.79, and 3.09, respectively) versus international averages (2.63, 2.54, 2.38, and 2.52). However, in other areas, Taiwan's averages are lower and less focused versus international ones: Read (2.88 < 3.09), Memorize (2.28 < 2.69), Explanation (3.10 < 3.39), Life (3.28 < 3.46), and Test (2.17 < 2.45).

In Fig. 8.4b, Taiwanese students' science learning activities are compared to the other three top-ranking major countries/regions and some interesting differences were found. Below, we will discuss the characteristics of students' learning activities of each country/region based on information shown in Fig. 8.4b.

a. KSJ: KSJ has a similar emphasis on experiments (questions a, b, c, and d with scores 2.61, 2.64, 2.74, 3.12, respectively) as Taiwan, but also a higher frequency in the following: (2) Read (3.16), (3) Memorize (2.88), (4) Explanation (3.36), and (6) Test (2.42). However, in (5) Life (3.22), the focus is similar to Taiwan and lower in comparison to the USA and the Russian Federation.
b. The USA: In comparison to the other three regions, the frequency for "Experiment" is in the mid-range, while in (2) Read (e), (3) Memorize (f), (4) Explanation (g), and (5) Life (h) the frequency is similar to Taiwan, with relatively lower frequencies. On the other hand, only in the area of (6) Test (2.46), the frequency is higher than that of Japan's.
c. The Russian Federation: In comparison with the USA, KSJ, and Taiwan, it has the lowest frequency for "Experiment" (2.10–2.64). However, in (2) Read (3.78), (3) Memorize (2.97), (4) Explanation (3.87), (5) Life (3.70), and (6) Test (2.50), the frequencies are higher than Taiwan, KSJ, and the USA.
d. Taiwan: In the area of "Experiment"-related questions (items relating to observation, demonstration, plan and conduct), received scores of 2.86, 2.75, 2.79, and 3.09 respectively, which are all higher than those of the USA, the Russian Federation, and KSJ. However, in the questions of Read (2.88), Memorize (2.28), Explanation (3.10), Life (3.28), and Test (2.17), Taiwan's scores are the lowest in frequency in comparison. These remind us, to what extent and how should we enhance students learning in these domains.

As to the distinct feature of giving weight to experiment-related works in science classroom in Taiwan, there are at least three factors contributing to this. First, the Curriculum Guideline in Taiwan depicted that science and technology should be learned via inquiry and experiment. This tenet directly influenced what to be taught and how to teach science. Second, the thin science textbooks and the ways of arranging and presenting the textbook allow students to "experiment" and to "acquire," but not to "read" and to "memorize" in their science learning process. Third, elementary science teachers in Taiwan have an above average ability in understanding and applying inquiry instruction (Lien 2012). Teacher's readiness promotes the implementing experimental activities in science class.

The higher frequency of implementing experimental activities requires more resources and support; as a result, teachers in Taiwan inevitably expressed extraordinarily strong feelings of shortage in: (a) teaching materials, (b) science teachers, (c) information software, (d) library resources, (e) audio/video resources, and (f) scientific equipment as indicated in Fig. 8.1. To cope with this situation, educational authorities should strength the supporting system to satisfy schools' and teachers' needs for effective science teaching.

From the above analysis and data from the four countries/regions, different patterns were identified. This implies that various educational bodies may have their own focus on processing skills, acquiring knowledge, thinking, application, and evaluation, which in turn, shape their own patterns of student learning. "Further investigation and discussion on pros and cons in different educational systems are needed, so that ideal science teaching models and best practices can be shaped."

## 8.4 Conclusion

Elementary science education in Taiwan, with its special backgrounds, has its own overall appearance and features in the international community. Our chapter utilized the secondary analysis of the TIMSS data and related references to depict elementary science education in Taiwan and some selected top-ranking countries/regions.

According to this study, under (1) Schools' resources and their environment: Taiwan's facilities for teaching science seem to be adequate, but a variety of opinions still exist among the school administrators and teachers on the shortage of various resources. Family and parental support systems, on the other hand, are solid and are a great advantage to school development and in promoting education in Taiwan. These unique and valuable assets (Ping and Lin 2010; Shen 2011) will enhance science education and students' learning, if the educational system makes better use of them. As for (2) Science curriculum and text-books: Taiwan's science curriculum and content distribution are relatively the same in comparison to KSJ. Both focused more on physical sciences. It is noteworthy that its overlapping with the TIMSS questions is relatively low and that the textbooks used are relatively thinner as well. There is room for improvement in the connectivity and depth of conceptual contents, as well as the ways of structuring the curriculum (Liu and Chiu 2012). In addition, the reliance on textbooks in Taiwan is also quite heavy. In the third section, (3) Teaching and learning: Taiwan's science class hours are lower versus most other countries/regions. Its learning activities focused on experiments, but under-weighed reading, memorizing, thinking, and applying skills, which are more focused on in other countries/regions and therefore, Taiwan has room for further reflection and improvement.

Education is an important industry for preparing youth in a society and is also an important factor in helping students unleash their potential in realizing their own dreams. Surely, educators should not fall under the temptation to pursue being number one in the world; yet, they should and need to allow students to have an adequate environment and opportunities to develop themselves. By frequently examining the comparative educational indicators, the characteristics of different educational bodies can be revealed, which provides us with an opportunity for reflection of further potential educational improvements.

During the course of this study, the authors also perceived that currently in Taiwan there is a need for establishing science education indicators more broadly and profoundly, (e.g., in textbooks, teachers' demands and allocations, teachers' teaching practices, instructional materials and equipment, students' scientific literacy, special science education, and human resources for science educators and researchers, etc.). These are all waiting to be strengthened in order to help position and direct the development of Taiwan's science education. Further development of science education in Taiwan is calling, and it requires the Ministry of Education, Ministry of Science and Technology, various educational authorities, schools, and all the science teachers, scientists, and science educators to work together in meeting a new quality in Taiwan's science education.

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# Chapter 9
# Comments on Section 2: Significant contributions to research on learning and assessment

**David Treagust**

**Abstract** As has been discussed throughout this volume, the vision and direction of the National Science Council has resulted in science educators in Taiwan being very prominent among the world's science educators in the international literature and at international meetings and conferences. As an example, I have recently returned from the annual conference of the Australasian Science Education Research Association held in Melbourne, Australia. At this conference, among the international scholars in attendance were several from Taiwan who presented their work as an oral session or a poster. The research presented in every case that I attended was of high quality and was shown with posters; these could serve as good examples of successful poster presentations and layouts. Consequently, my experience from the first week of July 2014 in Melbourne was consistent with the quality of the research work presented in the four chapters in this section. Over the past 15–20 years, Taiwanese science education researchers have contributed substantially to the extant published literature and discussions, and debates at international conferences. These publications generally utilize rigorous methodologies and explain findings within the theoretical framework presented.

## 9.1 Conceptual Change

In examining the contribution of Taiwanese researchers to the literature on conceptual change, Chiu, Lin, and Chou (Chap. 5: Content analysis of conceptual change research and practice in science education: From localization to globalization) have taken a very broad look at comparing the international and Taiwanese published literature over the past three decades. They have analyzed international and Taiwanese studies from a number of different perspectives including the direction of the research taken—being largely of an instructional or epistemological perspective. The analysis showed that in this research area of conceptual change, Taiwanese scholars were relatively late into this field of endeavor compared to other research areas. But once research in this field started, within 10 years the contributions to the

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literature from Taiwanese scholars comprised a significant amount of the published research in this domain.

As Chiu et al. show, researchers in conceptual change have primarily focused on a single conceptual framework—the most frequent frameworks being epistemology, ontology, affective/social, and developmental. During the period of this review, the National Research Council invited international proponents of these different conceptual frameworks to Taiwan to conduct research seminars and workshops. A clear influence of these visits is the larger percentage of conceptual change studies in Taiwan using an ontological framework than by international authors using this framework. Of course, Chiu's postdoctoral studies with Chi in Pittsburg would have had an important influence on the orientation of her work, especially using an ontological framework. A multidimensional approach to understanding conceptual change is an area that few researchers have addressed. However, Taiwanese scholars are investigating science learning with this approach and Chiu et al. recommend that this framework needs more attention.

According to the data in Chui et al.'s chapter, instruction is the conceptual framework used most often by international and Taiwanese researchers of conceptual change with similar relative amounts of studies (61.1% international and 69.8% Taiwan). It would be useful to know more about this framework, which is described as involving the design and implementation of instructional materials, and whether or not this framework encompasses the other frameworks of epistemology, ontology, affective/social, developmental, etc.?

Chiu et al. describe extensive implications from conceptual change for science education research. Each of these seven suggestions provides valuable directions for conducting further research studies in science education.

An additional suggestion for future research is to work with a large number of science teachers for the implementation of effective science lessons informed by conceptual change research. This is research with a slightly different orientation along the lines of teacher professional development which can be viewed as a set of substantial conceptual changes that teachers have to undergo (Duit et al. 2013). Research has shown that "teachers' views of teaching and learning are limited when seen from the perspective of the implemented constructivist conceptual change ideas about teaching and learning" (p. 498). If teachers are to learn to teach for conceptual change, they need to experience conceptual changes themselves and this is best done through teacher learning in the context of teacher professional development. Some research along these lines has been conducted previously (see for example, Beeth et al. 2003; Feldman 2000; Stofflet 1994), but has not been extensively implemented and investigated with a wide range of teachers with different teaching styles and working in different schools. These studies have tended to draw on the classical conceptual change model by Posner et al. (1982) using intelligibility-plausibility-dissatisfaction-fruitfulness. To explicitly employ other theoretical frameworks described by Chiu et al. and the more recent multidimensional conceptual change perspectives would be a worthwhile addition to the suggestions for conceptual change research. This is one way to close the gap between teaching in normal classrooms and what might be accomplished based on teacher development in conceptual change.

## 9.2 Learners' Epistemic Beliefs and Culture

Fang-Ying Yang is very well placed to write this chapter, given the recent co-edited review of empirical studies on personal epistemology and science learning in the *Second Handbook of Science Education* (Yang & Tsai 2012). I am curious, as I suspect was Fang-Ying Yang (Chap. 6: Learners' epistemic beliefs and their relations with science learning: Exploring the cultural differences) to understand why of 106 published papers on empirical studies about learners' epistemic beliefs the predominant researchers in this area were from Turkey, Taiwan, and the USA with Taiwan having approximately the same total as the Turkish and the US studies combined. To examine the data presented in articles from these three countries, Yang looked at the notion of cultural context. Yang noted that high-context cultures—Turkey and China—and low-context cultures—the USA and Taiwan—proposed by Hall (1976) could be used to explain many of the findings. To use this theoretical framework from anthropology to interpret and understand the data is very insightful and will be useful for other researchers who are analyzing differences in studies that compare date between data, especially in areas like beliefs and may be useful to analyze data from learning environments research. For example, there has been much research by Taiwan and Australian colleagues on comparisons between schools and students in the field of leaning environments. To analyse the data through this theoretical lens of cultural context may also provide a deeper understanding of the data.

The rationale presented and which is supported by the review in this chapter is that high-context cultures might promote conformity, and thereby teachers and their students develop a simpler form of beliefs in scientific knowledge. On the other hand, low-context cultures allow more room for personal improvement and adjustment of an individual's epistemic beliefs. Such an argument is well made and could form the rationale for an empirical study that investigates whether or not epistemic beliefs are related to cultural differences using data from countries other than Turkey, Taiwan, and the USA, which are identified at the outset as having high-context and low-context cultures.

## 9.3 Diagnostic Assessment

Tam (Chap. 7: On the identification of students' misconceptions in a two-tier item) reviews the use of two-tier tests in science education and raises issues about how the data collected from these tests should be analyzed and interpreted in order to provide more useful information. The content of this chapter relates to the Taiwanese National Science Concept Learning Study in the early 2000s. One of his major concerns is that the decision to ignore less than 10 % of students selecting a particular combination of choices in reports is arbitrary and that this decision could result in students with this choice of fact and reasoning being ignored by teachers to the detriment of their education because teachers will not know about their particular views and understanding. While this is a pertinent point, I do not believe that the lost information will create any problems for teachers and students because the practicality of the classroom is that teachers cannot address all students' misconceptions or alternative ideas. Indeed while the 10 % rule was arbitrary and has been followed by many researchers, it is a practical decision to identify and accommodate the main ideas that students express that are not consistent with the science view.

On other discussion points to improve the use of two-tier tests in research studies, Tam considered collecting data in large studies using multiple booklets, the analysis of fact reason combinations by experts to identify whether or not there was any evidence of misconceptions, and the search for pattern formations among the various students responses. Each of these points is a useful issue to attend to in research using two-tier tests. Indeed, several authors have taken up these points in their research on diagnostic assessment.

During the past decade especially, there has been an increasing interest among science education researchers about more optimum ways to diagnose student learning of science concepts with two-tier tests and other variations. An outcome is a range of different diagnostic schedules. One limitation of two-tier diagnostic instruments is that students can select a second-tier response based on cues from the options in the first tier. When students respond in this way, the analytical ability of the instrument is diminished. To overcome this limitation, Loh et al. (2014) developed items with a dichotomous first tier (True-False) each followed by four choices that were different for the True or the False selection. The authors claim that this procedure provides a more robust item because it requires greater cognitive processing to answer the item correctly.

In another development, Briggs et al. (2006) used ordered multiple-choice (OMC) items which are designed to provide deeper insights into students' thinking compared to traditional multiple-choice items. OMC items are easy to analyse with each response option reflecting a particular level of understanding. OMC items not only provide information about which alternative conceptions of a scientific concept students hold, but can also help determine whether or not students are on their way toward a deeper understanding of the respective concept (Hadenfeldt et al. 2013). Students who consistently choose response options related to one level across a set of OMC items can be expected to have obtained that level of understanding (Alonzo and Steedle 2009). In another alternative approach, Liu et al. (2011) developed and used explanation multiple-choice (EMC) items to diagnose students' conceptual understanding. The first tier of the multiple-choice items was followed by a second tier with explanations and these explanations were scored in terms of knowledge integration levels being nonnormative ideas, normative ideas, or linked ideas. Using the same concepts, multiple-choice items, multiple-choice with constructed response, and the EMC, were compared.

## 9.4 Elementary Science Education

Lu and Lien (Chap. 8: Elementary science education in Taiwan: From an international comparison perspective) examined elementary science education in Taiwan compared to other countries based on recent findings from the international comparative studies Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). The high performance of Taiwanese elementary students in these tests compares well with other nations and the chapter specifically compared Taiwanese with top seven ranked countries, three of which were also in the East Asian regions, including Taiwan. Notably, Taiwanese elementary teachers are well qualified with all having a Bachelor's degree and 42 % holding a masters degree. Teachers in Finland—the standout nation since the reporting of PISA results—need a masters degree to hold a teaching position and this level of education may be a common theme across these top performing elementary students. Another notable point for me is the observation that the elementary school science textbooks are one fifth the size of those used in the USA. An explanation for this finding is that the textbooks should be an affordable price and that inquiry teaching is an expectation for science in the elementary school. Clearly, reading about science and doing science are not the same and these findings from Taiwan may be a useful indicator for improving elementary science education in the USA and other nations.

In Australia, where elementary school teachers do not have bachelor's degrees in science and few have masters degree, a different approach has been taken to improve primary science education. *Primary Connections* project, an initiative of the Australian Academy of Science is based on the 5E's inquiry approach (Bybee 1997) and is an investigative and inquiry based approach to doing and learning science. The project is aimed at all elementary school years for students aged from 5 to 12 years. The subtext of *Primary Connections* is *linking science with literacy* and the project is designed to develop students' knowledge, understanding, and skills in both science and literacy. In this way, elementary school teachers' confidence and competence for teaching science is enhanced. Digital and text resources are available and these cover biological sciences, chemical sciences, physical sciences, and earth and space sciences for each of the elementary years of schooling.

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# Part III
# Innovative Technology for Science Learning and Instruction

The positive influences on innovative technology on science learning seem no longer to be questionable in science education research. Lin and Tsai (Chap. 10) conducted a review and analysis of technology-assisted science learning studies from Taiwan. It was found that there was a shift to mobile technology in Taiwan and a predilection for quantitative and experimental research methods. Hsu and Wu (Chap. 11) developed a technology-infused learning environment to arouse students' learning motivation and cultivate their inquiry skills. They took seasons, air pollution, and water reservoirs as real-life examples to illustrate how to design technology-rich materials to facilitate students' conceptual understanding and development as independent learners. More recently, there have been new trends in conducting science education, namely EEG and eye tracking, which were widely used in psychology and neuroscience research. Liu and Huang (Chap. 12), with a particular interest in the role of brain waves, investigated how brain waves could be used in interpreting learners' cognitive learning in science. They argued that neuroscience data can provide researchers with an objective measure of science learning. If this objective measure is available for more researchers to explain how and why learners have difficulty in learning science, successful and effective instruction can be designed to facilitate our understanding of the obstacles in learning science.

Eye-tracking techniques used in science education are one of the current trends in science education. These techniques were used to depict the degree of attention in reading or other cognitive activities via the investigation of locations, durations, and number of gazes. Yen and Yang (Chap. 13) analyzed 15 articles published by scholars from Taiwan and comment that although there was limited research completed in the area of eye tracking in science education, the fruitful outcomes of eye tracking lead to new directions of explaining the fine-grain size of analysis of cognitive processing of learners.

As the last chapter of this section, Huang (Chap. 14) identifies the unexpected impact of media in science. He discusses the power the media has over people's conceptions of science. However, due to a decreasing number of researchers with science education engaged in media education, the quality of reports in the media or press makes them insufficient to guide the public.

Krajcik (Chap. 15) commented that innovative technologies and techniques facilitate teaching and learning across different science disciplines and throughout K-12. The advantages of the use of technologies have been widely recognized across the globe. However, he also caveated although innovative technologies can serve their purposes of scaffolding students' learning, the role of teachers in science class, design and development of technologies for learning, and new teaching strategies still remain prominent and necessary.

# Chapter 10
# Innovative Technology-Assisted Science Learning in Taiwan

**Tzu-Chiang Lin and Chin-Chung Tsai**

**Abstract** The utilization of technology for enhancing science learning has gradually become one of the major trends in science education. This chapter first describes the background of technology-assisted science learning research in Taiwan. Then, it reviews the journal publications of technology-assisted science learning by Taiwan researchers in the last 10 years (2003–2012). The usage of innovative technologies (such as virtual reality, mobile learning, ubiquitous learning, augmented learning, or game-based learning), research methodologies, and research topics is analyzed. With regard to the studies conducted in Taiwan during the period 2003–2012, the researchers placed more emphasis on mobile technologies to strengthen the web-based learning of science. Educational games, augmented reality (AR) technologies, and audience response systems (ARS) have gradually been utilized to support interactive learning environments. The selected studies preferred to adopt a quantitative approach with (quasi-) experimental settings in the design of their research. As for the research topics, the researchers showed major interest in the learning environment and students' motivation. The derived suggestions and potential implications for future implementations are discussed.

## 10.1 Introduction

In Taiwan, science education has been one of the most important research fields in recent decades. Researchers, stakeholders, and science teachers have together put great efforts into the development of this field in order to improve the learning of science. In particular, the science educators in Taiwan have contributed enthusiastically to the academic community worldwide, with many of their research works published in the international journals. According to previous content analysis of the literature, researchers in Taiwan have consistently published in the major journals of science education, and have started to play an important role in

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this field (Tsai and Wen 2005; Lee et al. 2009). Reports of local studies on science learning, such as conception of learning science (Tsai 2004; Tsai and Kuo 2008), students' epistemological views toward science (Tsai 2000; Tsai and Liu 2005), inquiry-based learning (Chang 1999), science concept learning (Chiu 2007), as well as motivation toward science learning (Tuan et al. 2005), have been frequently cited in educational journals of high quality. However, seeking ways to encourage meaningful learning of science may still be a major task for Taiwanese researchers in science education.

In the field of education, educational technologies have been widely accepted as powerful tools to support learning (Dillon and Gabbard 1998; Lawless and Pellegrino 2007; Lee et al. 2011). The learning process facilitated by electronic media is defined as e-learning which, to some extent, diminishes the time or location barriers in traditional learning environments (Govindasamy 2002; Wentling et al. 2000). From the cognitive perspective, e-learning provides learners with more opportunities to enhance their knowledge acquisition, higher order thinking, metacognition, and even collaboration (Shih et al. 2008). In order to reveal the positive impacts of innovative technologies in science education, researchers have also conducted studies to verify how electronic media benefit science learning. For example, Hoffman et al. (2003) developed "Artemis" to facilitate students' understanding of science through processing and managing online resources that are relevant to science learning. Linn et al. (2003) developed a web-based teaching platform "WISE" to assist learners' knowledge integration by participating in online course and learning activities. Moreover, with the aim of overcoming students' difficulties in learning abstract science concepts, Wu et al. (2001) as well as Marbach-Ad et al. (2008) applied visual tools to address learning needs through representations of the molecular-level concepts. Besides supporting learning activities, utilizing new technologies in educational settings may also allow researchers to reinspect the appropriateness of existing learning theories in e-learning.

Based on Hung's (2012) review of the academic literature on e-learning during the period 2000–2008, researchers from Taiwan participated in 10.27 % of the studies and were ranked the third most prolific country in terms of number of publications. In the recent 2 years (2011–2012), Taiwanese researchers published more papers than researchers from other countries in three influential journals regarding e-learning. The journals include *Computers & Education* (87 from 467 papers), *British Journal of Educational Technology* (39 from 197 papers), as well as *Journal of Educational Technology & Society* (67 from 199 papers). Taiwanese researchers' efforts can also be found in other important e-learning journals such as *Educational Technology Research and Development, Journal of Computer Assisted Learning*, and *Innovations in Education and Teaching International*. This provides evidence that the works of researchers in Taiwan on the one hand impacted and contributed to the academic community worldwide. On the other hand, locally conducted investigations and research findings potentially influence the practices underlying the educational system of Taiwan.

It may be due to the recent milieu of academic research in Taiwan. The Taiwanese government has consistently allocated a considerable budget to support the development of e-learning via both industrial and scholarly research (Chang et al. 2009). From the political perspective, the government supported the e-learning research for improving Taiwanese people's attitudes toward learning, developmental process of knowledge and literacy, as well as national competitiveness. This policy has attracted researchers' attention and hence reinforced their endeavors to publish their research achievements internationally. Taiwanese researchers of e-learning have broadly investigated technological learning aids such as web-based learning platforms (Chou and Liu 2005), audience response systems (ARS) (Yeh and Tao 2013), interactive whiteboards (IWB) (Yang et al. 2012), educational games (Tao et al. 2009), virtual reality (VR) and augmented reality (AR) (Chen and Tsai 2012; Yang et al. 2010), as well as mobile learning and ubiquitous learning (u-learning) technologies (Tan et al. 2007; Tsai et al. 2010). While the subject domains in the aforementioned studies are varied, it seems necessary to establish a clearer view of how these innovative technologies are applied to the science education research of Taiwan.

Content analysis of the existing literature may reveal the developmental trends and researchers' interest in a certain research field, issue, or topic. As a result, content analyses of a variety of educational fields have been conducted. For example, Tsai and Wen (2005) as well as Lee et al. (2009) analyzed the articles published in the three major journals of science education during 1998–2002 and 2003–2007. To reveal the research trends in the field of technology-based learning, Hsu et al. (2012) analyzed the papers published in five relevant journals from 2000 to 2009. To conduct a similar content analysis of existing literature regarding educational psychology, Smith et al. (2003) conducted an examination of the articles published in five major journals in the field. In the case of adult education, Taylor's (2001) study reviewed all submissions between 1989 and 1999 to a single academic journal. In order to inform the readers, of the details, of research themes in the empirical studies, these content analyses reported the applied methodologies in the studies, including the research approach (e.g., quantitative or qualitative), characteristics of participants (e.g., age, gender, or academic level), data source (e.g., questionnaire, interview, or observation), and data analysis procedure (e.g., statistical analysis or interpretative analysis). Therefore, in order to reveal the development of innovative technology-assisted science learning in Taiwan, a careful examination of the research designs of relevant studies published by Taiwanese researchers may be useful.

In addition to the variations in technologies and methodologies applied in e-learning investigations, the diversity of research also includes a variety of research topics. A previous review study regarding e-learning conducted text mining on 689 papers and categorized them into four major groups by research topic (Hung 2012). The categorization indicates that e-learning educators mainly focus on the research topics of "systems, models, and technologies," "content design and interactions," "educational studies and projects," and "e-learning application in medical education and training." Accordingly, he observed a shift in research focus "from issues of the effectiveness of e-learning to teaching and learning practices" (p. 14). Besides, in order to analyze the research topics of technology-based learning, Hsu et al. (2012) developed a 13-category framework according to the themes of some important international conferences and handbooks such as the International Conference on e-Learning (ICEL), the IEEE International Conference on Advanced Learning Technologies (ICALT), and the SAGE Handbook of e-Learning Research. The analytical findings indicate that most of the researchers in the selected studies emphasized "pedagogical design and theories" in their investigations. As for Shih et al.'s (2008) study, the researchers especially focused on cognitive studies regarding learning supported by electronic media. The analytical findings from 444 research papers indicated that the research topics in cognitive studies of e-learning embrace dimensions including "motivation," "information processing," "instructional approaches," "learning environment," "prior knowledge," "metacognition," and "cognitive psychology characteristics." Their study revealed that the three most published research topics were "learning environment," "instructional approach," and "metacognition." Even though the categorization of research topics varied in the aforementioned reviews, the revealed topics in the published studies may still reflect the academic community's preferences. From this perspective, an examination of influential literature by identifying the research topics is helpful for comprehending the recent developments in innovative technology-assisted science learning in Taiwan.

To summarize, the major purpose of this chapter is to investigate recent developments in research in Taiwan regarding e-learning in science learning. To this end, it is proposed to thoroughly examine the status of Taiwanese researchers' major publications in terms of the similarity (or difference) of applied technologies, research methodologies, and research topics. In this study, therefore, articles published within the most recent 10 years (2003–2012) by journals indexed in the Social Science Citation Index (SSCI) were identified and analyzed. Consequently, the research questions addressed in this chapter are as follows:

1. What educational technology related to science learning was applied in Taiwanese researchers' studies published in the SSCI journals in the recent 10 years (2003–2012)?
2. What methodology related to science learning was administered in Taiwanese researchers' studies published in the SSCI journals in the recent 10 years (2003–2012)?
3. What research topics related to science learning were explored in Taiwanese researchers' studies published in the SSCI journals in the recent 10 years (2003–2012)?

## 10.2 Method

### *10.2.1 Inclusion of Research Articles for Analysis*

In order to find out target articles for analysis in this chapter, we determined the criteria to define the scope of sample inclusion. First, the articles must be published by SSCI-listed journals to ensure the research quality. Second, in order to align with the exploratory purpose of the current study, the research in the articles had to be empirical and simultaneously related to e-learning and science learning. Third, the investigations had to be conducted with Taiwanese participants and published during the period 2003–2012.

According to the above criteria of article inclusion, we utilized the Web of Science database to initiate the search of valid targets on 10 July 2013. The keywords for the search included "technology," "computer," "digital," "science learning," "science education," and "Taiwan." The combinations of keywords in Table 10.1 were applied to actual exploration for proper articles. The results of the searches were compared and integrated. Any irrelevant or inappropriate articles were then manually screened out. For example, we excluded articles which did not report empirical data as well as those articles regarding nonscience learning and science teacher education. Any investigations that did not involve Taiwanese participants were also eliminated. Finally, the current study identified 17 target articles for further analysis. These articles were published in the following 9 journals: *Computers & Education, Educational Technology & Society, Innovations in Education and Teaching International, Instructional Science, Interactive Learning Environment, International Journal of Science Education, Journal of Computer Assisted Learning,* and *Science Education*.

### *10.2.2 Educational Technologies Involved*

The educational technology involved in each of the target articles was categorized into one of the following groups: (1) Off-line computer-assisted-instruction (CAI) tools, which support students' learning through software on personal computers without an Internet connection; (2) Web-based learning platforms, which enhance

**Table 10.1** The keyword combinations for article inclusion on 10 July 2013

| Keywords combinations | Results |
|---|---|
| Science learning + technology + Taiwan | 49 articles |
| Science learning + computer + Taiwan | 22 articles |
| Science learning + digital + Taiwan | 14 articles |
| Science education + technology + Taiwan | 37 articles |
| Science education + computer + Taiwan | 16 articles |
| Science education + digital + Taiwan | 10 articles |

students' learning in a designated online environment; (3) ARS, which bridges the interactions between students and teachers through immediate answering or feedback through clickers; (4) IWB, which enriches traditional teaching with multimedia and multisensory experience in presentations and derived interactions; (5) educational games, which coordinate subject content into games to make learning more enjoyable, effective, and learner-centered; (6) VR or AR, which shapes visual environments to provide learners with authentic learning experiences; (7) mobile and u-learning technology, which applies wireless technologies to support learning anywhere and at anytime; (8) other (e.g., research tool development for measuring learners' characteristics related to educational technologies). The categories were mainly adapted from the topics of interest in the ICALT conference (http://www.ask4research.info/icalt/2013/).

### *10.2.3 Research Methodologies*

The current study examined the research methods of the target articles. In the following five categories, the articles were coded in accordance with the subcategories: (1) participants, including elementary school students, high school students, undergraduate students, graduate students, and adults outside of the formal education system; (2) subject domain, including general science, biology, chemistry, earth science, and physics; (3) research approach, including quantitative approach, qualitative approach, and mixed-method approach; (4) data sources, including questionnaire/survey, test, interview, observation, and online discussions; (5) data analysis, including descriptive analysis, statistical analysis, and content analysis. Owing to certain studies' multidimensional research design feature, multiple coding was applied in the examination of research method, except for the subcategory of research approach. The frequencies of all categories and subcategories were consequently calculated.

### *10.2.4 Research Topic*

In this content analysis of e-learning literature of science education, we adapted Shih et al.'s (2008) categorization regarding cognition in e-learning to analyze the research topics in the target articles. The articles were subsequently examined with regard to the following eight categories: (1) motivation; (2) information processing; (3) instructional approaches; (4) learning environment; (5) prior knowledge; (6) metacognition; (7) cognitive psychology characteristics; and (8) learning achievement in science. The definitions of the categories with typical topics are listed as follows:

1. Motivation: Studies that investigate the fundamental variables related to learners' affective intention toward e-learning. The typical topics include attitudes, beliefs, and behavioral change.
2. Information processing: Studies that concentrate on learner's cognitive processing in the learning environment supported by technologies. The typical topics include information seeking, information management, individual difference, decision-making, problem-solving, and critical thinking.
3. Instructional approach: Studies that aim at learners' better achievement in learning by integrating technologies into instructional approaches. The typical topics include cooperative or collaborative learning, contextual or situated learning, and problem-based learning.
4. Learning environment: Studies that emphasize the specifically designed learning environments to afford learning needs. The typical topics include interactive learning environment and learning community.
5. Prior knowledge: Studies that concern the probable influences of learners' prior knowledge of technology on their learning processes and outcomes. The typical topics include technology knowledge and technology experiences.
6. Metacognition: Studies that discuss learners' self-regulated processes or derived outcomes in e-learning. The typical topics include visualization, perception and awareness, planning, as well as self-evaluation.
7. Cognitive psychology characteristics: Studies that examine learners' psychological characteristics while they are situated in an e-learning environment. The typical topics include schemata, concept maps or mental models, cognitive loads, and cognitive styles.
8. Learning achievement in science: Studies that evaluate how technologies improve learners' science learning outcomes. The typical topic is the same as the category.

It is notable that Shih et al.'s (2008) content analysis generally recruited target papers without respect to any particular domain of learning content. By contrast, the current study particularly focused on the e-learning research regarding science learning. Some research may naturally consider learning achievement in science as a principal research topic. We hence added the last category "learning achievement in science" to make the analysis more precise.

In addition, the target articles may explore more than one of the aforementioned research topics. For that reason, all research topics involved in each study were analyzed and coded. In other words, multiple coding was also allowed in this part of the content analysis of the literature. The analysis was carried out by a postdoctoral researcher. All the analytical results were further validated by a professor who specializes in science education and e-learning.

## 10.3 Usage of Innovative Technology in the Science Learning of Taiwan

### *10.3.1 Analysis of Educational Technologies Involved*

The analysis of the target articles regarding Taiwanese learners' science learning unveiled the following findings. In the most recent 10 years (2003–2012), five studies were largely involved with web-based learning platforms, while another four studies utilized mobile and u-learning technology to support science learning. Fewer studies were conducted with off-line CAI tools or educational games (two studies respectively). There is only one study that integrated ARS in the science classroom. The visualization technology of VR or AR was also applied in only one of the target articles. Other than applying technological tools in research, there are two other studies that focused more on the development of research tools for probing students' science learning in the technology-enhanced context. However, none of the articles took advantage of IWB to assist Taiwanese students' learning in science. In the preliminary search for valid target articles for further analysis, there were two articles related to IWB in science education in Taiwan (Jang 2010; Jang and Tsai 2012). These two articles were excluded thereafter owing to their focus on science teachers' professional development rather than issues of science learning. The expense and maintenance for setting-up IWB in K-12 classrooms may be a major concern to conduct relevant investigations in Taiwan. But the finding still indicates that certain research space about applying IWB in science learning was still limited.

#### 10.3.1.1 Web-Based Learning Platform

Several studies designed learning platforms with web-based technologies. For example, Hsu et al. (2003) applied a series of web-based lessons to support senior high school students' learning of earth science and biology. The web-based lessons were considered to foster students' learning in designated sections such as "data query," "constructing/testing of hypotheses," and "problem-solving." In other words, web-based learning platforms do indeed afford the integration of "daily life questions, real data, and animations that prompt students' scientific inquiry" (p. 359). Besides, Hsu et al. (2003) also indicated that access to the Internet provides more opportunities for asynchronous interactions among students and teachers. With the extra interactions in the web-based environment of science learning, students' science process skills, such as communicating, interpreting data, formulating hypotheses, and predicting may be improved.

To investigate the interactions regarding science learning in a web-based environment, Guan et al.'s (2006) study specifically aimed at senior high school students' online discussions. In a non-course-based forum, the researchers intended to shape the pattern of online discussion of physics topics relevant to the content in high school textbooks. To this end, they analyzed a group of students' discussions in an online forum of a virtual physics laboratory with moderators who supervised the in-depth interactions. In one condition, namely the R-condition, the students had to post their own opinions if they intended to see others' responses to a certain topical subject. In the other condition, namely the NR-condition, there was no requirement for reading others' responses. The findings of this study indicated that fewer participants strayed from the topical subject and socialized with each other while situated in the R-condition. By contrast, in the NR-condition, participants' responses showed more metacognitive skills. The researchers also concluded that the guidance of moderators, such as professors or teachers, in a non-course-based online forum might be critical for the quality of discussions.

In addition to the non-course-based application of web-based technologies, Jang (2006) integrated a resource website, entitled "Dream Weaving Village House," into physics courses at high school level. To support both learning and teaching, this platform provided multiple functions including supplemental materials for textbooks, a notice board, assignment submission, as well as discussion groups. The multiform assistances in a web-based learning platform may simultaneously enhance students' academic achievement and their positive attitudes toward learning science. Hung et al.'s (2012) study similarly aimed at students' achievement and motivation of science learning. The researchers introduced a web-based searching system, named "Meta-analyzer," for elementary school students participating in a project-based course. The "Meta-analyzer" system functioned as a problem-based portfolio that assisted students in collecting and storing data on the Internet for subsequent sharing and discussion. On the one hand, such a web-based platform may draw students' attention to information searching for the learning task. On the other hand, students' learning strategies and behaviors in a project-based course may be recorded as the foundation to adjust further instructional design.

Web-based learning platforms also act as multimedia carriers that afford representations of science concepts. Based on this idea, Wu and Huang's (2007) study applied the web-based software "Physlet," developed by Wolfgang Christian of Davidson College, to assist high school students in learning physics. The simulation in "Physlet" may help students visualize the unseen phenomena of physics, such as the concept of forces in real-life situations. Beyond motion picture and animations, the simulation enables students to manipulate the variables so as to examine models or hypotheses that are relevant to scientific phenomena. In comparison with teacher-centered utilization of "Physlet," Wu and Huang (2007) found that student-centered utilization improved the participants' emotional engagement in learning physics. As for academic achievement, both utilization approaches of the web-based simulation promoted Taiwanese students' conceptual learning of physics.

#### 10.3.1.2 Mobile and Ubiquitous Learning Technology

The aforementioned articles indicate that Taiwanese studies involving web-based learning platforms in science learning were mainly located in the context of schools or in computer laboratories. Whether or not for educational purposes, the recent development of mobile technologies enriches the possibility of bringing science learning outdoors. For instance, Liu et al. (2009) proposed a u-learning environment, namely “EULER,” to support science learning at a nature park. The structure of “EULER” is based on two subsystems, personal digital assistants (PDAs) as the “m-Tools” and the “MOBILE server.” The “m-Tools” mainly function as context-aware devices which read radio frequency identification (RFID) tags pre-attached to specific learning sites. With this context awareness, students may receive supplementary resources relevant to the learning sites from the “MOBILE server.” In Liu et al.’s (2009) study, the mobile and u-learning technologies assisted elementary school students’ collaborative learning at sites for crab watching and bird watching during a trip to nature park. The researchers also observed students’ improvements in learning achievement and in their positive attitudes toward learning.

With similar hardware, that is, PDAs and RFID tags, Hwang et al. (2010) established a context-aware u-learning environment to support elementary school students’ natural science observation activities. Especially, the researchers aimed at the students’ competence to classify the host plants of butterflies, a skill which is relevant to the “butterfly and ecology” unit in the fourth-grade natural science course in Taiwan. In addition to providing supplemental learning materials for students in the u-learning context, the researchers integrated a “decision-tree-oriented guidance mechanism” to recognize students’ difficulties in plant taxonomy. The u-learning system accordingly provides adaptive hints and assistance to acquaint the students with critical features of certain species of plants. Such a learning environment significantly improved the affective domain of science learning, including the perspectives of participation, motivation, and interaction. Moreover, Hsieh et al.’s (2011) consecutive study regarding “butterfly and ecology” focused on the reflection levels of students within a similar u-learning context. Based on the findings, the researchers concluded the positive effects of “matching of the learning styles with the associated teaching styles” (p. 1199) in a u-learning context.

Huang et al. (2010) also employed u-learning technologies to improve elementary school students’ learning of plant taxonomy. The researchers developed the “Mobile Plant Learning System” that works on PDAs to provide four major functions, namely “content synchronization,” “plant searching,” “plant navigation,” and “knowledge sharing.” Rather than reading pre-attached RFID tags, the study applied global positioning system (GPS) technology to construct a location-aware environment for “plant navigation.” Besides, the researchers also emphasized the “knowledge sharing” of photographs, text notations, or the physical location of plants to strengthen the function of the learning community in the u-learning environment. As Huang et al. (2010) argued, collaboration within the learning community may contribute to the students’ positive attitudes toward outdoor learning and hence improve their knowledge of botany.

#### 10.3.1.3 Off-line CAI Tool, ARS, and AR

In comparison with the outdoor science learning assisted by mobile and u-learning technologies, a variety of technologies have been applied to formal classroom settings with the aim of enhancing Taiwanese students’ science learning. Chang

(2004) developed an off-line CAI software package to support whole-class learning of earth science. The CAI software, called the "multimedia computer-aided tutorial (MCAT)," provided a large amount of earth science content information and data represented in video, graphics, animation, and sound formats. In Chang's (2004) study, the "MCAT" acted as the key for a "mixture of whole-class presentation, interactive discussions among the teacher and students, and classroom activities using MCAT software" (p. 6). Such an instruction approach can, to some extent, contribute to students' understanding of and attitudes toward earth science. Besides, Chang (2003) compared two different manners of CAI application in the earth science classroom. According to the findings of this study, students with teacher-directed CAI had significantly higher score gains than the student-controlled CAI students on the "Earth Science Achievement Test" and the "Attitudes toward Earth Science Inventory." The researcher attributed the findings to the specific classroom culture. The human interactions and discussions guided by teachers and CAI may not be fully replaced with students' self-paced learning with computers.

To address classroom interactions and discussions, Shieh's (2012) study aimed at the implementation of "Technology-Enabled Active Learning" to support small-group discussion during the instructional process of a physics classroom. In her study, classroom interactions and discussions are fully supported by the integrated ARS that enabled teachers to immediately track and assess students' individual responses to the announced questions. The findings of her study indicated that the ARS may engender greater interest on the part of the students in attending physics classes. Part of the experimental group of students became more active in participating in extracurricular science activities.

In addition to interactions among students within a technology-supported environment, Hsiao et al. (2012) specifically focused on the interactions between students and image-based technology. The researchers developed an "Ecosystems Augmented Reality Learning System (EARLS)" that integrated AR technology to support science learning. In learning the lesson of ecosystems with the "EARLS," students used gestures to interact with the AR system, such as generating reactions of real-world objects according to students' operations captured by webcams. As for the game-like learning section in "EARLS," students do physical exercises such as boxing and jumping movements to answer the questions presented on the AR screen. Compared with learning with traditional instruction and keyboard/mouse-based CAI, the students showed more positive learning attitudes toward the "usefulness of learning ecosystems" and "anxiety in learning ecosystems" in the AR environment. Besides, the students may simultaneously achieve science learning and do physical exercises, something that is usually unattainable in a formal classroom.

#### 10.3.1.4 Educational Games

In the selected articles, there are only two studies that mainly targeted the effects of educational games in science learning. Chen et al. (2010) developed an educational game "FORmosaHope" to assist students' learning of science, technology, and society using a role-play approach. For the science learning part, "FORmosaHope" made use of the life cycle of flying fish as the main theme to facilitate students' learning about ecology conservation and sustainable use in the fishery industry. Students may learn with free exploration in the gaming environment as they encounter a series of learning events based on interactions with the virtual characters. In such game-based learning, the students showed improvement in their cultural identity related to science, such as "interest in doing science activities," "usefulness of learning science", and "development of science in Taiwan."

Clark et al. (2011) conducted a cross-nation comparison of Taiwanese and American students' learning of physics with an educational game. The researchers developed a conceptually integrated 3D game, called "SURGE," to examine the connections between students' intuitive "spontaneous concepts" about kinematics and Newtonian mechanics. By learning with "SURGE," students from both countries showed great similarity in terms of positive learning outcomes and engagement. Based on the findings, the researchers also suggested that conceptually integrated games may sustain a learning environment for a variety of learners from diverse cultural backgrounds and with different levels of interest.

#### 10.3.1.5 Others

There are two other articles that focused on the development of research tools that probe students' science learning in an innovative technology-supported environment. Wu et al. (2009) developed, validated, and utilized the "Technology Integrated Classroom Inventory (TICI)" to examine secondary school students' and teachers' perceptions of technology-integrated science learning environments. By analyzing 1118 student questionnaires and 23 teacher questionnaires, the researchers revealed eight relevant scales: (1) technological enrichment; (2) inquiry learning; (3) equity and friendliness; (4) student cohesiveness; (5) understanding and encouragement; (6) competition and efficacy; (7) audiovisual environment; and (8) order. In these scales, both students and teachers ranked "equity and friendliness" as the highest. It is still notable that the Taiwanese students showed a significant actual-preferred discrepancy in all the scales. Especially, the students showed the largest actual-preferred discrepancy in classroom order of innovative technology-supported environment.

Besides, Tsai (2005) developed a questionnaire to explore students' "preferences for constructivist Internet-based science learning environments." With the investigation of 853 Taiwanese high school students, the study also revealed eight relevant scales: (1) ease of use, (2) relevance, (3) multiple sources, (4) student negotiation, (5) cognitive apprenticeship, (6) reflective thinking, (7) critical judgment, and (8) epistemological awareness. The Taiwanese students strongly preferred the "relevance" of Internet-based learning environments. In comparison with the male students, the female students particularly believed that Internet-based learning environments could help them connect scientific knowledge with real-life situations. The female students also tended to prefer to receive the guidance of the system, online experts, or experienced peers through the Internet.

## 10.4 Analysis of Methodologies

Table 10.2 illustrates the methodologies applied in the selected articles. Accordingly, more than half of the 17 studies recruited Taiwanese high school students as the target participants. The remaining studies aimed at investigating the innovative technology-assisted science learning of elementary school students in Taiwan. It is notable that these studies focused on e-learning in science learning for neither university students nor adults outside of the formal education system. Furthermore, all of the researchers of the articles involved with mobile and u-learning technology (Hsieh et al. 2011; Huang et al. 2010; Hwang et al. 2010; Liu et al. 2009) conducted their studies with elementary school students. By contrast, most of the web-based studies (Guan et al. 2006; Hsu et al. 2003; Jang 2006; Wu and Huang 2007) as well as the two studies which applied off-line CAI (Chang 2003, 2004) focused on high school students learning science.

**Table 10.2** Methodologies in Taiwanese researchers' articles on innovative technology-assisted science learning

| Methodologies | Counts |
|---|---|
| *Participants* | |
| Elementary school students | 6 |
| Junior high school students | 3 |
| Senior high school students | 8 |
| Undergraduate and graduate students | 0 |
| Adults out of formal education system | 0 |
| *Subject domain* | |
| Biology | 4 |
| Chemistry | 0 |
| Earth science | 3 |
| Physics | 5 |
| General science | 7 |
| *Research approach* | |
| Quantitative | 15 |
| Qualitative | 0 |
| Mix-method | 2 |
| *Data sources* | |
| Questionnaire/survey | 15 |
| Test | 9 |
| Interview | 6 |
| Observation | 4 |
| Online discussion | 1 |
| *Data analysis* | |
| Descriptive analysis | 17 |
| Statistical analysis | 17 |
| Content analysis | 6 |

As for the subject domain involved in the selected articles, almost half of the studies placed the emphasis on e-learning in general science. Except for the two tool-development studies (Tsai 2005; Wu et al. 2009), all of the major participants in the investigations focusing on e-learning in general science were elementary school students. However, the studies that focused on a specific subject domain (e.g., biology, physics, and earth science) all enlisted high school students as their research samples. This may be related to the Taiwanese curriculum standard that divides science subject domains from the high school level.

It seems that the researchers of the selected articles showed greater interest in students' learning of ecology and relevant issues. The studies involving u-learning and AR (Hsiao et al. 2012; Hsieh et al. 2011; Huang et al. 2010; Hwang et al. 2010; Liu et al. 2009), all focused on the major concepts of ecology. Ecological issues such as "global warming" (Hung et al. 2012), "debris flow" (Chang 2003, 2004), and "conservation" (Chen et al. 2010) were also emphasized. With regard to physics learning, the concept of forces and motions is frequently addressed by investigations involving varied technologies, including ARS (Shieh 2012), educational games (Clark et al. 2011), and web-based learning environments (Wu and Huang 2007).

The findings listed in Table 10.2 also indicate that most of the studies adopted a quantitative approach in their research designs. Owing to this approach, these studies mainly applied questionnaires/surveys to explore certain learning characteristics. Tests for science knowledge were used to measure students' academic achievement. Some of the quantitative studies (e.g., Huang et al. 2010; Hung et al. 2012) claimed to have extra data sources to use in a more interpretative manner, such as interviews or observations. However, in quantitative studies, such data were mostly deemed as supplemental or minor evidence. Only two studies adopted a mixed-method approach (Jang 2006; Wu and Huang 2007) and presented the research findings in a more interpretative manner. Beyond the research approach, more than half of the selected articles adopted an experimental or quasi-experimental setting in their research designs. This implies that Taiwanese researchers of e-learning in science learning mainly intended to test their hypotheses regarding specific treatments, that is, the innovative technologies involved.

## 10.5 Analysis of Research topics

The results of the analysis of research topics of the selected articles are shown in Table 10.3. In terms of the popular research topics, the Taiwanese educators expressed particular interest in "motivation" and "learning environment" of technology-supported science learning. Especially, the researchers paid considerable attention to the combination of the research topics "attitude" and "interactive learning environment." For instance, the aforementioned studies of Huang et al. (2010) and Liu et al. (2009) highlighted students' positive attitudes toward learning in a u-learning environment. Students also showed less anxiety regarding learning ecology with the integration of AR technology (Hsiao et al. 2012). The interactive learning environment enhanced by "MCAT" in Chang's (2004) study was found to significantly improve students' overall attitudes toward earth science.

More than half of the selected studies regarded students' "learning achievement in science" as one of the most important research outcomes. Most of these studies applied examinations in a paper-and-pencil form to evaluate students' learning achievement of science knowledge. There are two studies, however, which utilized the "Force Concept Inventory" adapted from Hestenes et al. (1992) to explore

**Table 10.3** Research topics in Taiwanese researchers' articles on innovative technology-assisted science learning

| Research topics | Counts |
|---|---|
| *Motivation* | 15 |
| Attitudes | 12 |
| Beliefs | 3 |
| Behavioral change | 2 |
| *Information processing* | 6 |
| Information seeking | 1 |
| Information management | 1 |
| Individual difference | 1 |
| Decision-making | 1 |
| Problem-solving | 3 |
| Critical thinking | 1 |
| *Instructional approach* | 6 |
| Cooperative or collaborative learning | 4 |
| Contextual or situated learning | 2 |
| Problem-based learning | 1 |
| *Learning environment* | 14 |
| Interactive learning environment | 13 |
| Learning community | 1 |
| *Prior knowledge* | 1 |
| Technology knowledge | 1 |
| Technology experience | 1 |
| *Metacognition* | 4 |
| Visualization | 0 |
| Perception and awareness | 2 |
| Planning | 0 |
| Self-evaluation | 2 |
| *Cognitive psychology characteristics* | 2 |
| Schemata | 0 |
| Concept map or mental model | 0 |
| Cognitive load | 0 |
| Cognitive style | 2 |
| *Learning achievement in science* | 10 |

students' conceptual understanding of Newtonian mechanics (Shieh 2012; Clark et al. 2011). Moreover, Hsu et al. (2003) considered science process skills as the major learning achievement in science and hence applied a test for measuring such competence.

In addition, some Taiwanese researchers placed emphasis on students' higher level thinking skills in learning science with technological supports. For example, Wu and Huang (2007) analyzed students' engagement in making in-depth reflections on what they had done in the technology-enhanced learning activities. Hsieh et al.'s (2011) study explored the participants' reflection levels in u-learning to reveal how elementary school students self-evaluate their learning in a technology-enhanced environment. Guan et al.'s (2006) content analysis of students' online discussion may in part unveil the patterns of the participants' problem-solving and critical thinking in a web-based community for learning purposes.

Fewer studies paid attention to learners' "cognitive psychology characteristics" while learning with innovative technologies. Hsieh et al. (2011) investigated students' learning styles in a u-learning environment. Wu and Huang (2007) explored students' styles of cognitive engagement while situated in diverse types of technology-enhanced classrooms (e.g., teacher-centered and student-centered classrooms). Furthermore, there is only one study (Hsu et al. 2003) that measured students' "prior knowledge" of technology. Their findings indicated that high school students in Taiwan are quick learners in technology-enhanced learning environments. Only a few participants required guidance for Internet access, graphing, and information searching.

## 10.6 Final Remarks

This chapter presents a series of content analyses of studies on innovative technology-assisted science learning in Taiwan. In order to clearly summarize the possible trends in this research field, Fig. 10.1 presents a summary of the selected studies published within the last decade (2003–2012). This overview indicates an obvious shift in technological application in supporting science learning. The existing research relies more on mobile technologies to strengthen "traditional" web-based learning. Enjoyable technologies, such as games, AR, and ARS, are gradually being applied in interactive e-learning environments that were formerly supported by CAI tools with plenty of multimedia contents. Taking a quantitative approach in a (quasi-)experimental setting is the most frequently adopted research method in these investigations for the period from 2003 to 2007. In the respective 5-year-periods, for example, 2003–2007 and 2008–2012, the researchers similarly showed great interest in affective perspectives, learning environment development, as well as academic achievement of technology-assisted science learning.

According to the conclusions revealed in Fig. 10.1, this chapter provides the following suggestions regarding possible directions for future research. Science educators in Taiwan may try to identify further potential for innovative technology to

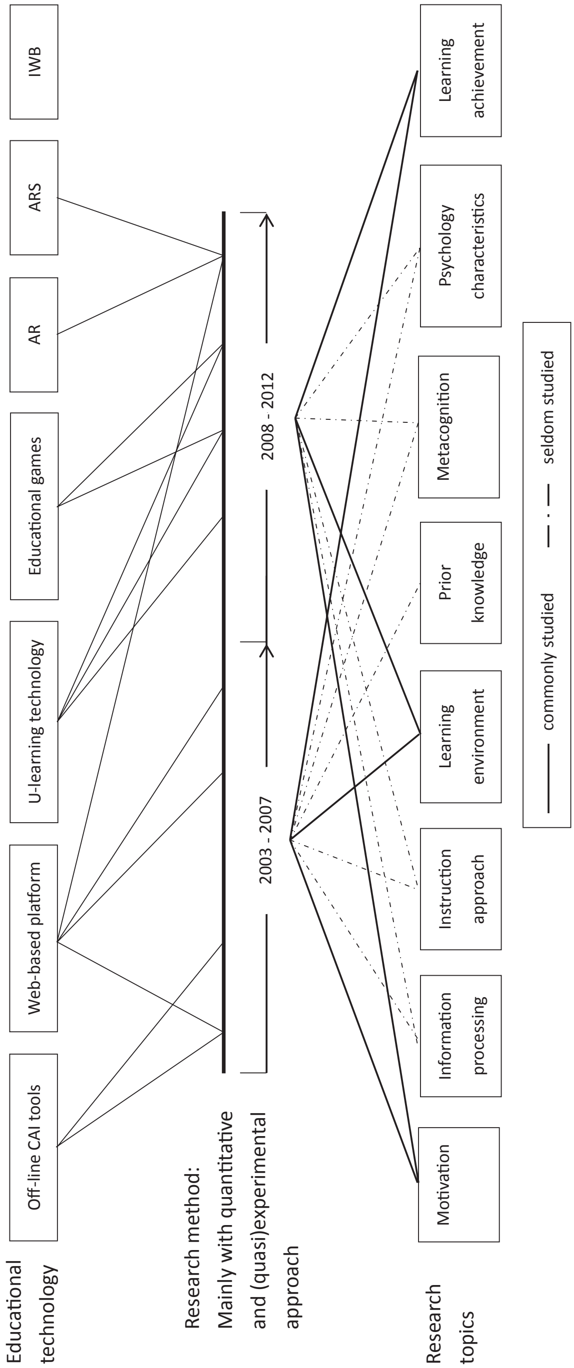


**Fig. 10.1** An overview of the innovative technology-assisted science learning in Taiwan during 2003–2007 and 2008–2012

support science learning, such as combining "location-based" AR technologies and u-learning environments to enhance students' interactive experiences in scientific inquiry (Cheng and Tsai 2013). We also recommend that Taiwanese researchers apply qualitative approaches more often in technology-assisted learning research so as to create extra research space and data sources, while the innovative technologies may potentially record more details of learners' processes of learning. As suggested by Shih et al. (2008), the applications of technological tools or databases can enable researchers' further interpretations of log files, discourse, or other forms of interaction. To this end, analytical approaches, such as social networking analysis (Martinez et al. 2003), text mining (Dringus and Ellis 2005), eye-tracking analysis (Tsai et al. 2012), as well as behavioral sequential analysis (Hou 2012), may be useful for representing Taiwanese students' technology-assisted science learning. Finally, more emphasis may be placed on learners' characteristics besides motivation toward science learning with technologies. For instance, future studies may focus on the sharing, construction, and creation of science knowledge in CSCL environments (van Aalst 2009; Suther 2006) to shed light on learners' features in collaborative learning contexts supported by innovative technologies.

The reviewed innovative technologies regarding science learning in this chapter also provide insights for practices of instruction. Successful experiences in the reported studies may, to some extent, support science teachers' adaption of innovative technologies in teaching. From such perspective, this chapter may also reflect science teachers' competence that is necessary to guide students' e-learning. With the long-term impact, the issue is especially important to science teacher education. This would encourage in-service science teachers' reconsideration and adjustment of instructional design to afford students' learning needs in the current era. Moreover, science teacher educators have to carefully consider the necessity to prepare preservice teachers' sophisticated knowledge and to foster them successfully facing challenges in the future career.

This chapter has reviewed the recent innovative technologies in the science learning of Taiwan, and indicated certain research directions for the future. However, based on the possible reason that there were fewer studies regarding both e-learning and science learning in the field of science education, the number of selected articles is limited. Moreover, to ensure the quality of the reviewed articles, preliminary studies reported in the latest conferences or non-SSCI-listed or local journals were excluded. In spite of these limitations, this chapter does indeed depict the trends and the potential of Taiwanese educators' endeavors in the contemporary field of technology-assisted learning in science education.

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# Chapter 11
# Development and Evaluation of Technology-Infused Learning Environments in Taiwan

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The purpose of this chapter is to present how the technology-infused learning environment (TILE) research team in Taiwan developed and evaluated innovative learning environments for science education. The three environments presented in this chapter cover important scientific topics and involve real-life issues such as the seasons, air pollution, and water reservoirs. These learning environments aim at facilitating students' conceptual understanding, cultivating their inquiry abilities, and contributing to the goal of developing independent learners. To achieve these goals, the features of these environments include: (1) helping students visualize scientific concepts and principles to enhance their conceptual understanding; (2) providing multiple linked representations and web-based sharing tools to promote sharing and communication; and (3) integrating innovative and advanced technologies that enable teachers to utilize digital resources and support students in conducting authentic scientific investigations. In the past 5 years, multiple sources of data were collected to evaluate the effectiveness of these environments, and the results suggest that by providing well-designed features, TILEs could support students' engagement in authentic inquiry and demonstration of desirable learning practices.

## 11.1 Background

Teaching and learning with technologies become widespread around the world and continue to change with a variety of technologies. Taking the USA as an example, at least one computer was available in 97% of its classrooms in 2009 (Gray et al. 2010). The fever about pursuing electronic classrooms has spread to develop-

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ing countries. Zhang (2007) reported that governments of most eastern countries launched projects or reforms in classrooms since 2000 to infuse information and communication technologies (ICT). The Ministry of Education in Taiwan provided funding to enact the policy of "at least one computer in every classroom" in 1996 and announced the Blueprint of Information Education in Elementary and Junior High Schools (Ministry of Education 2008) to strengthen students' technology literacy. However, even though there has been, since then, a significant increase in the number of computers in schools in Taiwan, teaching with technologies still needs quality educational applications and well-designed learning environments. Effective use of technology in classrooms requires well-designed computer applications as well as a change in instructional approaches (Windschitl and Sahl 2002). Therefore, we proposed design principles for developing theory-based TILEs that integrate the use of multimedia tools into instruction and support the development of students' conceptual understanding, modeling practices, and decision-making (DM) strategies.

## 11.2 Design Principles of Technology-Infused Learning Environments

### *11.2.1 Visualizing Scientific Concepts and Principles*

One important goal of science education is to help students develop understanding of scientific concepts and principles. However, some students' difficulties in conceptual learning have been attributed to the invisible and imperceptible nature of scientific phenomena and entities (Wu and Shah 2004). For example, atoms and molecules cannot be directly observed or touched, and although students can see the phases of the moon, they are not able to observe how the moon moves around the earth or how the earth goes around the sun. Thus, to support students' conceptual learning, the first design principle of our learning environments is to help students visualize scientific concepts and principles by exploiting the potential of technologies (Rutten et al. 2012).

Two visualization approaches were taken when we designed our learning environments. First, technologies such as animations can integrate virtual objects to represent the invisible scientific entities and demonstrate the behaviors of entities to reveal the concepts and principles underlying a scientific phenomenon. For example, an animation of a chemical reaction allows students to observe how molecules move at the microscopic level and how chemical bonds are formed and broken (Chiu and Wu 2009). As will be presented later, the design of SeasonSim used a series of animations to support students' visualization of the concepts of seasonal change. A second approach is embedding scientific variables and models into simulations and learning environments. When exploring the simulations and manipulating the variables, students can observe the simulated results, establish relationships between variables, and construct understandings of scientific concepts and models.

An Air Pollution Modeling Environment (APoME), which will be presented later, was developed by taking this approach.

### *11.2.2 Embedding Multiple Representations*

The representations of learning materials (e.g., texts, tables, figures, and visualizations) act as a synergistic way of promoting scientific learning. When the learning module displays knowledge with a synergy of multiple representations (MRs), students can receive support from multiple and co-occurring forms of curricular supports (McNeill and Krajcik 2009; Tabak 2004). In addition, the synergy of MRs supports diverse learners within changing task demands and their growing abilities, skills, and background knowledge in a classroom. It is important that synergistic representations align with a defined learning goal and meet students' needs. Instructional designers should assess students' prior knowledge and then set up a proper learning goal for them. Based on the learning goal, designers can then select several representations to display knowledge and organize it structurally and synergistically. Using more than one representation can possibly capture a student's interest and promote efficacy of learning (Ainsworth 1999). For instance, MR simulations embedded in a situated learning environment can provide an authentic task for students to explore a particular phenomenon. Empirical studies have shown that the use of MRs, story-based animations, and discipline-integrated themes facilitates students' understanding of the correspondence between abstract symbolic expressions and real-world situations (Hsu 2006).

Sometimes, however, when several representations are presented simultaneously, students could feel frustrated due to information overload (de Jong 2010). Therefore, some researchers have suggested introducing MRs sequentially rather than simultaneously (Ploetzner et al. 1999; Verdi et al. 1997; Wu and Puntambekar 2012). The sequence of representations is critical for learning particular concepts. The representation sequences could affect the foci of students' explanations and shape their perceptions of the representations, suggesting an interplay among representation sequences, spatial ability, and students' understandings (Wu et al. 2013a). The results of empirical studies provide insights into the design and arrangement of MRs for science learning.

### *11.2.3 Integrating Technology into Scientific Investigation*

Scientific investigations are an essential part of scientific inquiry, and engaging students in inquiry is one of the current efforts of science education reform in Taiwan (Ministry of Education 1999). However, some scientific investigations are too dangerous, take a very long time, or are costly, and so cannot be easily conducted by students in traditional laboratories. Technologies can address these challenges (Edelson et al. 1999) and provide an engaging environment for students to explore their ideas.

Previous research has indicated that integrating technology into scientific investigations can provide access to information, structure the investigation process with strategic support, and control the complexity of the process (Quintana et al. 2004). Therefore, when designing technology in the learning environments, we provided a database for the students to analyze data and generate interpretations (see an example in the Jing-Si Reservoir module), decompose and structure a modeling process in APoME, and manage the complexity of an investigation by supporting their identification and examination of the major variables in a system (SeasonSim).

## 11.3 Summary of Empirical Studies

We present three innovative learning environments which aim at facilitating students' conceptual understanding and cultivating their inquiry abilities, including the seasons, air pollution, and water reservoirs.

### *11.3.1 Technology-Infused Learning Environments for Conceptual Change*

We have designed a technology-infused learning module to help students develop their conceptions of seasons through inquiry-based learning. First, we designed instruments (e.g., concept mapping, two-tier assessment, and interviews) to diagnose students' alternative conceptions of the causes of seasonal change. Then, based on the identified patterns of the students' alternative conceptions, we developed an online course and examined how their conceptions changed. Second, we refined the online course and traced the students' conceptual change in different instructional phases. Finally, we embedded metacognitive scaffolding into the online course and explored the students' inquiry abilities in such a learning environment. A series of studies we conducted attempted to demonstrate how we elaborated technology-infused learning modules to promote students' conceptual change, inquiry abilities, and metacognition. The major findings from these studies are described as follows.

A simulation, SeasonSim (see Fig. 11.1), was developed to help students visualize scientific concepts and principles to enhance their conceptual understanding. SeasonSim provides multiple linked representations such as animations and graphs for students to explore the concept of the seasons. Following a Technology-Enhanced Learning (TEL) model which includes five cognitive phases, that is contextualization, sense-making, exploration, modeling, and application (see Fig. 11.2, Hsu et al. 2008) , Lesson Seasons, which includes a series of online learning activities, was designed to engage students in scientific inquiry processes and to help them bridge the gap between their real-world experiences and the simulated scientific model.

These learning activities integrate innovative technologies that utilize digital resources and support students in conducting authentic scientific investigations; that

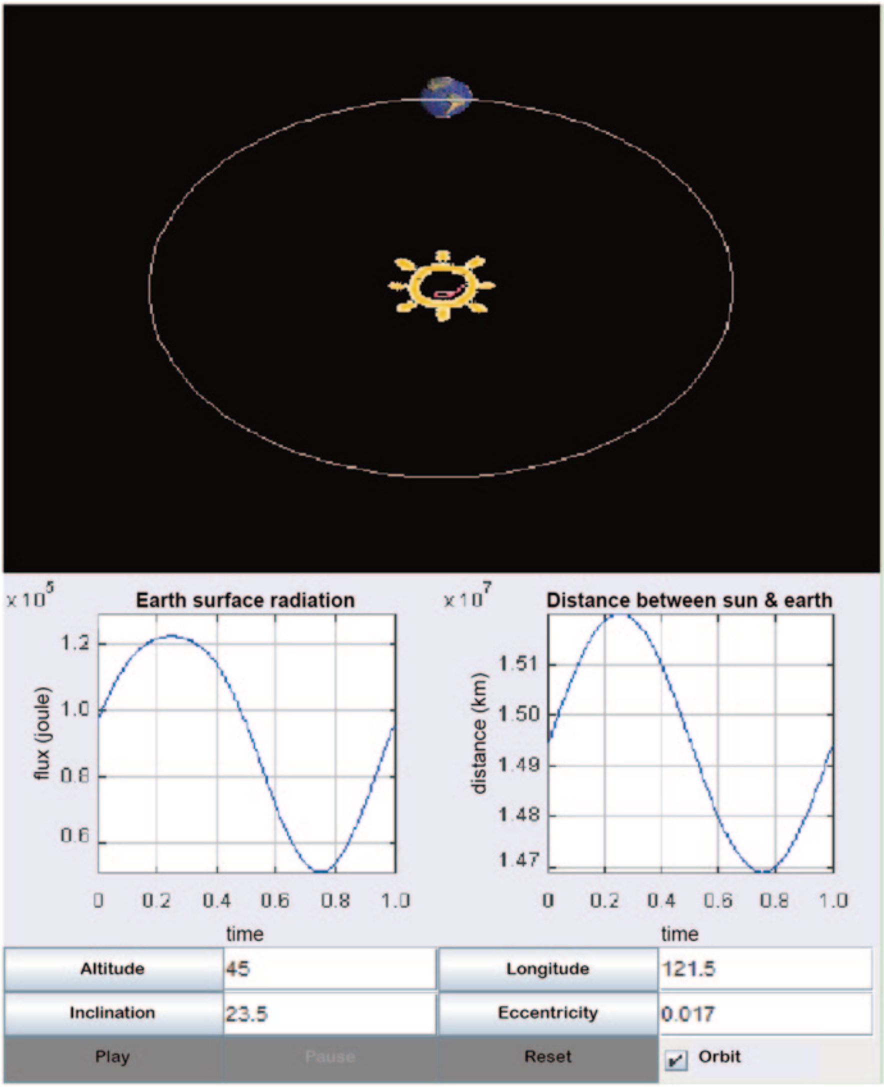



**Fig. 11.1** A screenshot of SeasonSim

is, modeling the concept of the seasons. First, the photos of natural scenes from around the world during different seasons help to promote students' contextualization of the phenomenon of the four seasons (see Fig. 11.3). Second, a series of animations which present possible reasons for the seasons helps students visualize the scientific concepts embedded in this phenomenon. The students are given questions which guide them to "make sense of" the problem as to why the Earth has four seasons (see Fig. 11.4). Third, a computer simulation called SeasonSim provides the variables related to seasons, such as latitude, longitude, the tilted angle of the earth's axis, and eccentricity (see Fig. 11.1). Students can change these variables to

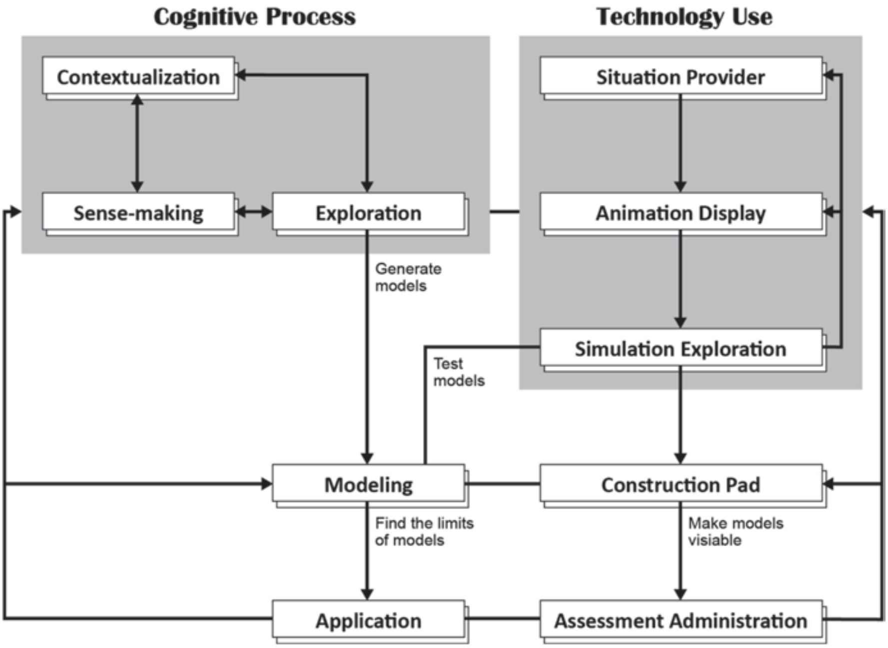



**Fig. 11.2** Framework of the *Technology-Enhanced Learning Model* (Hsu et al. 2008)

**Fig. 11.3** The animation with photos for contextualization


test their hypotheses and reconstruct or build a model to explain seasonal change. Fourth, students are required to draw concept maps on an online construction pad to show their ideas about seasons after exploring the computer simulation (see Fig. 11.5). Finally, students are asked to explain how the seasons on Mars change on an online forum which helps them to apply their model in a new situation, verify the accuracy of their model, and discover its possible limitations (see Fig. 11.6). This web-based sharing tool is used to promote students' sharing and communica-

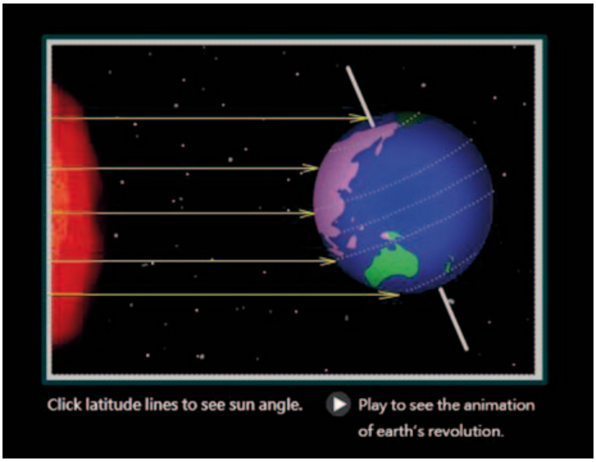



**Fig. 11.4** A series of animations for sense-making

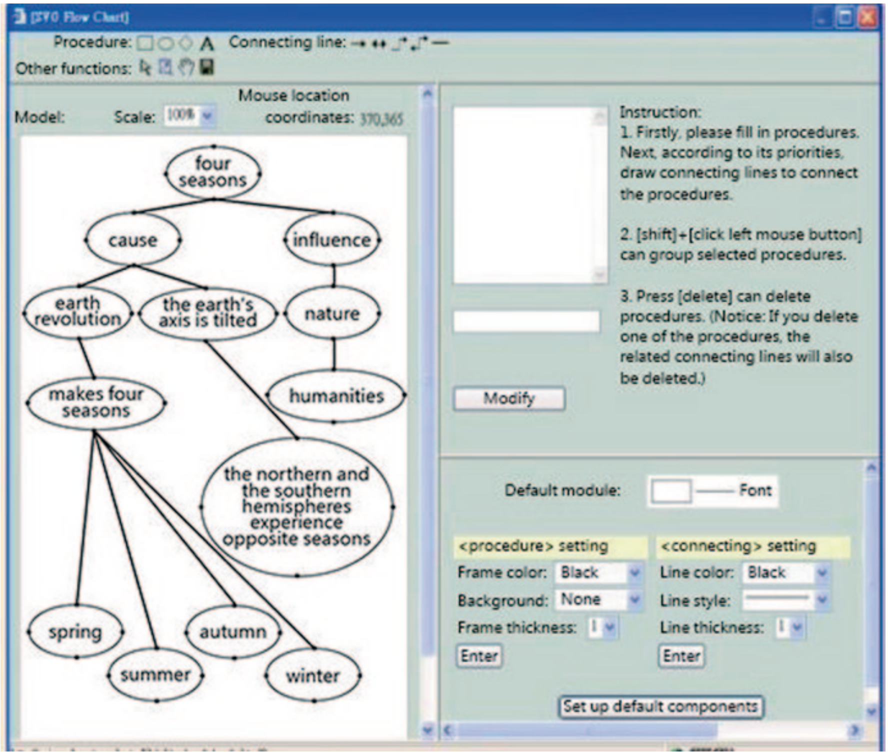



**Fig. 11.5** Concept mapping tool

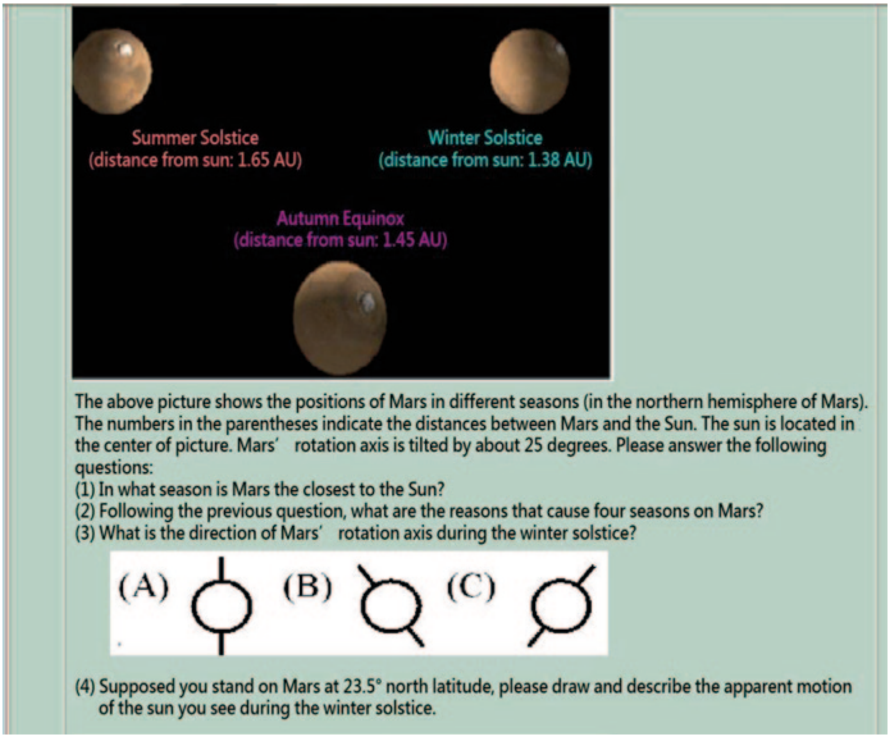



**Fig. 11.6** A new situation for students to apply their model

tion. Through communication, students have a chance to develop their multiple perspectives on seasons.

*Study 1: Conceptual change after technology-infused learning*

After developing an online course based on the TEL model, 75 high school students participated in this study, and multiple sources of data were collected to investigate their conceptual understandings and the interactions between the design of the environment and the students' alternative conceptions (shown in the appendix). The findings show that the number of alternative conceptions was reduced, except for the incorrect concepts of "the length of sunshine" and "the distance between the sun and the earth." The percentage of partial explanations was also reduced from 60.5 to 55.3 %, while the percentage of those students holding complete scientific explanations after using Lesson Seasons rose from 2.6 to 15.8 %. Some students succeeded in modeling their science concepts closely to the expert's, but others failed to do so after the intervention. The unsuccessful students who could not remediate their alternative conceptions possibly did not benefit from the explicit guidance and scaffolding provided by the teacher and the instructional design (Hsu et al. 2008).

*Study 2: A comparison study of teacher-guided and student-centered approaches*

In order to explore the ways in which teacher-guided (TG) and student-centered (SC) instructional approaches influence students' conceptual understanding of the seasons, we refined the online course, Lesson Seasons, to compare the learning outcomes of two groups of students: a TG class (with whole-class presentations) and an SC class (with individual online learning). The TG approach emphasized whole-class presentations and step-by-step demonstrations of animations and of SeasonSim using an LCD projector and a computer. Two classes of second-year senior high school students (not science majors) in Taiwan were assigned to the TG and SC groups.

Before the intervention, the students took part in a training activity on concept-mapping skills and the use of computer interfaces in the online lesson. They were then required to complete their pre-concept maps, which were used to make clear the patterns of their alternative conceptions. As Fig. 11.7 shows, the students completed the learning materials designed to achieve the cognitive goals of contextualization and sense-making in stage I (Intuitive Understanding Stage), and then they drew their mid-concept maps. In stage II (Relation Construction Stage), they were guided to explore, or on their own initiative explored, the problem as to why the Earth undergoes seasonal change. At this stage they received a new "situation" requiring them to explain how the seasons change on Mars; then they were asked to draw their post-concept maps. In total, this took 12 h of class time.

Overall, the results showed that most students developed a deep and accessible understanding of the reasons for the change of seasons after experiencing the TEL course. More importantly, it was found that, in this technologically enhanced environment, the SC approach was more effective than the TG approach in altering students' alternative conceptions of the seasons ($F=28.05$, $p<0.001$). The conceptual evolution of students in the two groups was plotted and compared. These plots indicated that, first of all, the cognitive processes of contextualization and sense-making helped the students reexamine their old ideas about the phenomena, leading them to generate alternative conceptions and undergo both positive and negative conceptual change. Positive changes (in the direction of the correct scientific explanation) were facilitated by the computer simulation-based exploration and modeling, guiding the students to make both incremental changes and wholesale changes (Hsu 2008).

*Study 3: Embedded metacognitive scaffolding*

Based on previous research results, we considered the complexity of exploring the cause of seasonal change. Therefore, metacognitive scaffolding was embedded into the online course to understand how such metacognitive scaffolding helps students develop their scientific inquiry and metacognition. We investigated students' metacognitive behaviors (i.e., planning, monitoring, and evaluating) that were aroused by the scaffolding during their scientific inquiry tasks.

A mixed-method approach was used to explore the effects of metacognitive scaffolding on students' scientific inquiry practices and metacognition. Two junior high school classes participated in this study in which one class was randomly selected as the experimental group ($n=26$), which took an inquiry-based online course with metacognitive scaffolding, and was compared to the other class, the comparison group ($n=25$), which took the same inquiry-based online course without metacognitive scaffolding. Data sources included a test of inquiry abilities, a questionnaire of metacognition, worksheets, and computer log files. A specific student in the experimental group was purposefully identified as the target for an in-depth case study.

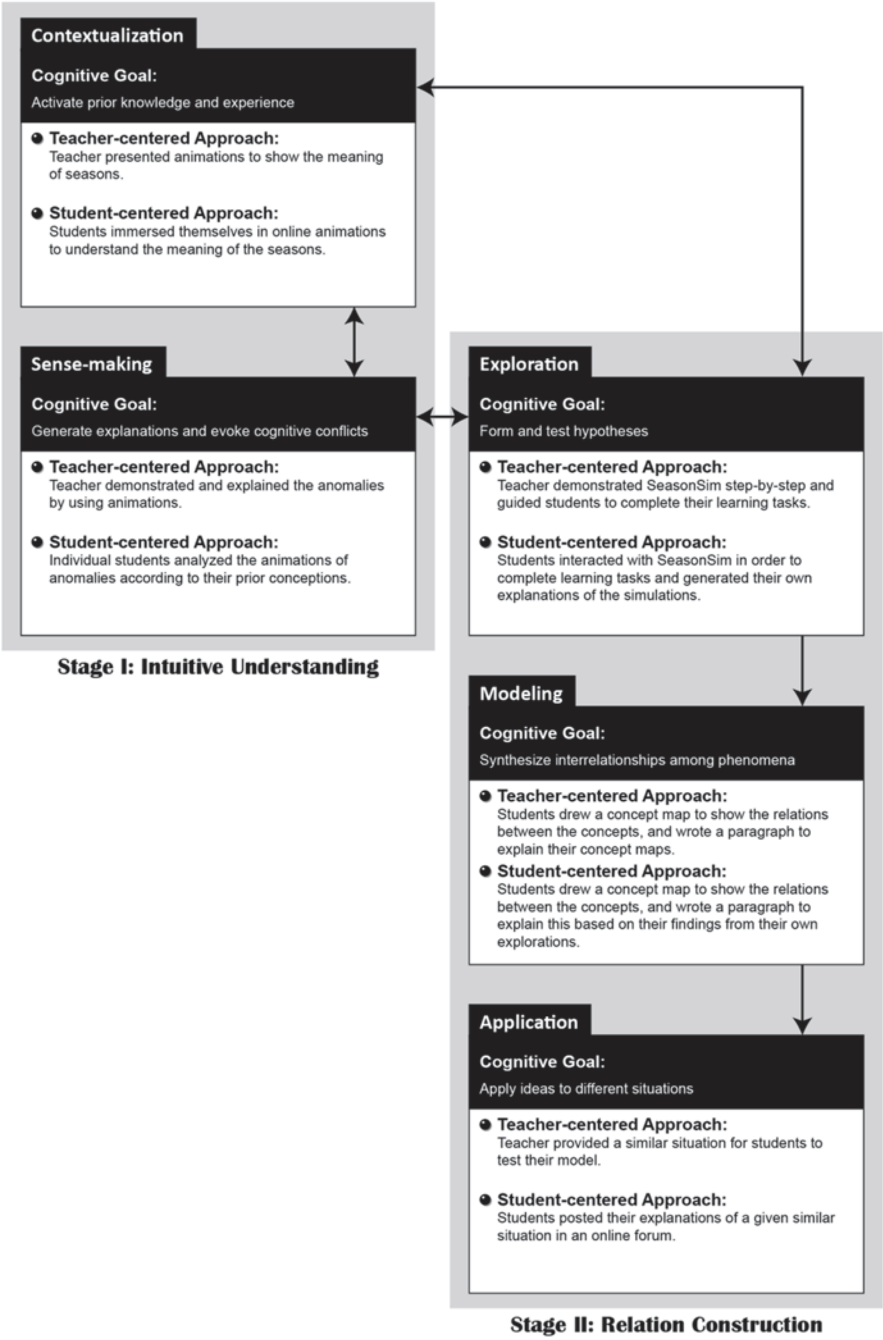



**Fig. 11.7** Summary of the activities and cognitive goals of the different instructional approaches

The quantitative results showed that metacognitive scaffolding had significant impacts on the students' inquiry practices, especially their planning abilities. Furthermore, the metacognitive scaffolding appeared to have a differential effect on students with lower level metacognition, as this group showed significant improvements in their inquiry abilities, reducing the gap that originally existed between them and the group with higher level metacognition. The case study student demonstrated that his self-monitoring strategies were improved after he received a series of metacognitive scaffolding instructions. This study suggests that science curricula should provide metacognitive scaffolding throughout the inquiry cycles to evoke and promote students' metacognition and inquiry practices (Zhang et al. 2015).

This series of studies showed how we incorporate visualization tools based on the guidelines of the TEL model we proposed. These research experiences are very valuable for researchers in science education. We strongly suggest that a series of follow-up studies be conducted to deepen the understanding of one specific and important topic whenever more research questions arise from a study.

### *11.3.2 Technology-Infused Learning Environments for Modeling: APoME*

Modeling is an essential part of inquiry learning (National Research Council 2011) and air pollution is an important environmental issue in Taiwan. To support students' modeling practices and contextualize learning in real-life situations, an APoME was developed to help students construct a systematic view of air quality (Wu 2010).

To structure the modeling process, the modeling tool decomposed the process into four modes: Build (Fig. 11.8), Test (Fig. 11.9), Apply, and Case. In Build mode, the Advance Organizer (Fig. 11.8) could help students identify and connect major variables that influence air pollutant dispersion. Students had to choose major variables from those provided, establish relationships among the variables, and create a model. They could then move to Test mode (Fig. 11.9) in which they could examine the relationships and test their model about how a variable might affect air pollution dispersion. This mode allowed students to select one variable from the list while others were controlled, input a variable value, and run a simulation. After running simulations, students concluded their observations in the Data Explanation box and compared their conclusions with the relationships built in Advance Organizer.

Similar to Test mode, Apply mode was also designed for students to manipulate variables, visualize simulated results, and describe their findings. However, Apply mode allowed students to change more than one variable each time, thus supporting more sophisticated modeling practices, such as multivariable reasoning (Wu et al. 2013b). In this mode, the students could integrate what they had learned about the effects of individual variables in Test mode and observe possible interactions among variables. Finally, Case mode offered five cases of pollutant dispersion. After choosing a case, students could employ their models to make predictions about the case, run simulations, and compare the simulated results to their predictions. This mode was designed to help the students generalize their conclusions and

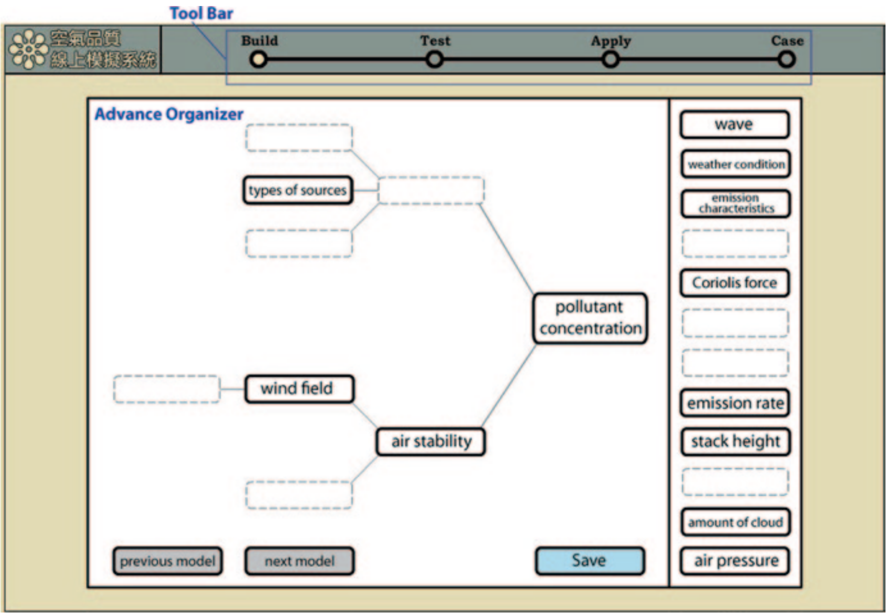



**Fig. 11.8** Interface of Build mode in the modeling tool

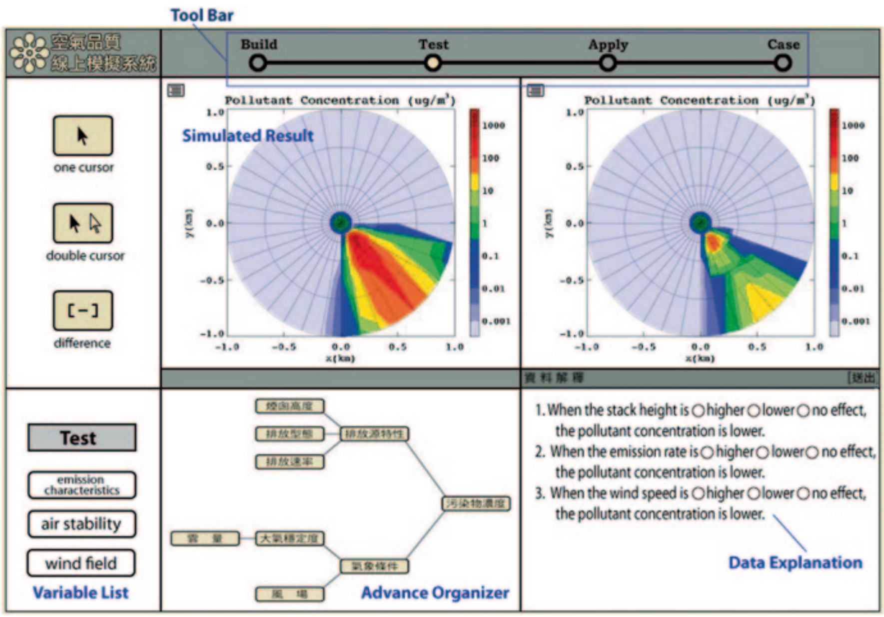



**Fig. 11.9** Interface of Test mode in the modeling tool

apply their models and concepts learned to different cases. Wu et al. (2010) provide more details about the design of the modeling tool.

*Study 1: High school students' modeling practices*

Our first implementation study of APoME examined students' conceptual understandings and modeling practices using the tool (Wu 2010). One teacher and 29 tenth graders from a public school in Taipei participated in the study. Multiple sources of data were collected including pre- and post-tests of concepts, classroom observations (class videos), video recordings of students' use of the modeling tool (process videos), worksheets, and interview transcripts.

The test data were analyzed using SPSS 11.0. We took several steps to analyze the qualitative data (Erickson 1998). We transcribed interviews and video recordings into text format. Each class period was segmented into episodes that maintained a coherent interaction pattern among class members. We coded the transcripts based upon a scheme that contained five categories of modeling practices: making a plan, identifying variables, establishing relationships, applying the model, and evaluating the model. We then reviewed the coded transcripts, generated analytical notes, and searched for assertions about students' modeling practices. Assertions were validated by confirming evidence from the data corpus.

The study showed that students' understandings of air quality were significantly improved after they engaged in the modeling activities in APoME. A paired two-sample *t*-test showed a significant difference between the pre- and post-tests ($t=3.32$, $p=0.004<0.01$). The item analysis indicates that while the students did not show improvement on the items involving factual knowledge (e.g., sources of air pollution and types of pollutants), they performed significantly better on items that required them to explain the formation mechanism of air pollutants, predict atmospheric stability under different weather conditions, and describe how vertical temperature structure affects air pollutant dispersion. This suggests that after completing these activities, these tenth graders developed substantial understandings of air quality.

In terms of the students' modeling practices, analyses of the qualitative data showed that the students became aware of possible errors in their plans and revised them to avoid the errors. After the activities, they were able to identify more major variables relevant to air pollutant dispersion, clearly define these variables, and describe their impact on air pollutant dispersion. During the interviews, the students carefully controlled and manipulated variables to test their model, applied their model in new cases, and explained why their model did or did not work. These findings suggest that APoME is effective in supporting students' demonstration of expert-like modeling practices.

*Study 2: Affordances of the modeling tool*

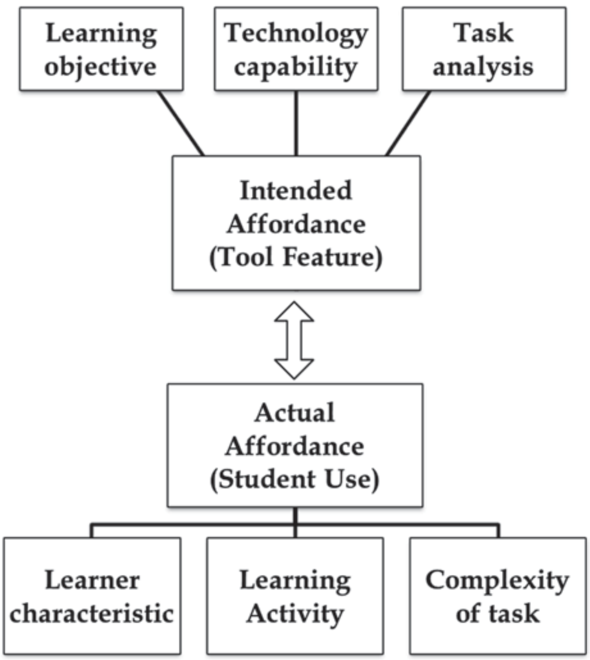
To further examine how the tool supported scientific modeling, we conducted another study to explore the relationship between the designed features of a modeling tool and students' actual modeling practices. To investigate the relationship, in Wu et al. (in press), we conducted an affordance analysis and defined two types of affordances: intended and actual affordances. The affordance analysis from a learner's perspective could help researchers and developers to validate and realize the design of learning technologies (Dalgarno and Lee 2010). In TILEs, it is usually assumed that learners can perceive the existence of the design features and use these features in desirable ways. However, a gap between what the tool features are designed to offer (intended affordances) and how they are actually used (actual affordances) may exist (White 2008). Therefore, in this study we explored how students' enactment of modeling practices interacts with their use of the designed features.

A total of 23 tenth-grade students (10 males and 13 females) from a public high school in Taipei participated in the study, and engaged in 16 h of learning activities with APoME. To analyze the participants' modeling process and their use of the tool, multiple sources of data were collected in the activities, including video and computer activity recordings. We conducted a detailed analysis of the video recordings of these modeling activities. We focused on how modeling practices (i.e., building, testing, and analyzing practices) were enacted with the use of the tool's features (e.g., Variable List and Screen Shot).

Through a close examination of the students' use of the modeling tool, the findings indicated varying gaps between the intended and actual affordances. While some design features such as Variable List and Testing Variables were perceived as being useful by the students and successfully afforded their enactment of building and analyzing practices, others, including Screen Shot and Edit, were rarely used or were not utilized in desirable ways.

The study also suggested that other factors may be involved in determining the intended and actual affordances (Fig. 11.10). Through a task analysis, tool features (intended affordances) were designed intentionally to exploit the capabilities of

**Fig. 11.10** The affordance analysis scheme of intended and actual affordances



computer simulations and to support students' achievement of the learning objectives. However, whether these features actually afforded students' modeling practices seemed to depend on the learners' characteristics, the design of the learning activities, and the complexity of the tasks. For instance, the findings of students' testing practices suggest that learner characteristics, such as prior knowledge and capabilities, should be taken into account. Although the students perceived the intended affordances, they may not have been able to execute the actions due to a lack of knowledge and skills. Also, in this study, the students did not test multivariable relationships in Apply mode as we expected. One explanation for this finding may be because of the complexity and difficulty of simultaneously controlling and manipulating multiple variables (Wu 2010), even though the students perceived the existence of the design features and were able to use them.

Taken together, the findings indicated that the distinction between actual and intended affordances is useful for instructional design, because rather than focusing only on the design of tool features, it also takes other relevant factors into account. The realization of intended affordances may involve factors of learners' characteristics, the nature of learning activities, and the complexity of tasks, and constructs an affordance analysis scheme to inform the design of computer-based learning tools.

### *11.3.3 Technology-Infused Learning Environments for Decision-Making in Socio-Scientific Issue Contexts*

The DM learning module designed for cultivating students' DM and justification used a socio-scientific issue (SSI) context related to building a water reservoir. Such a context involves geographic, geological, biological, and socioeconomic information about the area and society, and is a mediator of students' DM in SSIs that influences students' procedures, sources, and rationales for collecting evidence, generating DM criteria and making post-activity decisions (Lee and Grace 2012). Therefore, we believed that the issue of "where to build a dam" was an interesting and compelling problem space. The design of the learning module incorporated a DM framework to promote the efficacy of student DM (Zeidler et al. 2003). The evidence-based three-phase process was chosen as the DM framework for the learning module: recognizing the decision problem, differentiation, and post-decision consolidation (Svenson 1996).

As Fig. 11.11 shows, one training activity (Activity 1) was used to focus on prerequisite ability before the DM activity. Activity 1, a 1-h whole group lesson, was to model DM strategies for students. This training activity had the teacher demonstrate how to choose an appropriate bicycle, considering biking path conditions and a limited budget, by applying DM strategies. After introducing three different DM strategies (cutoffs, scoring, and weighting), the teacher guided a whole-class discussion about the pros and cons of these DM strategies, and when and how they might be better adopted.

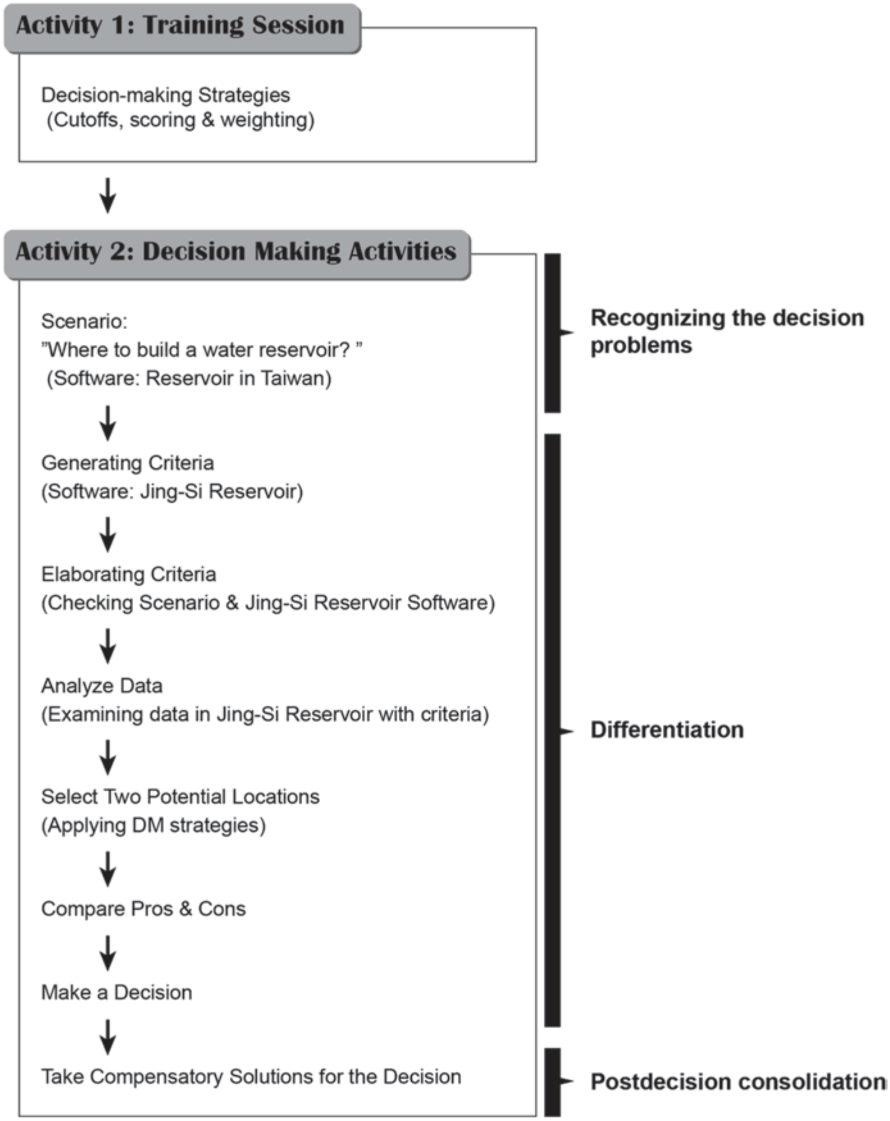



**Fig. 11.11** Framework of a learning module for DM in an SSI context

After the training activity, Activity 2 (the DM activity), which consisted of 3 h of small group work with a custom-designed software package, was designed following the DM framework, that is, recognizing the decision problem, differentiation, and post-decision consolidation. In the phase of recognizing the decision problem, the information about the functionalities of reservoirs and possible impacts on the environment after building was provided to the students. The students were required to synthesize the common conditions of building a reservoir considering the as-

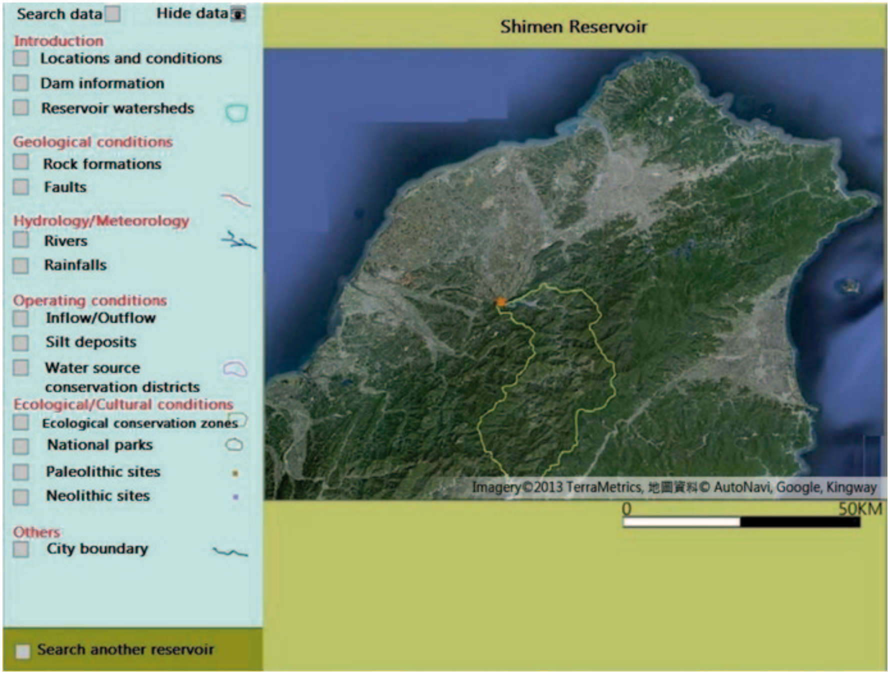



**Fig. 11.12** A screenshot of the "Reservoirs in Taiwan" software. (The copyright of the map belongs to Google)

pects of geology, meteorology, ecology, population, distribution of factories, and cultural heritage. Then, a visualization tool called "Reservoirs in Taiwan" (as shown in Fig. 11.12), which was embedded with the information of two water reservoirs in northern Taiwan, was used to help the students understand the conditions of building a water reservoir on a river. They could recognize the factors related to the decision problem, "where to build a water reservoir" using this tool. A worksheet guided the students to generate the criteria for their decision about the problem. The role of the software tool was to allow the students to visualize the information and to restrict the complex information within a manageable range.

In the differentiation phase, the students were engaged in the context of deciding where to build Jing-Si Reservoir with the aid of the visualization tool, "Jing-Si Reservoir" (see Fig. 11.13). The tool allowed the students to search for and evaluate the data regarding six locations along a river. They refined the criteria they had generated after browsing the Jing-Si Reservoir tool. Then, they analyzed and evaluated the data of the six locations based on their criteria and chose two potential candidate building sites. After careful evaluation of these two sites, they made a decision on which location would be the best choice, and discussed its impact on future water resources and the surrounding environments.

The interface of the "Jing-Si Reservoir" tool includes several main functions, namely Tips, About reservoirs, Data center, and Simulation (as shown in Fig. 11.13,


**Fig. 11.13** A screenshot of the "Jing-Si Reservoir" software

an actual screen capture). The students could find the necessary information on how to use the tool in the "Tips" interface, and look for relevant information on the construction costs of reservoirs, calculations of water supplies based on rainfall, and the geological conditions of the river and catchment area in the "About reservoirs" interface. The "Data center" interface allows students to query the data of the six locations and to judge which location is suitable to build a reservoir based on their own criteria. The students were required to organize the data they found in the tool into the worksheet which guided them to reason based on the data. After choosing a location for the reservoir, the students could use the "Simulation" interface to see a 3D bird's-eye view of the water cover area after building a reservoir at the chosen location, which helped them to evaluate the impact of their decision. The learning activities we designed along with the visualization tool guided the students to learn how to select suitable data as evidence, make judgments, reason based on evidence, apply DM strategies, and evaluate their decisions based on their own criteria.

Finally, the post-decision consolidation phase guided the students to ensure the decision they made was the most appropriate through sharing their decision and justifications with peers and writing the compensatory solutions for their decision from a reflective point of view.

The Wilcoxon Signed Ranks Test was used to compare the scores of the pre-test and post-test in DM abilities. The overall result showed that students' abilities of generating criteria ($Z=-2.75$, $p=0.006$), collecting data ($Z=-4.51$, $p<0.001$), analyzing alternatives ($Z=-2.12$, $p=0.034$), and using DM strategies ($Z=-3.99$, $p<0.001$) were all significantly improved after this DM learning module.

The empirical result indicated that visualization tools (the “Reservoirs in Taiwan” tool and the “Jing-Si Reservoir” tool) help students visualize data and scaffold their evidence use and DM. Also, the multiple linked representations provided in these two visualization tools facilitate students’ application of their DM strategies in an SSI context. Overall, integrating innovative and advanced technologies enables teachers to utilize digital resources and support students in making scientific decisions for complex SSIs.

## 11.4 Summaries from Empirical Studies

The findings from empirical studies provide insights on teaching and learning in technology-infused environments as following.

1. SC approach is more effective than the TG approach in altering students’ alternative conceptions through contextualization and sense-making to connect prior experiences, and through exploration and modeling to develop conceptual understanding in technology-infused environments.
2. Metacognitive scaffolding throughout inquiry cycles has significant impacts on students’ inquiry with technologies. Especially, students with lower metacognition could show significant improvements in inquiry abilities.
3. Even though students perceive the design features of simulations, the affordance of simulations in testing multivariable relationships still depends on the learners’ characteristics, the complexity and difficulty of simultaneously controlling and manipulating multiple variables.
4. Integrating a DM framework into innovative and advanced technologies supports students in making scientific decisions for complex SSIs.

## 11.5 Implications and Conclusions

This chapter presents how the TILE research team developed and evaluated innovative learning environments for science education. Our series of studies have shown that by applying design principles to the TILEs science learning can be promoted. Effective designs of such learning environments require an emphasis on visualizing scientific concepts and principles, embedding MRs, and integrating technology into scientific investigation. Multiple cycles of trials and refinements not only elaborate designs of TILEs but also provide insights into principles for guiding future designers and science education researchers. The major benefits of TILEs are that they facilitate students’ construction of their understanding of important science concepts, support the development of expert-like modeling practices, and scaffold students in making scientific decisions regarding complex SSIs.

However, there were some challenges when we implemented TILEs in Taiwanese classrooms. First, although the TILEs provided students with positive and engaging learning experiences, some students could not clarify and revise their alternative conceptions without the teachers' guidance and scaffolding. It is suggested that we should give students as much scaffolding as they need in a TILE to promote their conceptual understandings and modeling practices. Second, some teachers did not implement the learning modules as the way we designed the environments. They need pedagogical supports in order to create an effective TILE. Teacher education programs need to help teachers learn how to enrich curricula and assist students' learning with appropriate uses of technology. Therefore, one research direction we are taking in recent years is to develop and evaluate science teachers' technological pedagogical content knowledge (TPACK). Through a careful examination of teachers' TPACK and an effective teacher learning program, we hope to support more teachers to implement TILEs in classrooms and to have impact on students' science learning.

## Appendix

Alternative conceptions of the cause of seasonal change

| Mental model | Types of alternative conception |
|---|---|
| *No concept* | *1. No conception* |
| *Phenomenal* | *2. Pre-experience of phenomena* |
| | 2-1. The sun is covered by clouds |
| | 2-2. The moon absorbs the radiation of the sun |
| | 2-3. The tides and ocean flows |
| | 2-4. The planetary wind systems and air pressure |
| | *3. Facing toward or away from the sun* |
| | *4. The duration of the sun's irradiation of the earth* |
| | 4-1. The change in the sun's radiation |
| | 4-2. The length of day and night |
| | 4-3. The duration of sunshine in the northern and southern hemispheres due to the tilt of the earth's axis |
| *Assimilatory* | *5. The tilt of the earth's axis causes the change in earth–sun distance and/or sunshine area* |
| | 5-1. The angle of the earth's tilt changes during revolution around the sun |
| | 5-2. The tilt of the earth's axis means some locations on the earth are close to the sun and some are far away from the sun |
| | 5-3. The "sunshine area" in the northern hemisphere is bigger than that in the southern hemisphere because of the earth's tilt |
| | *6. It is winter at the aphelion and summer at the perihelion in the northern hemisphere* |
| *Scientific* | |
| | *7. Partial explanations* |
| | *8. Complete scientific explanations* |

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# Chapter 12
# Innovative Science Educational Neuroscience: Strategies for Engaging Brain Waves in Science Education Research

**Chia-Ju Liu and Chin-Fei Huang**

**Abstract** Science educational neuroscience is a new discipline that integrates science education, psychology, and biological processes. The potential of science educational neuroscience is to bridge the gap of research trends, methodologies, and applications between science education and neuroscience, and to translate research challenges into opportunities. In this area, researchers combine science education and the fundamental techniques of cognitive neuroscience such as electroencephalograms (EEG), event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI) to provide specific and objective suggestions to science learners, educators, and curriculum designers. In recent years, a lot of educational neuroscience researchers have focused on students' cognitive abilities and emotions by analyzing neuroscience data. However, few studies have highlighted students' science learning abilities and strategies by engaging neuroscience. Furthermore, the orientations of methodology, data analysis, and philosophy differ between science education and neuroscience. Although there are many research challenges to face, there are some studies that provide practical implications for engaging neuroscience in science education.

## 12.1 Introduction

Over the past decade, the interest in brain research has been growing in science education (Huang et al 2014; Liu et al 2015). An increasing amount of evidence from brain research has been applied in the explanation of science educational research, such as the research of Liu and Chang (2014). Furthermore, the findings from neuroscience research provide many insights into teaching and learning. This chapter introduces the "innovative research idea" of science educational neuroscience, the innovative research approach of science educational neuroscience, the applications of science educational neuroscience, and the implications and suggestions for learning and teaching.

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Before discussing the idea of science educational neuroscience, the limitations of the mind, brain, and education need to be clarified in this chapter. In 1966, Soviet philosopher Evald Ilyenkov claimed that the brain does not think, but a human being thinks with the help of his/her brain. He mentioned that the brain is an operational mechanism and that the mind controls that mechanism actively. David Bakhurst (2008) published a paper in the *Journal of Philosophy of Education* in which he discussed the philosophical views on the mind and the brain, indicating the importance of personal potential.

> ….First, my mental states are unified because they are all states of a particular person, me. Second, they are unified in that they express my orientation to the world, which comprises both a conception of how the world is and commitments to change the world in various ways through action…. (Bakhurst 2008, p. 422)

Combining these points of view through 1966 to 2008, the brain can be considered to be a biological machine, with the human mind seen as its operator. On the surface, it seems that the operator (the human mind) is more important than the machine (the human brain) in actual practice (educational practice). In reality, an operator could not operate a machine well without understanding its characteristics and limitations. For education, although the general teaching or learning strategies could help some students' learning, they could not improve all students' studying since each brain is unique. In view of this, Evald Ilyenkov suggested that the purpose of education is to improve every student's potential, but not to try to train their brains. David Bakhurst also mentioned the importance of adaptive development. Some talented or gifted students have inborn advantages of brain functions which allow them to learn well, and educators and teachers need to help them to develop their potential.

To help students to learn actively and to develop their own potential is one of the most important aims of education. In actual learning, students' minds could be seen as operators and their brains as machines. If we want to teach someone to operate a machine well, we need to thoroughly understand the characteristics and limitations of the machine. In other words, the characteristics and limitations of the human brain play a significant role in learning and teaching. That is the reason why we need to bridge the gap between neuroscience research and science education research, such that the linkage of these two domains will bring new insights regarding the practice of science education.

## 12.2 The Innovative Research Idea of Science Educational Neuroscience

The idea of bridging education and neuroscience can be traced back to the 1990s. In 1997, Bruer encouraged researchers from the two different domains of neuroscience and education to enter into a dialogue. However, at that time, Bruer felt that the distance between these two domains was too great. Byrnes (2001) also commented in 1994, the beginning of the application of brain research in education, that he did not believe that the results from neuroscience could reflect the reality of physiology and education. Thus, the idea of linking neuroscience and education arose in the 1990s, but the gap between the two was seen to be too great at that time.

From 1990 until now, many researchers have devoted their time to bridge this gap between neuroscience and education and achieved excellent results (Bakhurst 2008; Howard-Jones 2008; Prudy and Morrison 2009; Mason 2009; Willingham 2009; Coch and Ansari 2009; Carew and Magsamen 2010; Baker et al. 2012). Byrnes (2001) argued that the results from neuroscience could not reflect the reality of physiology and education was wrong. He found that many important theories of psychology and education, such as attention, memory, emotions, and reading comprehension, could be supported or judged from the evidence of neuroscience. Therefore, he wrote a book, "Minds, Brains, and Learning: Understanding the Psychological and Educational Relevance of Neuroscientific Research," that supports the importance of the linkage between neuroscience and education, and he also agreed that the psychology and education domains need to engage in neuroscience research. Purdy and Morrison (2009) and Baker et al. (2012) also argued that brain-based learning packages needed to be considered in school learning. It seems that the idea of educational neuroscience was gradually gaining emphasis.

From 2001 to 2014, there were 625 Taiwan theses and dissertations related to neuroscience and education (the data were collected from the System of National Digital Library of Theses and Dissertations in Taiwan). Although educational neuroscience was developing in these few years, Mason suggested that researchers needed to consider other educational phenomena and, in this chapter, we will focus on discussing the domain of science education. Science education is more concerned with engaging science contents and processing, and the branch of science learning needs students to use a lot of specific cognitive skills. Take the definition of 2D chemical structural formulas as an example; students need to memorize the chemical elements and the rules of chemical structures, and use their imagination and spatial ability to rotate the chemical structural formulas in their mind; then they can identify the 2D chemical structural formulas well (Huang and Liu 2013). In contrast, this ability of mental rotation is not used in learning Chinese or history, for example. Hence, the characteristics of science education and science learning are unique in the field of education.

Some cognitive processing of science learning depends on the brain's function and limitations. The example of the identification of chemical structural formulas shows that students need to use their spatial and mental rotation abilities to complete the task. Although such abilities could be trained, those talented and gifted students with innate spatial abilities should not be ignored (Liu et al , 2014b; Huang et al 2014; Liu et al 2015). Moreover, how these gifted students use their abilities to identify chemical structural formulas might be important reference material to use in training other students. In this case, the understanding of cognitive processing in students' science learning requires greater emphasis, and the engagement of neuroscience is a better way to help us to fully understand cognitive processing.

In this chapter, we suggest the innovative research idea of science educational neuroscience. Researchers do not need to understand all of the functions of the brain; neither do they need to carry out neuroscience research right now. What we suggest though is that researchers in the science education field could start to read the important findings of neuroscience and try to engage those findings in their science education research. We believe that the findings from neuroscience would provide many insights into science education research.

## 12.3 The Innovative Research Approach of Science Educational Neuroscience

The commonly used research approaches used in science education can be divided into quantitative and qualitative approaches (Liu et al , 2014a; Huang et al 2014). In the quantitative research approach, questionnaires and tests are used most, the data from which are analyzed statistically. In the qualitative research approach, open-ended questionnaires and interviews are commonly used. The data from open-ended questionnaires are often scored by experts in the corresponding fields, and the scores are also analyzed statistically. The interview data are generally tape-recorded and then transcribed verbatim. The contents of the verbatim text are then coded according to the theoretical framework adopted by the researchers. Of course, if the researchers want to use grounded theory, the contents of the verbatim text will be categorized without expectations and be used to form the basis of the theory. The advantage of quantitative research is that it could collect huge amounts of data in a short time, and trends can be identified by analyzing these statistical data. On the other hand, the advantage of qualitative research is that it can collect detailed data which reflect individual differences. These two research approaches are complementary in science education research. Hence, an increasing amount of research in science education adopts mixed research methods to interpret the findings.

In this chapter, we agree that the quantitative and qualitative research approaches both need to be used in science education research. Moreover, we suggest that the neuroscience research approach is also worth engaging in science education research. The neuroscience research approach could collect individual brain activities and transfer these activities into statistical data. In other words, neuroscience data could be quantitatively analyzed with the detailed data from individuals. Further, the results of brain activity analysis will be additional evidence to interpret the findings of science education research. Based on this idea, we suggest that the innovative research approach of science educational neuroscience might combine the commonly used quantitative and qualitative research approaches, while also adding the neuroscience research approach.

The instruments of the quantitative research approach could collect the data that reflect the participants' choices after they make decisions. On the other hand, the instruments of the qualitative research approach could help us to understand why the participants decided to choose a specific answer. In this section, the key point is to emphasize the introduction of the neuroscience research approach.

The most commonly used neuroscience technologies in exploring students' learning are electroencephalograms (EEG), event-related potentials (ERPs), and functional magnetic resonance imaging (fMRI). EEG and ERPs are the procedures to measure the electrical activity in the cerebral cortex when a person carries out

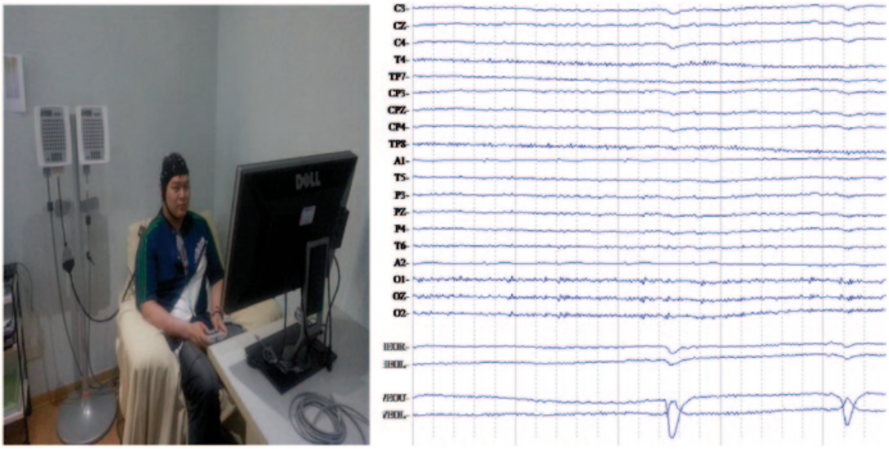

**Fig. 12.1** The **a** procedure and **b** the raw data of EEG and ERPs

a task, and fMRI is the procedure to detect the location of electrical activity in the brain. Furthermore, the EEG methodology involves collecting the participants' normal biology responses when not performing cognitive tasks, such as opening and closing their eyes. On the other hand, the ERPs methodology is to collect the participants' specialized responses when doing assigned cognitive tasks, such as remembering or mental rotation. To sum up, the procedures and raw data are similar in the EEG and ERPs methodologies (Fig. 12.1), but the treatments of the two methodologies differ.

In the EEG or ERPs procedures, the participants need to wear an electrode cap (commercial electro-cap, Electro-Cap International, Eaton, OH) on their head before performing a set task (Fig. 12.1a). There are many kinds of Electro-Cap used in EEG or ERPs experiments; the most commonly used are 36 channel, 128 channel, and 256 channel. In educational research, we recommend that the 36 channel Electro-Cap is sufficient to collect the data of human cognitive processing. Figure 12.2 shows the assigned symbols, numbers, and locations on the Electro-Cap. The

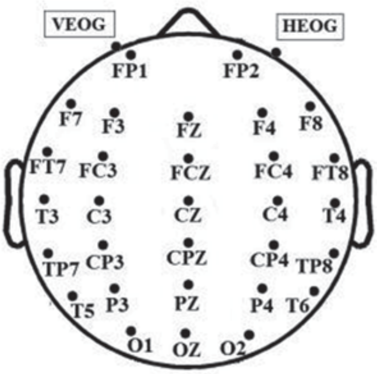


**Fig. 12.2** The electrode sites of the electrode cap

HEOR and HEOL indicate the horizontal electro-oculogram (EOG), and the VEOU and VEOL data record the vertical EOG. The data from these four electrodes could help to adjust the brain wave by excising the effect of the tremble from the muscles around the eyes when the subject reads the tasks on the computer screen or blinks. The other EEG raw data are shown as serial symbols and numbers in Fig. 12.2, such as C3, CZ, C4, etc. These symbols and numbers follow the 10–20 international system. For example, the symbol "F" is located in the frontal lobe of the brain area, the odd numbers (1, 3, 5, and 7) are located in the left brain hemisphere, and the even numbers (2, 4, 6, and 8) are located in the right brain hemisphere.

Although the EEG and ERPs technologies could show the brain areas where the data are located in the brain, fMRI has higher location resolution of the brain areas than EEG and ERPs. On the other hand, the EEG and ERPs have higher time resolutions of cognitive processing than fMRI. EEG, ERPs, and fMRI each have their strengths and weaknesses, but EEG and ERPs are more commonly used because of their cheaper price and greater convenience compared with fMRI.

The cerebral cortex is one of the most important structures in the human brain. It deals with the transferring and presenting of the processing of consciousness, sense perception signals, and actions. The EEG and ERPs technologies could collect the electrical activity from the cerebral cortex of the whole brain, and the results could reflect what kind of cognitive abilities the participants used in completing the cognitive tasks. In identifying the EEG and ERPs data from the cerebral cortex, the researchers need to consider where these data are located in the brain areas since the different brain areas respond to different functions (Fig. 12.3).

In Fig. 12.3, the four brain areas of the cerebral cortex respond to different cognitive functions. Table 12.1 shows a brief categorization. We must remind the readers that Table 12.1 is a simple classification, and that they need to read specialized books and journal papers to thoroughly understand the theories of the human brain and cognitive processing.

The electrical activity from the cerebral cortex in different brain areas could provide biological evidence to help researchers infer participants' cognitive processing. We suggest that science researchers should reference the findings from neuroscience and combine the results from quantitative and qualitative research methods to create an innovative research approach of science educational neuroscience. This would provide more integrated annotations than adopting the single research methods for interpreting the findings of science education.

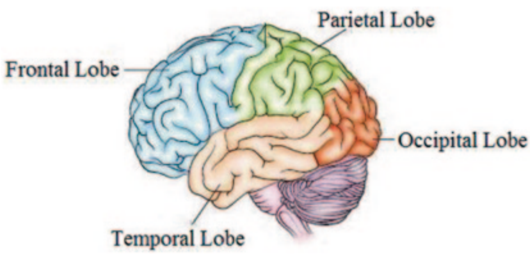


**Fig. 12.3** The four brain areas of the cerebral cortex

**Table 12.1** The corresponding brain areas and cognitive functions

| Brain areas | Cognitive functions | Education applications (examples) |
|---|---|---|
| Frontal lobe | Specialized verbal or reading abilities, memory, attention, emotions, reasoning | Reading skills, reading strategies, learning motivation |
| Parietal lobe | Memory, attention and mathematics abilities | Learning attention, number sense, mathematics problem solving |
| Occipital lobe | Visual processing, working memory about spatial abilities | Spatial abilities about chemistry, physics or mathematics |
| Temporal lobe | Auditory processing, emotions, working memory | Emotions about learning, verbal abilities about learning |

## 12.4 The Applications of Science Educational Neuroscience

In recent years, researchers have strived to apply the findings from neuroscience to interpret the phenomena of science learning and science education, with interesting results.

### *12.4.1 Emotion and Scientific Creativity*

In the science education research domain, Petty and Cacioppo (1986) found that positive emotions improve a person's scientific creativity, but there are no statistically significant differences between scientific creativity and negative emotion. However, the study findings from George and Zhou (2002) indicated that negative emotions could improve students' performance of scientific creativity. In 2006, Filipowicz performed similar research and suggested that students' performance of scientific creativity is affected by positive emotion in some cases and by negative emotion in others. Why are the results of these studies so different? The first concern in these studies might be: "Do these students really experience the assigned emotions before they exhibit scientific creativity?" In studies on emotion, it is not in fact possible for the researchers to be certain of the participants' emotions at the time of performing the set tasks. We could let the participants self-report their emotions, but how can we confirm the reliability and validity of their self-reports? We can never be certain of the participants' real emotions at the exact moment of testing. To overcome this difficult situation, Huang et al. (2008) used the EEG methodology to detect the participants' emotions throughout the testing. They chose 30 pictures from the international affective pictures system (IAPS) to induce the participants' affect. Of these 30 pictures, 10 were designed to elicit positive emotions, 10 were to elicit negative emotions, and 10 were neutral in that they did not reflect any emotion (Fig. 12.4). Each participant needed to take part in the three affect experiments individually while wearing an electrode cap to collect the EEG data. After the participants took part in one affect experiment, they completed a questionnaire

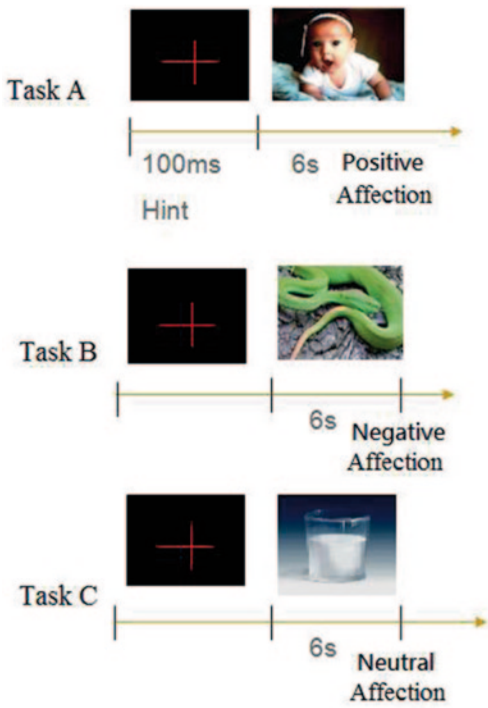


**Fig. 12.4** Examples of pictures from IAPS (Huang et al. 2008)

of scientific creativity. Hence, the participants needed to complete three scientific creativity questionnaires which had similar validity, reliability, and consistency. The participants were asked to take a rest between each of the three experiments. The EEG data could ascertain whether the participants did indeed show the assigned emotions. If they did not show the assigned emotions, the data would be rejected.

The results from Huang et al.'s study indicated that scientific creativity will show greater improvement when positive and negative emotions are being experienced than when feeling neutral emotions (Fig. 12.5). They also found that students' performance of scientific creativity is better with negative than with positive emotion. The findings from Huang et al.'s study supported the results of Filipowicz's study.

It could be questioned, since the IAPS is a reliable instrument to induce participants' emotions, why researchers need to use it in combination with EEG methodology. The reason is that researchers need to seek more meticulous and detailed data in science education research. Although the IAPS has higher reliability than other instruments in inducing participants' emotions, individual differences still exist. Take Fig. 12.4 as an example; the second picture is a snake. Of course, most people will feel fear while viewing a picture of a snake, and that fear would be a negative emotion. However, there are always those people who may feel excited when they see a picture of a snake, which would be a positive emotion. With neuroscience research, we can reject the exceptional cases and command the variables well, thus making the findings and results more reliable and powerful.

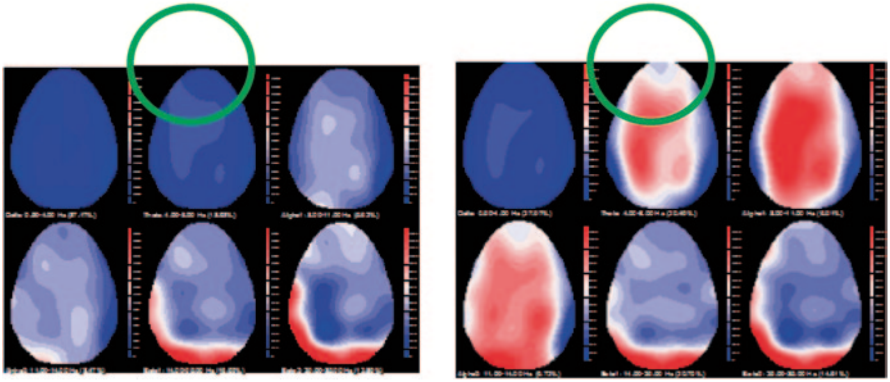

**Fig. 12.5** An example of EEG data with emotional reflection: **a** *left* figures: neutral emotion; **b** *right* figures: positive emotion (Huang et al. 2008)

Based on the results of emotions and scientific creativity, further research on affect will be discussed. Many studies have indicated that some students fear facing traditional written tests; therefore, they have tried to help these students to overcome their negative affect by testing them by computer. The next section will discuss neuroscience research on affect and computer-based learning.

### *12.4.2 Affect and Computer-Based Learning*

Self-assessment is an important issue in the evaluation of students' learning in the computer-based learning field. Based on the immediate responses of computer-based learning, affective reflection has been added to computerized self-assessment to promote students' learning motivation in the recent few years (Cassady and Gridley 2005; Economides 2009; Nicol and Macfarlane-Dick 2006).

In order to promote students' positive emotion in computerized self-assessment, Moridis and Economides (2012) adopted applause as an achievement-based reward in a test. The results of their study indicated that the male students performed better in the test with applause than without, but there was no significant difference for the female students.

In the case of this study, there could be two reasons why the female students did not perform better or worse in the test with applause than the one without applause. First, the treatment of applause did not induce the female students' positive or negative affection. Second, the applause might have induced the female students' specific affect, but the affect did not help them to learn better. Neither of these two possible reasons could be interpreted by questionnaires, tests, or interviews, but could only be detected by neuroscience methodology.

To find out the possible reasons why the female students did not perform better or worse in the test with applause than without applause, we designed a similar treatment by using EEG methodology in our lab (paper submitted for publication). Fifteen male and fifteen female students participated in our study. They were asked to solve mathematics problems with and without applause feedback. The results showed that both the male and female groups had higher alpha frequency power values when receiving the applause feedback; moreover, the brain activities of the male students were higher than those of the female students. Alpha frequency power is seen as an indicator proving the inducement of positive affect. The higher alpha frequency power indicated more positive affect. Hence, we can say that both the male and female students' positive emotions were induced by receiving the applause feedback, but the effect is larger in males than in females.

Furthermore, both the male and female students' delta frequency power values of their brain waves were higher when completing the controlled computer-assisted self-assessment test without applause feedback than for the test with feedback. The delta frequency in the frontal lobe of the brain could reflect humans' high-level cognitive processing (Ho et al. 2012). The higher delta frequency indicated more difficulties faced when the participants completed this task. To sum up, the results of delta frequency power indicated that both the male and female students did the mathematics task better with applause feedback than without it. However, for the female students, there was no significant difference in the delta frequency power between these two treatments.

In our study, we used the EEG methodology to identify the reasons why the female students did not perform better or worse in the test with applause than without, while the male students performed better. We proposed two hypotheses. First, we considered whether the treatment of applause induced the female students' positive or negative affect. The evidence from the neuroscience data (the increasing alpha frequency power) showed that the applause did in fact induce the female students' positive affect. However, the effect of inducing positive affect using applause is less in female than in male students. Second, we wanted to confirm whether the affect had an influence on the students' learning. The evidence from the neuroscience data (the increasing delta frequency power) showed that the positive affect could indeed help students to learn better and more easily. Therefore, in conclusion, we supported that the applause feedback with computerized self-assessment could help to improve students' positive affect and promote their performance in mathematics tests. However, the applause feedback is more useful for male students than for females since it could not induce sufficient positive affect in the female students.

In this section, we find that gender differences will influence the performance of science learning. Further, we hypothesize that some specific cognitive skills will exhibit individual differences, and we suppose that these cognitive skills will affect students' science learning performance. The next section will provide research findings about mental rotation and chemistry learning, and discuss the influences of students' science learning performance on the differences in specific cognitive skills.

### *12.4.3 Mental Rotation and Chemistry Learning*

Chemistry is a difficult subject for students to learn since it involves many abstract concepts, symbols, and unfamiliar specific terms (Gilbert and Treagust 2009; Tsaparlis et al 2010). One of the basic areas of knowledge in learning chemistry is chemical structural formulas. Unfortunately, many students cannot identify 2D chemical structural formulas well. In the science education domain, there are different opinions as to why some students can identify such formulas well while others cannot.

> Many researchers mentioned that mental rotation would affect the identification and learning of chemical structural formulas (Korakakis et al. 2009; Mayer 2001; Shubbar 1990; Wu et al. 2001). However, some researchers argued that low-achieving students may need to identify chemical structural formulas with mental rotation……As Larkin, McDermott, Simon and Simon (1980) mentioned in their study, participants who were experts in science reported that they could solve problems and form mental images which included 2D and 3D representations in their field without using mental rotation strategies…It seems that the role of mental rotation in identifying chemical structural formulas is not clear based on the research discussed above." (Huang and Liu 2012, p. 38)

From the results of previous studies, the effects of mental rotation are not clear in chemical structural formula identification. Therefore, Huang and Liu adopted ERPs to detect the participants' use of mental rotation in identifying chemical structural formulas. They adopted a chemical conceptual questionnaire, ERP experiments and interviews in their study which were administered to 18 university students in Taiwan. By analyzing the neuroscience data they found that both high- and low-achieving students used mental rotation cognitive processing to identify 2D and 3D chemical structural formulas. In other words, their findings supported that mental rotation does in fact affect the identification of chemical structural formulas. Then, through analysis of the interview data, they found that both high- and low-achieving students used similar strategies of mental rotation in identifying 3D chemical structural formulas, but they used different strategies of mental rotation to identify 2D chemical structural formulas. They found:

> … low-achieving students used similar strategies to identify 2D chemical structural formulas as they did to identify 2D figures because they did not realize that the 2D chemical structural formulas were the projections of 3D chemical structural formulas. On the other hand, the HSG students used different strategies to identify 2D figures and 2D chemical structural formulas because they understand that the concepts of 2D figures and 2D chemical structural formulas are different. (Huang and Liu 2012, p. 51)

Furthermore, Huang and Liu (2013) analyzed other neuroscience data and indicated that the chemical element symbols are meaningless for low-achieving students. This would be another reason why they could not identify chemical structural formulas well.

Huang and Liu's study provides new, biological evidence to support the belief that mental rotation affects the identification of chemical structural formulas, and provides reasons why some students fail to identify the chemical structural formulas through the interviews. Their study not only provides a new insight into science education research, but also raises some objective suggestions for science education. From the results of Huang and Liu's study, we may suggest that the training of students' identification of chemical structural formulas should first involve training their cognitive processing of mental rotation, and then help them to understand the translation between 2D and 3D chemical structural formulas by the use of virtual and real models. In other words, we agree that it is important to teach students to use analytical strategies to identify chemical structural formulas, but the teachers also need to consider the basic cognitive strategies of mental rotation when teaching the strategies and materials related to chemical structural formulas.

## 12.5 Suggestions for Science Education

In this section, we provide some suggestions for science education researchers, and science teachers and educators.

### *12.5.1 The Challenges for Future Researchers*

In this chapter, we have mentioned the new trends of combining research on neuroscience and science education, and we also made efforts to do the related researches (Liu et al 2014a; Liu et al 2014b; Huang et al 2014; Liu et al 2015). However, as interdisciplinary researchers, we need to provide information regarding the difficulties faced in the engagement of neuroscience and science education for future researchers. First of all, the validity of the methodologies and technologies of science educational neuroscience needs to be confirmed by professional science educational neuroscience experts but not only by neuroscience researchers, because they could supply suggestions from the perspectives of both science education and neuroscience and remind other scholars of the limitations of research in both fields. Second, the inferences of the evidences from neuroscience need to be explained carefully. Many results from neuroscience data could only explain physiological responses which do not involve thinking; these kinds of findings do not reflect human thinking and learning, which are fundamental for science education. Therefore, the findings from neuroscience evidence need to be inferred more carefully. Third, we suggested that scholars who intend to become interdisciplinary researcher need to realize the importance of team work, and make efforts to cooperate with professional groups. A well-experienced group could increase the quality of interdisciplinary researches and decrease the flaws in the research design. That is a particularly important suggestion for naïve researchers who are interested in joining the study on science educational neuroscience.

### 12.5.2 Suggestions for Science Education Researchers

In the fourth part of this chapter, we introduced some examples such as emotions and scientific creativity, mental rotation and chemistry learning, and affect and computer-based learning. All of these science educational studies raised research questions which required evidence from neuroscience data to interpret the results. The neuroscience data not only provided evidence to explain the results, but also provided objective suggestions for human learning. Hence, we suggest that science education researchers need to focus on the new findings of neuroscience and apply this evidence to interpret the findings in science education research. It is not necessary to understand all of the theories regarding the human brain or neuroscience, but to apply the important results in science education would provide many insights. To comprehend the innovative research ideas of science educational neuroscience might be the first step. Applying the important results from neuroscience that interpret the findings of science education might be the second step. Finally, researchers could try their best to develop strategies for engaging neuroscience methodology in science education research.

### 12.5.3 Suggestions for Science Teachers and Educators

At the beginning of this chapter, we stressed that the most important purpose of education is to help students to learn actively and develop their potential. The same purpose is relevant in science education, which is more concerned with science content and processing than general education is. We mentioned at the beginning of this chapter that the human mind can be seen as the operator while the human brain is the machine. A science teacher or educator should clearly understand which cognitive abilities the students need to have to learn each science concept, and help the students to try their best to perform the corresponding cognitive abilities. Besides, science teachers and educators need to have a basic understanding of the human brain. At least, they need to know that the characteristics and limitations of each student's brain are different and unique, and their mission is to help each student perform their best.

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# Chapter 13
# Methodology and Application of Eye-Tracking Techniques in Science Education

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**Abstract** Eye-tracking techniques have the potential to reveal learning processes and problem solving strategies when dealing with science content. For instance, locations, durations, and numbers of gazes in predefined areas of interest together with transitions between areas indicate the degree of attention allocation to these areas. These measures combined with achievement tests, thinking aloud, or interviews can shed light on how or why learners gain or do not gain knowledge. This chapter aims to introduce issues in science education that can be explored with eye-tracking techniques and methodological concerns that should be considered when conducting research and interpreting data. The first section of this chapter outlines the methodological issues and the second section presents a survey of empirical studies conducted in Taiwan. Specifically, since material with science content usually consists of multiple representations, attentional distribution in text and illustration is one of the research foci. Furthermore, how participants' prior knowledge and additional cues in the material guide attention allocation is also investigated. Implications for future development are discussed in the last section.

Investigating online cognitive processes during learning and problem solving is one of the key issues in science education. Thinking aloud protocols (Ericsson and Simon 1993), videotaping, and computer logs have been utilized to reveal the online process. Recently, eye-tracking (van Gog and Scheiter 2010) and neuroimaging Liu and Huang (in press) techniques have been applied in educational studies. These techniques can record the natural behavior involved in performing the task without additional demands (such as concurrent verbal reports). For instance, the eye-tracking data provide valuable information about *which* parts of the material are attended to and *how long* they are processed.

The purpose of this chapter is to document the applications of eye-tracking techniques to study issues in science education with a focus on research conducted

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in Taiwan. Since the first study in 2009, 15 journal articles on empirical studies executed in Taiwan have been published to date. The accelerated and flourishing development in educational research applying eye tracking in Taiwan is partly due to the support of multidisciplinary research projects from the National Science Council since 2007. Furthermore, researchers were intrigued by understanding the process of learning through online measurement rather than solely observing the end result of the intervention. The survey presented in the second section of this chapter illustrates what can be investigated with eye-tracking techniques, and reveals potential future exploration. Since learning material and problems with science content may consist of multiple representations so that information selection and integration may be demanded, multiple factors should be considered to interpret the complicated cognitive processes revealed by eye-tracking data. Therefore, several methodological issues of eye-tracking techniques that should be considered are briefly introduced in the first section. However, this introduction is by no means comprehensive, and is limited in scope. To gain more information and insights, readers can refer to other books (such as Duchowski 2007; Holmqvist et al. 2011) and review articles (such as Rayner 1998, 2009).

## 13.1 Methodological Concerns: The Cognitive, Physiological, and Technical Bases of Eye Tracking

Since the proposal of the eye–mind assumption by Just and Carpenter (1980), eye-tracking techniques have been adopted by researchers in various fields to reveal the underlying processes during visual tasks. The eye–mind assumption suggests that the eyes remain fixated on the region being processed. Thus, gaze duration in that area can be used as an index of processing time. However, parafoveal processing was found in subsequent studies (see Rayner 1998 for a review). In other words, stimuli that are not directly fixated on (i.e., projected to the fovea) can also be processed. For example, as Just and Carpenter acknowledged, stimuli from previous fixation(s) may still be processed and integrated with the information obtained from the present fixation. In addition, nearby stimuli that have not been fixated on can be processed to some extent (which is usually referred to as parafoveal preview). The region from which useful information can be extracted during fixations is called the perceptual span, the size of which varies with task demands, task difficulty, and perceivers' experience and skill. Many researchers in the fields of reading, scene perception, and visual search have investigated what information can be extracted from the perceptual span (especially the parafovea) and what influences the decision of the next saccadic targets. Although the mechanism of eye movements during visual tasks is more complicated than that suggested by the eye–mind assumption, it is still a useful approximation because, for example, gaze durations are influenced by linguistic factors such as the frequency and predictability of the fixated word (Rayner et al. 2003), indicating immediate cognitive (linguistic) processing during fixation.

To sum up, gaze duration may reflect the time for processing stimuli in the fixated and nearby areas, as well as the information obtained from the previous fixations. That is, it can be an assemblage of encoding new information and integrating with recently extracted information and prior knowledge.

### 13.1.1 Eye-Tracker System

There are several eye-tracking techniques, such as electrooculography (EOG), search coils (scleral contact lens), and video-based eye trackers (Duchowski 2007). Among these techniques, video-based eye trackers are often used in the fields of cognitive psychology, education, sports, advertising, consumer behavior, etc. The movement of the pupil, corneal reflection, and some facial features are tracked by video-based eye trackers. The system usually consists of a host PC (where eye movements are recorded and monitored) and a display PC (where experimental stimuli are presented and screen capture may be conducted), which are usually connected by an Ethernet cable. Video-based eye trackers can be desktop and head mounted. Desktop-mounted eye trackers can track the eyes remotely; nevertheless, a chin rest is used for some trackers. Some head-mounted eye trackers can be used when participants freely move in the surroundings; eye movements are recorded by a connected device and might be monitored in another computer through a wireless connection. Sometimes, a scene camera is set up to record what the participants are looking at, which can also be recorded by screen capture software if the material is presented by computer. Eye trackers also differ in their sampling rates (e.g., 30, 60, 120, 250, 500, 1000 Hz) and algorithms to parse sampled data into fixations and saccades (or non-fixations), which will be described in the following subsections. After setting up the tracker, calibration is usually conducted to obtain the point of regard on the monitor or in the real scene. Typically, several fixation points are presented one-by-one in the center and corners of the monitor or the scene to be viewed. The order of the location of the fixation points is usually random. The participant is instructed to fixate on those fixation points in turn. A validation procedure is then conducted to verify the accuracy. Some oculomotor errors (e.g., $0.4 \sim 1°$) are acceptable, but the criterion varies among laboratories and can be set according to the specific task demands and the grain size of the areas of interest. For mobile eye trackers, calibration can also be conducted by recording some markers in the real scene.

### 13.1.2 Basic Patterns of Eye Movements

Due to the decrease in visual acuity (i.e., the drop in the density of photoreceptors in the retina) from the fovea to the periphery, people need to move their eyes to sample information for further processing (Findlay and Gilchrist 2003). The eye movement pattern during visual tasks is characterized by a series of alternating fixations and saccades. The eyes move rapidly during saccades (the duration and maximum velocity of which depend on saccade length, which is called the saccadic main sequence) while they remain *relatively* static during fixation. There are fixational eye movements to prevent photoreceptors from saturation (Martinez-Conde and Macknik 2007). It follows that there is no clear-cut distinction between fixations and saccades (Inhoff and Radach Inhoff 1998), although several criteria can be set to distinguish them. Some trackers segment raw data based on detecting saccades, whereas others based on detecting fixations. The raw data provided by video-based eye trackers are x- and y-positions as well as the diameter of the pupil captured in each sample. Some eye trackers adopt a velocity threshold. That is, if the speed and acceleration of the eye movements are higher than the predefined thresholds, these samples are categorized as saccades whereas others are treated as fixations. A typical saccade duration for a reading is 20–50 ms. If the sampling rate of the eye tracker is not high enough, it may be difficult to detect saccades. For example, with a 60-Hz sampling rate, the interval between two consecutive samples is 16.7 ms. Then, it cannot detect a 20-ms saccade. In some eye trackers or software, duration and distance threshold are used to aggregate samples into fixations. For instance, when the distance between consecutive samples is less than 0.5° of visual angle for 80 ms, these samples are treated as fixations, whereas others are treated as non-fixations. In some software, for instance, the start of a fixation is defined when six consecutive samples are located within 0.5°, and the end of a fixation is defined when three consecutive samples are located more than 1° apart. The types of threshold are usually determined by the particular eye trackers. Nevertheless, researchers can design their own software to process the raw data.

Information is mainly extracted during fixations, although it is continuously processed during saccades and blinks (Inhoff and Radach 1998; Rayner 1998). Therefore, fixation is the main concern in most cognitive studies. There is large variation in how long the eyes remain fixated. The range of fixation duration can be from shorter than 50 ms to longer than 500 ms (Rayner 1998). Although fixation duration can be influenced by cognitive processing, very short or long fixations may be caused by factors unrelated to the current cognitive task. As it takes time for visual information to travel from the eyes to the brain (about 60 ms, Reichle and Reingold 2013), short fixations may result from oculomotor errors and may not be enough for visual processing. Thus, they are combined with consecutive fixations or discarded in some studies. On the other hand, very long fixations are sometimes discarded because the participants may be absentminded or distracted by something unrelated to the task. The criteria to exclude duration data from analysis vary among cognitive tasks. The typical mean fixation duration in different tasks can be taken into consideration. For example, the mean fixation durations during silent reading, reading aloud, and scene perception are 225–250, 275–325, and 260–330 ms, respectively (Rayner 2009). Whether or not additional criteria for fixation durations are used, and the particular cut-off values are determined by the research focus and task used.

### 13.1.3 Data Processing

There are a variety of eye movement measures. In general, these measures concern the spatial, temporal, frequency, and sequential dimensions, namely, how far the eyes move and which part of the stimulus is fixated on, how long and how many times it is fixated on, and the pattern of transitions among different parts of the material (Holmqvist et al. 2011; Lai et al. 2013; Radach and Kenney 2004). Sometimes, new measures are created to reflect the cognitive process specific to the task. Although analyzing all fixations in the unsegregated material can be meaningful, most of the time, investigating eye movement patterns in and between specific target areas in the material can further reveal the attentional distribution and strategies used during the task. These target areas are called the areas of interest (AOIs). In some software, AOIs are also called regions of interest (ROIs), interest areas (IAs), and look zones (LZs), to name a few. In basic reading research, words are used as AOIs. However, in studies of high-level processing, clauses and sentences are treated as AOIs. Larger segments, such as paragraphs and diagrams, can be used as AOIs in applied studies. Diagrams can be further segmented into the different elements that are depicted. When different AOIs in a study vary in size, their areas have to be taken into consideration when the duration and frequency of the fixations are compared among AOIs. For example, the number of fixations and fixation duration per pixel can be calculated. In addition, transitions between AOIs can also be investigated. Whether or not number of transitions between AOIs A and B is significantly more than that between A and C can be an indicator of the strategies used. The techniques to calculate transitions between AOIs are described comprehensively by Holmqvist et al. (2011).

Once AOIs are defined, the number and duration of fixations in each AOI can be calculated and then comparisons between AOIs can be made. At one extreme, an AOI can be skipped (i.e., not fixated on at all) when the stimuli are presented, presumably because it can be easily processed parafoveally or it does not attract the participant's attention; the corresponding measure is fixational probability or skipping rate. If it is fixated on, besides calculating the total number and duration of fixations, these fixations can be distinguished into first pass, second pass, etc., to reflect different stages of processing (Inhoff and Radach 1998; Radach and Kennedy 2004). First-pass fixations are the group of fixations in which the AOI is inspected for the first time after stimulus onset; there might be multiple fixations before leaving the AOI. If the eyes return to the AOI after leaving it, second-pass fixations can be identified. The AOI can further receive third- and fourth-pass fixations, and so on. Parenthetically, passes are named runs or visits in some software and studies. First-pass measures seem to reflect the initial encoding of the stimuli in the AOI. On the other hand, if the AOI receives additional pass(es), it may reflect later integration with information obtained from other AOIs. For instance, Kaakinen et al. (2003) found that readers with high working memory capacity (WMC) spent more time processing relevant than irrelevant information during the first pass, whereas those with low WMC spent less time processing irrelevant information during the first pass but increased look-back time (second pass) on relevant information. Distinguishing the first pass from additional passes reveals the detailed strategies used by different readers.

The nomenclature of eye movement measures varies across software and laboratories. In the field of basic reading research where word recognition during reading is one of the research foci, fine-grained measures for first-pass fixations are specified. For instance, the sum of the duration of all first-pass fixations is called (first-pass) gaze duration (GD). In some software, GD may be called first-run dwell time. The duration of the very first fixation during the first pass is called first fixation duration (FFD). Other first-pass fixations are called refixations. Fixations other than first-pass ones can be labeled as regression, look backs, rereading, or revisits. For instance, look-back time, rereading time/rate, and regression probability can all be calculated. When all fixations are considered, the number of fixations and the number of gazes/passes/runs can be measured. In addition, the sum of durations of all fixations is called total reading time, total viewing time, total fixation duration, total inspection time, dwell time, etc.

Besides AOIs, periods of interest can be investigated as well. For example, what the learners explore during the initial 30 s may indicate the areas that most attract their attention. Similarly, the number of fixations or time before a certain AOI is fixated on after stimuli onset can be calculated to reveal the search efficiency. This duration of time is called latency or time to first fixation. In addition, researchers may be interested in where participants fixated before they made decisions. It should be noted that if presentation duration of the material is determined by the participants, total time in trial has to be considered when comparing fixation durations among participants. For instance, a 1-s total viewing time in an AOI can be long for a 5-s presentation, although it can be short for a 15-s presentation.

In the articles mentioned in the second section, several eye movement measures as well as transition patterns were reported. Two of the measures were total fixation duration and total fixation count. In some studies, the sizes of different AOIs were taken into consideration. In addition, some studies reported fixation counts during reinspection and fixation duration during the first pass. The other two frequently reported measures were mean fixation duration and mean saccade length. The design and findings of these studies are described in the second section and summarized in the Appendix.

### *13.1.4 Factors that May Influence Eye Movement Patterns*

Eye movement is a natural behavior in tasks that involve visual processing. Factors along the information processing pathways might influence *where* the eyes locate and *how long* they remain fixated. As the review by Henderson (2003) stated, there is bottom-up information embedded in the scene and top-down information generated by the cognitive system. A uniform region with single color, brightness, texture, etc., may be uninformative, whereas a sharp contrast in these dimensions may signify a boundary between multiple objects or their surroundings. Thus, saliency can play an important role in parsing the scene and signifying potential targets in it. On the other hand, task demands such as searching for a specific target among distractors, viewing the scene to make a decision (e.g., to evaluate whether or not to buy the product or how effective the advertisement is), or comprehending a learning material can influence attention distribution in inspecting the stimulus. Knowledge of the target or the scene (such as a living room or a hospital) can indicate the cognitive relevance of the stimuli and locations in the scene, and guide the allocation of attention to them. For example, world knowledge suggests that a watch is more likely to be located on a table, while it is nearly impossible that it will be floating in the air or hung from the ceiling. In addition, task-relevant knowledge suggests how to process the scene. For instance, when driving a car, frequently looking through the windscreen or mirrors is needed to check the traffic lights or the behavior of other vehicles or pedestrians. To sum up, stimulus characteristics and knowledge jointly determine how the presented material or the scene is processed and how the eyes extract information for further processing.

Several descriptive or computational models have been constructed to illustrate the coordination of visual processing, cognitive processing, and oculomotor systems during a variety of tasks. In models concerning basic reading process, it is generally agreed that linguistic processing plays an important role in the *where* and *when* decisions of eye movements (see Reichle et al. 2003, for a review). It should be noted that as it takes time to initiate and execute a saccade (with latency around 150 ms) once the saccadic target is decided, linguistic processing and saccade programming overlap in time during fixation. However, the period in which linguistic processing can influence whether the same target is refixated on or not is quite limited (e.g., in a typical 250-ms fixation, the where decision may be made during the initial 100 ms). Thus, parafoveal processing may be important during reading. As expected, models propose different mechanisms of how linguistic processing (foveal and parafoveal) is conducted and then influences oculomotor control, which is beyond the scope of this chapter. However, these models mainly concern word recognition (and factors such as word frequency and predictability from context) in the linguistic processing, with recent attempts to take higher-order processing (such as sentence-level comprehension and reading goals) into consideration (Radach et al. 2008; Reichle et al. 2009).

Processing educational material can be complicated. For example, multiple representations usually coexist; whether “a picture paints a thousand words” or not may largely depends on task demands and learners’ prior knowledge. In addition, learners may not have enough knowledge to determine relevant parts of the material so that their information extraction may be influenced by perceptual saliency, information densities, etc. Although cognitive processing is the main concern in educational research, perceptual-level and stimulus-based properties should be taken into consideration. Eye movement patterns can be influenced by both perceptual and cognitive levels of processing. Furthermore, although fixation duration may reflect how much attention is allocated to the fixated and nearby areas it is fixated on and attended to probably because it is interesting, relevant, or difficult, which leads to different interpretations. Combining eye movement measures with others such as thinking aloud, retrospective interviews, or comprehension tests may resolve the ambiguity. Moreover, considering a set of eye movement measures together instead of interpreting a single measure can be useful. For example, a long mean fixation duration together with a long mean saccade length may indicate that information is extracted from a large surrounding area during each fixation (Rayner et al. 2001). On the contrary, a long mean fixation duration with a short mean saccade length may imply that the material has high information density or is difficult to process (Chen et al. 2014). In the following subsections, some models and studies on how saliency and task demands influence scene perception are introduced.

#### 13.1.4.1 Perceptual Saliency Versus Cognitive Relevance

Concerning scene perception and visual search, models disagree on whether saliency or higher order cognitive processing (such as task demands) dominate in where and when decisions (Tatler 2009). As Tatler's introduction to the special issue in *Visual Cognition* mentioned, models arguing against the pure saliency model have been developed recently. Factors that may influence fixation location include prior knowledge of similar scenes and targets (e.g., where a certain target is more likely located in a particular scene), oculomotor tendencies (e.g., central fixation bias, Tatler 2007), and perceptual saliency. Two of the models that incorporate higher level factors are briefly introduced as follows.

Navalpakkam and Itti (2005) constructed a computational model in which saliency and task-relevance maps are combined into an attention guidance map from which the next attentional (saccade) target can be selected through a winner-takes-all competition. First of all, task specification (e.g., to find what the man is eating) activates relevant prior knowledge in the long-term memory (e.g., knowledge about food, humans, and eating behavior) and then biases associated features (i.e., a certain color or shape) in the perceived scene in the visual system. Second, a saliency map is computed with weighting for associated features. At the same time, a task-relevance map is also computed taking the likely or relevant locations (e.g., the likely locations of a man and the food he is eating) into consideration. Third, a potential object or location is attended to and recognized, and then its relevance to the task is evaluated. Finally, working memory is updated. If the attended region is not relevant, then look for the next relevant region. If it is somewhat relevant (e.g., a man is found), then look for a more relevant region (e.g., his mouth or hand). The cycle will iterate until the task is completed.

On the other hand, Henderson et al. (2009) proposed a cognitive relevance theory in which salience helps to build an unranked scene representation upon which potential saccade targets are weighted by cognitive relevance. In other words, saliency simply makes it easy to parse the scene into different objects or regions; it is the cognitive relevance that determines the fixation location. In their study, participants were instructed to search for a non-salient target object in a real scene with other salient objects or regions. Nevertheless, participants rarely looked at the salient region (less than 12% of time). In addition, chance is high that participants fixate on the target regions immediately after the stimulus onset (more than 87% of the time).

With a different task, Kaakinen et al. (2011) demonstrated both the effects of perceptual saliency and cognitive relevance on scene viewing. In their study, undergraduate students viewed sets of photos about the exterior and interior of three houses with one of the three types of instruction. The homebuyer group was instructed to decide which house they would like to buy, the burglar group was instructed to decide which house to break into, whereas the memory group was instructed to prepare for a memory test about these pictures. The eye movement patterns of the memory group served as the baseline because the group viewed the photos without any particular perspective. An additional group of participants selected regions in each photo that were relevant to either homebuyers or burglars. Saliency was analyzed by software. For each perspective (homebuyers or burglars), there were salient-relevant, non-salient-relevant, salient-irrelevant, and non-salient-irrelevant regions in each photo. The results showed that, compared to the baseline, viewing perspective lengthened the total viewing time and first-pass dwell time, as well as raised the number of visits in perspective-relevant areas, whereas it shortened the total viewing time and lowered the number of visits in perspective-irrelevant areas. However, it did not decrease the number of visits in salient-irrelevant areas. For the memory group, saliency was the only factor to increase total viewing time, number of visits, and first-pass dwell time. For the other groups with specific viewing perspectives, saliency and relevance had general additive and sometimes interactive effects (which may result from differences in burglar-relevant and homebuyer-relevant regions). In general, total viewing time was 1047, 844, 620, and 324 ms, and number of visits was 1.77, 1.54, 1.45, and 0.83 in the salient-relevant, non-salient-relevant, salient-irrelevant, and non-salient-irrelevant areas, respectively. The pattern of results in the first-pass dwell time for homebuyers and burglars was less obvious; the effect of perspective relevance was observed whereas the effect of saliency was not. Furthermore, probabilities of fixating relevant or salient areas during the first ten fixations were analyzed. For the memory group, only the saliency effect was detected. On the other hand, for the groups with specific perspectives, there was an interaction between relevance and fixation order. For the first fixation, only a main effect of saliency was found. From the second fixation on, both effects of saliency and relevance were observed. To summarize, although saliency influenced the location of the first fixation, both saliency and relevance determined subsequent fixation location, number of visits, and total viewing time. That is, in a task without prespecified targets (such as search targets in the study of Henderson et al. 2009), an immediate effect of saliency followed by a rapid relevance effect and their joint effects were observed.

#### 13.1.4.2 Influence of Task Demands

The influence of task demands was demonstrated by the two studies (Henderson et al. 2009; Kaakinen et al. 2011) exemplified in 13.1.4.1 Though relevance might overwrite the effect of saliency when a target was specified before the scene was viewed (Henderson et al. 2009), they might on the other hand cooperate in a task without specific targets (Kaakinen et al. 2011). That eye movement behavior is influenced by task demands can be further demonstrated in two studies conducted by Rayner et al. (2001, 2008). In their studies, real advertisements taken from magazines were used as the material, eight of which were about cars and eight of which were about skin-care products. In their first study, adult participants were instructed to pretend that they had just moved to another country and needed to buy either a new car or some skin-care products (half of the participants were assigned to one of the groups). In their second study, participants were instructed to rate how they liked each of the advertisements or judged how effective these advertisements were. In this second study, an additional 32 advertisements were used together with the 16 advertisements used in the first study. In the advertisements, there were pictures (some were photos of the products whereas others were related to the products) and text (with large and small print). In the first study, in which the participants pretended to be buyers for cars or skin-care products, they had longer looking time and more fixations on the corresponding relevant advertisements. They also had longer total looking time and more fixations on the text regions than the pictures even when the size (pixels) of the different regions was taken into consideration. In addition, the mean fixation durations and saccade lengths were longer in the pictures than in the text regions, suggesting that more information could be extracted from the pictures than the text regions in each fixation. Participants tended to read the large print, followed by the small print and then the pictures, although they did occasionally fixate on the pictures before reading the small print. When they read the text, they did not read all of it if the text was long, suggesting that they did not carefully read the text to fully comprehend it as they might do in a typical reading task.

On the contrary, in the second study, Rayner et al. (2008) found quite different patterns of results. First of all, when participants were asked to rate how much they liked the advertisement or to evaluate the effectiveness of the advertisements, they spent more time fixating and made more fixations on the pictures (61 %) rather than on the text areas (39 %). Separately analyzing the 16 advertisements for cars and skin-care products and the others for different products revealed that both task goals and specific material influenced eye movement patterns. The participants spent half of their time on the text and picture areas when they viewed the original 16 advertisements, but spent more time on the picture than on the text areas for the other material. Rayner et al. (2008) suggested that presumably because the advertisements about cars and skin-care products had a larger number of words, participants spent more time on the text for these advertisements than other advertisements used in the second study. Second, the probability of fixating on the picture in the first fixation after the stimulus onset was about 69 %, whereas that on the text areas was about 16 %. Nevertheless, consistent with their previous study (Rayner et al. 2001), the participants had longer mean fixation durations and saccade lengths for the pictures than for the text areas. In addition, no frequent alternation between the text and picture areas was observed. A comparison of the two studies revealed that the participants distributed their attention distinctively according to different task instructions. They also varied their sequence to extract information; specifically, they mainly relied on information carried in the text and then sought confirmation from the pictures in one study or vice versa in another.

The findings of Rayner et al. (2001, 2008) suggest that when viewing the same set of material, the attentional distribution and order of allocation among multiple representations change corresponding to task demands. To complicate the issue, when comprehending educational material, the "targets" may change over time. For example, in the material describing how a natural phenomenon takes place or how a machine works, there is a sequence of events happening during the process. It follows that the eyes and the mind change their foci among different parts of the material and then integrate new information with that obtained in previous fixations from different areas. The application of eye-tracking techniques in science education is in its infancy compared to the number of studies in basic reading, visual search, and scene perception, although some related work has been reported in the literature (e.g., Hegarty and Just 1993). At the exploratory stage, basic eye movement patterns are first identified, with increasing complexity being gradually considered in more recent studies. In the next section, studies related to science education conducted in Taiwan are documented.

## 13.2 Application of Eye-Tracking Techniques in Science Education in Taiwan

In this section, studies concerning science education and using eye-tracking techniques are discussed with an emphasis on research conducted in Taiwan. A total of 15 articles were selected by first identifying active researchers in the field and then searching their publication lists for relevant articles. The researchers were identified from the review article by Lai et al. (2013), abstract books of recent European Conferences on Eye Movements, and a special issue of the *International Journal of Science and Mathematics Education* (2014). In addition, research interests and publication lists of faculty members in departments and institutes of (science) education in universities in Taiwan were searched to identify active researchers. Empirical articles published in local and international peer-reviewed journals were then included in this survey.

Four major issues were investigated in these 15 articles. In most studies, the material consisted of verbal information and visualizations. Specifically, seven of them explored how participants comprehended or learned from material with written text and illustrations. Two studies compared the effects of presentation modes (e.g., animation versus simulation, narration versus text) on learning outcomes and eye movement behavior. One study documented how students inspected PowerPoint slides in a real classroom. Five studies demonstrated how participants solved problems with science content. In their data analysis, attentional distribution (manifested by fixation duration and frequency) between the illustration and text areas was one of the research foci. Another focus was the transition pattern among AOIs, revealing the strategies the participants used. In addition, some of the studies investigated how participants' prior knowledge influenced the way they processed the material. Also, the effects of coloring relevant parts or adding arrows on reading comprehension were investigated by Wu and colleagues (Chen and Wu 2012; Jian and Wu 2012; Jian et al. 2014). These 15 articles are outlined and discussed in the following subsections with their experimental manipulation, types of material, characteristics of participants, and findings summarized in the Appendix.

### *13.2.1 Learning from Material with Text and Illustrations*

Liu and Chuang (2011) demonstrated that when nonscience-major undergraduate students read text about the formation of winds and atmospheric pressure systems with illustrations for comprehension, they had a greater total number of fixations and longer total fixation durations in the text area than in the illustration area. This pattern remained when the sizes of different areas were taken into consideration (i.e., calculating fixation and duration densities). In addition, a similar pattern of results was found even when the size of the text area was smaller than that of the illustration area (because one of the concepts was presented step-by-step over five pages, the number of words was reduced on each page). Concerning transitions between text and illustration areas, participants inspected the illustration when they read the text describing the kinematics of the system (e.g., clockwise movement of the air). A global transition pattern was found in one concept (atmospheric pressure), in which participants fixated on the illustration more often following reading the end of a sentence than after reading any other parts of the sentences. Thus, readers seemed to build their mental models mainly based on reading the text, with the illustration playing a supplementary role. Last but not least, participants' attention was likely to be drawn to irrelevant decorative icons on the illustration which might disrupt the process of constructing a mental model about the concept to be learned.

Hung (2014) found similar attentional distribution when sixth graders read an expository text with illustrations. The participants were instructed to read aloud the material and then retell the content. Two types of dance honeybees use to communicate were described and explained in the material. The text areas included headings, figure captions, and main text, whereas the illustration areas consisted of decorational, representational, and interpretational illustrations. The proportions of these areas were 4, 3, 12, 24, 2, and 12 %, respectively (43 % of the material was blank space). Overall, 63 % of the fixations were made in the text areas (totally 19 % in space) and only 27 % of the fixations were made in the illustration areas (totally 38 % in space). The mean fixation duration in the text areas was about 50 ms longer than that in the illustration areas, whereas the mean saccade length was shorter in the text than in the illustration areas. In the text area, the main text and the captions received more attention (fixation counts and duration) than did the headings. Saccade length was shorter in the former two text areas than in the latter. Although readers exploited the interpretation function of the figure captions, they did not utilize the prediction function of the headings. In the illustration areas, readers paid the least attention to the decorational illustration. However, they did not pay enough attention to the informational illustration areas so that, in their retelling, they simply repeated *what* was mentioned in the text (e.g., the sun is the reference for the direction of the flowers) without fully understanding *why* (which was depicted in the interpretational illustrations). Furthermore, there was a trend that the more the readers fixated on the illustrations, the higher their comprehension levels were.

Liu and Hou (2011) explored the influence of prior knowledge on comprehending a diagram about plate tectonics. Undergraduate and master's degree students majoring in science first depicted what they knew about plate tectonics on paper. Their drawing and retrospective thinking aloud data were the basis for categorizing their levels of prior knowledge (low, medium, and high). They then read instructional material (a diagram with three AOIs: plates, mantle convection area, and labels) with their eye movement recorded. After reading the material, they had to revise their drawing as the posttest. The eye movement patterns revealed that the high-level prior knowledge group paid more attention to the labels than the low-level group (reflected by longer total fixation durations and higher fixation counts). On the contrary, the high-level group had shorter total fixation times in the mantle convection area than the low-level group. There was no difference in average fixation durations among areas or among groups. The high-level group also had more transitions between labels and back-and-forth scanpaths between labels and the plate area than the low-level group. The three groups were further divided into stable and advanced subgroups according to whether they progressed from pretest to posttest. For both the high- and low-level groups, those who improved (the advanced group) in the posttest had more transitions within the plate area compared to those who did not (the stable group). To summarize, participants with high-level prior knowledge had a text-oriented comprehension process. In addition, those who progressed at the posttest had different transition patterns from those who did not. Presumably, the improvement resulted from the attempt to integrate information.

Ho et al. (2014) also investigated how the prior knowledge levels of undergraduate students influenced their fixation patterns when reading a web page with a paragraph and two diagrams. In the text, the relationship between carbon dioxide concentration and global warming was described in four continuous sections. The first section introduced the greenhouse effect, the second section explained the data shown in the diagrams, the third section described the observation from the diagrams that $CO_2$ concentration and atmospheric temperature might be highly correlated, and the last section argued that greenhouse gas produced by human industry might cause global warming in the current age. To the left or right of the text area, two diagrams were presented to illustrate the changes in $CO_2$ concentration (top) and atmospheric temperature (bottom) in the past 200,000 years. Participants' prior knowledge levels were assessed by a paper-and-pencil pretest. Eye movements were then recorded when they read the web page. Overall, all participants spent more time fixating on the text area than on the diagram area. The text area was revisited more often than the diagram area. They also fixated longer on the $CO_2$ diagram than on the temperature diagram. When comparing two groups of participants, those with higher prior knowledge (PK) generally spent more time reading the material than those with lower PK. The high PK group had longer total fixation duration on the diagram area, especially in the $CO_2$ diagram, than the low PK group. The high PK group also revisited both diagrams more often than did the low PK group. In the text area, the high PK group paid more attention than the low PK group did to the middle two sections describing the data in the diagrams and their correlated relationships. Heat maps (representing total fixation duration) showed that the low PK group focused on definition terms in the first introduction section and seldom inspected the diagrams, whereas the high PK group fixated on keywords in the text area and paid attention to the axes in the diagrams. Concerning the transition between the text and diagram areas, the high PK group had more transitions than the low PK group, especially after reading the second and fourth sections. The high PK group also switched between the two diagrams more often than did the low PK group. The results suggest that the two groups used different strategies when reading inquiry-based science material, that is, the high PK group used a text–graphic integration and data comparison strategy while the low PK group used a text-based strategy. It is possible that participants with higher PK had the ability to comprehend and examine the diagrams whereas those with lower PK did not, so that the latter group relied more on reading the text.

Chen and Wu (2012) investigated the effects of coloring on comprehending geometry proofs. Undergraduates unfamiliar with geometry were recruited as participants. The stimuli included a question, a figure, and a worked-out example proof. Equivalent lines or angles on the figure were colored in two of four items. After reading all items, participants were assessed by a paper-and-pencil recall test. The eye movement patterns during reading revealed that total fixation time in the text area was significantly longer than that in the figure area for most items. It should be noted that the text area was larger than the figure area (the proportion of the figure area was 17~30 %). When the size of each AOI was taken into consideration, fixation duration per pixel was larger in the figure than in the text area. This may indicate that when reading geometry proofs, the figure area provides critical information for comprehension. The finding that the percentage of total fixation time in the figure area was about 38~48 % which was higher than the proportion of area 17~30 % also supported this interpretation. Moreover, the effect of coloring was observed on the initial comprehension time in the critical proposition area (CPA) in the worked-out proof, that is, there was shorter initial comprehension time in the colored than in the control conditions. The initial comprehension time was the sum of the durations of the first-pass fixations in the CPA, and subsequent fixations back-and-forth between the CPA and the figure area before leaving this CPA to move to another part of the text area. Coloring the figure area made the critical segments more salient and easier to process after reading the critical proposition in the text. It also facilitated integration between the colored segments and the corresponding CPA, thus resulting in shorter initial comprehension time. However, there was no significant difference in the look-back time and total fixation time between the colored and control conditions (except for shorter total fixation time in the most difficult item in the colored condition than that in the control condition). To summarize, when reading geometry proofs, participants spent more time fixating on the figure area (taking the number of pixels into consideration) to extract information for comprehension. In addition, coloring the critical segments in the figure area facilitated processing of the critical proposition in the text area and the integration between the CPA and the figure area.

In two studies, Jian, Wu and colleague ( Jian and Wu 2012; Jian et al. 2014) investigated the effect of adding arrows for comprehending illustrated material. In their first study, the material was composed of text and an illustration about neural pathways for processing emotional stimuli. Undergraduate and graduate students who were not familiar with neuroscience were recruited as participants. Half of them read the original material without arrows and the other half read the material with arrows indicating the sequence of information processing. After reading the material at their own pace, they were assessed by a comprehension test with text-based, sequential, and integrative questions. Overall, the readers spent about 80 and 20 % of total fixation durations on the text and illustration areas, respectively. There was no effect of adding the arrows on the total fixation durations in the different AOIs. However, the arrow group had shorter mean saccade length in the illustration area than the no-arrow group. There were three kinds of scanning patterns, namely, transiting between text and illustration areas at the beginning (60 and 73 % in the arrow and no-arrow groups), finishing reading the whole text before inspecting the illustration (5 and 18 %), and viewing the illustration before reading the text (35 and 9 %). Although a majority of participants in both groups read the text first and then inspected the illustration after reading two or three sentences, the arrow group tended to fixate on the illustration before reading, while the no-arrow group tended to finish reading the text before inspecting the illustration. The effect of adding arrows was also revealed in better performance in the sequential and integrative comprehension questions by the arrow than the no-arrow group. Thus, adding arrows for the sequence of information processing influenced the way participants read the material and their comprehension levels.

In the study of Jian et al. (2014), the learning material was composed of two diagrams about how a flushing cistern works. One of the diagrams depicted the outlet process of flushing while the other illustrated the inlet process, and both of them were presented on the same page on the monitor. The components in the flushing cistern were explained in a separate page before the participants saw the main diagrams; in other words, there was no label on the diagrams to reduce the number of stimuli that may attract participants' attention. Half of the participants received material with additional numbered arrows on the diagrams to illustrate the sequence of the flushing processes. The participants were undergraduate students majoring in nonscience subjects so that they were not familiar with the flushing processes. They were instructed to study the diagrams within 5 min and then describe the steps involved in the flushing processes. The results showed that the arrow group had significantly better understanding of the operation steps of the flushing cistern than the non-arrow group. Overall, the arrow group spent slightly more time (181.8 s) than the non-arrow group (158.7 s) on studying the diagrams, but the difference was not significant. However, the mean saccade length was shorter in the arrow than in the non-arrow group. When the two diagrams were analyzed separately, both of them received longer first-pass fixation times from the arrow than the non-arrow group, but there was no difference in the second-pass fixation time. There was also less saccade switching between the two diagrams in the arrow than in the non-arrow group. Furthermore, Jian et al. conducted sequential analyses of fixation transition among ten AOIs (five components in each diagram). The first-pass transition patterns showed that the arrow group tended to fixate back-and-forth between components according to the numbered arrows, while the pattern was not as apparent in the non-arrow group. The total-pass transition patterns were more diverse than the first-pass ones. However, the arrow group seemed to follow the numbered sequence whereas the non-arrow group tended to compare the same components in the two diagrams. This study illustrated the process of learning kinematic information from static diagrams. Without the aid of the numbered arrows, the participants tended to inspect the same components in both diagrams to infer the operation mechanism. On the other hand, the arrow group benefited from the numbered arrows by following the sequence so that they had better learning outcomes.

To summarize, a general text-directed comprehension process was found. Participants had more and longer fixations in the text than in the illustration areas. However, more attention would be devoted to the illustration if it provided additional information (such as the figure in a geometry proof). Furthermore, participants with more prior knowledge, compared to those with less prior knowledge, were more likely to inspect the illustration and tended to switch between critical parts in the text and illustration areas. Without sufficient prior knowledge or additional arrows, participants may not be capable of extracting information from the illustration. Thus, the only source they could rely on was the text. With the assistance of arrows signaling the sequence of events, participants could better follow the process depicted in the illustrations. Another possibility is that an illustration can be interpreted in multiple ways (such as illustrations in novels and paintings); in this situation, text or captions may constrain the meaning that the authors intended to convey, resulting in text-based comprehension strategies. This speculation may be consistent with the finding of Underwood et al. (2004). In their studies, participants were instructed to verify a statement about a photo. When the photo was presented before the statement, the inspection time on both was longer than when the photo was presented after the statement. That is, when the statement was presented first, it constrained the interpretation of the following photo so that the participants inspected the photo simply for confirmation. However, when the photo was presented without supplementary statements, participants might have to remember several interpretations and some details of the photo so that they spent more time on the photo and verifying these alternatives with the following statement. Undoubtedly, this speculation demands future investigations for confirmation.

### *13.2.2 Comparing Presentation Modes in Multimedia Material*

She and Chen (2009) compared the effects of interaction modes (animation versus simulation) and sensory modality modes (narration versus on-screen text) on learning the mitosis and meiosis processes by seventh graders. Scores of the posttest and retention-test 5 weeks later were consistent with eye movement measures (total inspection time and mean fixation duration in the pictorial areas). For the animation mode, learning outcome was better with narration than on-screen text, confirming the modality effect. The animation-narration group had longer total inspection time and larger mean fixation duration in the pictorial areas than the animation-text group. On the contrary, for the simulation mode, learning outcome was better with on-screen text than narration, presumably because it was easier to understand the difficult concepts through simulation with permanent text than fleeting narration. Analogously, participants in the simulation-text group paid more attention to the pictorial areas than those in the simulation-narration group. For the on-screen text mode, animation presentation may result in a split attention effect because learners could not control the learning pace. It follows that the animation-text group had shorter inspection time in the pictorial areas and had worse learning outcomes than the simulation-text group. However, although the animation-narration group focused more on the pictorial areas than the simulation-narration group, there was no significant difference in their learning outcomes. To summarize, without control of presentation rate, animation had beneficial effects when accompanied by narration. On the contrary, with the control of learning pace, simulation had facilitatory effects when learners could obtain information from steady text than from uncontrollable narration. In addition, the results also demonstrated that the longer the inspection time, the more effort was devoted to the learning material, and the better the learning outcome was.

Liu et al. (2011) investigated the redundancy effect of presenting both on-screen text and voice-over narration when nonscience-major undergraduate students read web pages with static graphical illustrations of weather systems. Each page consisted of a static graphical illustration and one of three types of verbal information, namely, on-screen text only (picture-text, PT), on-screen text and voice-over narration simultaneously (picture-text-voice, PTV), and voice-over narration only (picture-voice, PV). Eye movements were recorded when they read three web pages. After reading each of the pages, perceived cognitive load was rated separately. The perceived cognitive load was highest in the PTV condition and lowest in the PV condition, whereas that in the PT condition was similar to that in the PTV condition. The total fixation duration was longest in the PT condition, and there was no difference between the PTV and PV conditions (number of fixations showed a similar pattern). The text area was fixated on longer in the PT than in the PTV condition; although there was no difference in the illustration area between these two conditions. Comparing the PT and PTV conditions, the results suggest that the redundancy effect of voice-over narration was marginal; on the contrary, adding voice-over narration even reduced the time spent in the text area. In addition, replacing on-screen text (PT) with voice-over narration (PV) seemed to relieve cognitive load resulting from competition in the visual modality between pictorial and text information (before and when transforming the visual form of text information into verbal form). No difference among conditions in the illustration area was observed in this study.

In the study of She and Chen (2009), inspection time in the pictorial areas increased when the combination of interaction and sensory modality modes were suitable for learning (i.e., animation-narration and simulation-text). However, in the study of Liu et al. (2011), no difference was observed in the pictorial area among conditions. Instead, adding voice-over narration reduced inspection time in the text area (comparing PTV and PT conditions). It should be noted that the two studies differed in the visualization used. While that in the study of She and Chen it changed dynamically (controlled by the participants or the system), that in the study of Liu et al. remained static. Further and systematic investigation, in which static illustrations, animation and simulation modes together with text or narration are manipulated, may elucidate how learners combine information from different modalities on the one hand, and how verbal information facilitates information extraction from the illustrations on the other.

### *13.2.3 Real Classrooms*

Yang et al. (2013) demonstrated the application of eye-tracking techniques in a real classroom. In their study, an instructor gave a lecture with a PowerPoint presentation concerning evidence of the existence of dinosaurs and theories about the causes of their extinction. Due to the limitations of the current eye-tracking techniques, it was presented as one-to-one instruction. There were various formats in the PowerPoint slides, such as outline, photo only, photo with text, and conceptual graphic and text. Twenty-one undergraduate students participated in this study, with half of them majoring in earth science (ES) and familiar with the issues included in the lecture, whereas the other half majored in other science disciplines (non-earth-science, NES). The major findings are as follows. First, the proportion of time spent on the PowerPoint slide when it was presented (percentage of viewing time, PVT) was about 29.7–59.2 %, indicating that the students spent some of the time elsewhere, presumably on the instructor. The PVT on slides with text and photos (43.8 %) was higher than that on slides with photos only (35.1 %). On the other hand, the average fixation duration on slides with text and photos (261 ms) was shorter than that on slides with photos only (280 ms). Second, concerning different AOIs (title, text, and picture) in a slide, students rarely looked at titles. When both text and pictures were presented in the slide, the proportion of time spent in zone (PTSZ) was higher for text than for pictures, but the average fixation duration was generally higher for pictures than for text. However, for slides with conceptual graphics, the difference between text and pictures decreased. Also, the PTSZ was higher for conceptual graphics than for photos. Third, comparing students with different levels of prior knowledge, ES students tended to spend more time than NES students on text. As for pictures, either an opposite pattern or no significant difference was observed. Detailed analysis of slides with text and conceptual graphics describing the possible causes of dinosaur extinction revealed that, compared with NES students, ES students tended to focus on keyword areas in the text and critical areas in the conceptual graphics. ES students also had more between-zone scan paths. There are multiple sources of information in a real classroom, for instance, text and illustrations on slides, instruction, and gestures of the instructor, and interaction between students. Learners with different levels of prior knowledge may rely on different sources to gain knowledge. In addition, compared to multimedia learning material with recorded narration (which may be redundant if it is the same as the on-screen text), the instruction from the lecturer may play a different role and serve to guide students' attention to important parts of the slides.

### *13.2.4 Problem Solving*

Tsai et al. (2012) investigated the scanning patterns when undergraduate students majoring in computer engineering solved one multiple choice problem about which of the four factors (i.e., rainfall, slope, debris, and temperature) could cause landslides. Their think-aloud protocols during problem solving were analyzed and served as the basis to categorize them into successful and unsuccessful problem solvers. Overall, fixation durations on the chosen option were longer than those on the rejected options; similarly, the percentage of fixation durations (i.e., fixation durations in proportion to the total fixation durations in the trial) were longer on the relevant than on the irrelevant factors. Sequential analysis of transitions between different AOIs representing factors and the question showed that successful problem solvers had a tendency to transit from irrelevant factors to relevant factors, while unsuccessful problem solvers showed the reverse pattern and tended to look back to the question. The findings imply that some students had difficulty solving the problem, especially distinguishing between relevant and irrelevant factors.

Liu and Shen (2011) examined the strategies used by third and fifth graders when they solved propositional problems concerning concentration. In the orange juice test, for instance, option A consisted of one cup of juice and four cups of water whereas option B consisted of four cups of juice and one cup of water; participants had to decide whether option A or B was sweeter. The orange juice test could be presented iconically (i.e., with colored cups representing juice and water) or symbolically (i.e., with numbers, e.g., 1/4 for option A and 4/1 for option B). The test items also varied in difficulty. Overall, the third graders had longer total fixation duration and longer total time (including fixations, saccades, and blinks) than the fifth graders. Both groups of students had longer average fixation duration when solving problems with symbolic than with iconic representations. In addition, there were three possible transition patterns, namely, transition between cups of juice and water in the same option, transition between the same drink in both options, and cross transition between cups of juice in option A (or B) and cups of water in option B (or A). The third graders most often compared the same drink in both options, and sometimes compared cups of juice and water in the same option. Their transition patterns did not change with variation in presentation types (symbolic or iconic) or item difficulty. However, the fifth graders had different transition patterns that varied with item difficulty and presentation types. Thus, the fifth graders seemed to engage in different strategies flexibly according to the type of problem to be solved.

Lin and Lin (2014b) also investigated the eye movement patterns when senior high school students solved five geometry problems concerning similar triangles, in which an unknown length of a specific side should be calculated. These five problems varied in difficulty, in that they demanded horizontal/vertical translation, reflection, and mental rotation for one of the triangles. The pass rate confirmed the manipulation of item difficulty (at least, the fifth problem was the most difficult item) and it could be predicted by the participants' perceived cognitive load. Eye movement measures (total fixation time, fixation count, and number of runs) followed the order of difficulty. That is, difficult items had longer total fixation time, higher fixation counts, and more runs than easy items. Total fixation time and fixation count also positively correlated with cognitive load. Comparing heat maps of unsuccessful solvers to successful solvers revealed that unsuccessful solvers tended to inspect the whole problem, and had longer fixations in the informational areas (such as digits for lengths of sides of the triangles and the intersection between triangles). As the total fixation time lengthened when the difficulty increased, it follows that unsuccessful solvers had longer inspection times. In addition, they might not be able to distinguish critical regions from less important areas, so they tended to fixate on all locations in the problem.

In another study, Lin and Lin (2014a) examined how senior high school students solved the same five problems with a handwriting device. Thus, the AOIs included a one-line question, a diagram of similar triangles, and the output area (where the solution written through the handwriting device was presented). For the most difficult problem #5, successful solvers spent more time in the output area than the unsuccessful ones. Similarly, the correlations between the perceived difficulty of item 5 and number of fixations as well as total fixation time in the output area were negative, whereas they were positive in the diagram area. That is, when it was difficult to solve a problem, solvers needed to process the diagram extensively. In addition, unsuccessful solvers tended to have more fixations and look backs in the question areas. To summarize the two studies, fixation counts and durations signified the ease and efficiency in problem solving; therefore, they positively correlated with item difficulty. Furthermore, unsuccessful solvers might not be able to distinguish relevant from irrelevant information, so that they fixated on the whole diagram extensively to solve the problem.

Chen et al. (2014) investigated the eye movement patterns when science-major undergraduate students solved physics problems presented in either text or picture formats. The computer-based assessment performance was better with text than with picture presentation. For both formats, correct items received longer mean fixation duration (MFD) and more rereading time in proportion (RRTp) than incorrect items. The mean saccade distance (MSD) was shorter for correct items than for incorrect ones with picture presentation but there was no difference between the correct and incorrect items with text presentation. Comparing text and picture presentations, for both correct and incorrect items, MFD was longer, MSD was shorter, and RRTp was less with picture format than with text format. This finding suggests and confirms that the picture had higher information density than the text (longer MFD and shorter MSD); however, readers had to integrate information from the text rather than from the picture, resulting in more rereading of the text. In addition, the total inspection time for the text presentations was longer than for the picture presentations. Furthermore, one of the purposes of their study was to investigate whether eye movement measures could predict accuracy in problem solving. The results of the Generalized Estimating Equation (GEE) showed that MFD had the largest positive effect on accuracy (followed by RRTp) in both formats. When participants spent more time fixating and rereading the problems, they were more likely to answer them correctly. MSD had a negative effect on accuracy with picture presentation but no effect with text presentation. When participants made shorter saccades in solving the problems, they were more likely to have correct answers. In addition, for correct items, participants tended to fixate on critical areas in pictures and keywords in texts. They also fixated on these critical areas longer and reinspected them more often and longer. Thus, longer fixations and more reinspections, especially in the critical areas, increased the likelihood of correctly answering the problems.

To summarize, fixation durations and counts were positively correlated with item difficulty. Younger problem solvers might have few strategies available, whereas older problem solvers could change their strategies flexibly. Similarly, unsuccessful solvers might not be capable of identifying relevant parts of the problem, so that they might fixate on the problem extensively or leave the relevant part for the irrelevant part. On the contrary, Chen et al. (2014) found that mean fixation duration and reinspection frequency positively correlated with performance accuracy. This might seem to be contradictory at first glance; however, fixation duration and frequency are indicators of attention allocation. As mentioned in the first section, an AOI is fixated on and attended probably because it is interesting, relevant, or difficult to process. If enough test items are available in a single study, researchers can further analyze the interaction between item difficulty and accuracy. Maybe more attention is devoted to difficult problems; at the same time, when the problem solver pays attention to the relevant part of the problem, s/he is likely to succeed in solving the problem. Indeed, it was observed in the studies surveyed above that successful solvers tended to fixate on relevant areas longer than unsuccessful solvers. It should be noted that the participants in the study of Chen et al. were undergraduate students majoring in science. Thus, both the ability to identify relevant areas of the problem and whether enough attention is allocated to them contribute to problem-solving performance.

## 13.3 Summary and Suggestions for Future Investigation

Eye-tracking techniques take advantage of the fact that people naturally move their eyes to sample visual information for further processing. Where the participants fixate, how long they retain their gaze, and the sequence of fixations among several AOIs reveal the cognitive operation underlying information extraction from and processing of the material. The spatial, temporal, and sequential aspects of eye movements are influenced by both the stimulus properties and participants' knowledge about the cognitive relevance of the stimuli. The same stimulus can be processed in different ways if the task demands are different.

The common findings from the 15 articles about science education conducted in Taiwan are summarized as follows (refer to the summary table in the Appendix). First, a general text-oriented comprehension strategy in processing material with text and illustrations was found. Also, there were more fixations and longer inspection time for the text than for the illustration areas. Nevertheless, the general pattern altered when the illustration provided additional information (such as figures in a geometry proof) and when the participants had sufficient knowledge to obtain critical information from the illustration. In multimedia environments, the combination of presentation mode (static illustration, animation, and simulation) and modality of verbal information (text and narration) will influence how learners process the visual representation. Second, participants had different transition patterns among AOIs. Participants with higher-level prior knowledge tended to make transitions among (critical) AOIs, whereas those with lower-level PK rarely inspected different AOIs alternatively. Moreover, older or successful problem solvers had more and flexible transition strategies whereas younger or unsuccessful solvers had less appropriate and fixed strategies. In addition, additional arrows or coloring could guide participants' attention and facilitate the comprehension process. Specifically, participants could follow the sequence of events signified by arrows, and their initial comprehension could be facilitated by coloring relevant parts of the illustration. Third, participants with higher-level PK tended to fixate on the relevant parts of the material longer and more often than those with lower-level PK. However, without sufficient PK, participants may fixate on all of the material thus lengthening their inspection time to solve the puzzle.

Enlightened by the findings of the surveyed studies, a plausible sequence of research can be formulated as follows. Applying eye-tracking techniques to study the learning process and information processing during problem solving can first illuminate how high achievers or experts extract and utilize information, and then examine the difference between low and high achievers. They may differ in the abilities to determine the relevance of the material and to comprehend the material, especially the illustrations. Retrospective interviews may reveal possible sources of the deficiency. Afterwards, an intervention program can be designed accordingly. When the learners have sufficient knowledge of why some parts of the material are relevant and how to process that information, their eye movements can be recorded to assess their improvement. Whether they have similar eye movement patterns as those of high achievers can be an indicator of the necessity of further training.

Nevertheless, it should be noted that eye movement patterns can diverge substantially with different task demands. In addition, if multiple parts of the material are relevant to the task, their saliency may attract different amounts of attention. This may be artifact if saliency is unrelated to the research purpose. Furthermore, total fixation duration and mean fixation duration can have different meanings. For example, participants may process more information during each fixation in one AOI (long mean fixation duration), but they may not devote much time or attention to that AOI (short total fixation duration). Thus, a set of eye movement measures should be considered simultaneously for appropriate interpretation of the data.

Within the past few years, an increasing number of researchers have devoted themselves to applying eye-tracking techniques to educational environments. After basic eye movement patterns (such as attentional distribution between text and illustration areas as well as the strategies used by participants with different abilities) are well documented, fine-grained cognitive processing can be scrutinized. In addition, systematic manipulation of prior knowledge, presentation mode, etc. can elaborate our understanding of how people with different abilities succeed or fail in learning from different formats of material about a variety of content areas.

## Appendix

Appendix: Summary of the 15 articles conducted in Taiwan (in order of appearance in the main text)
Note: PK (prior knowledge): High/ Medium/ Low; T: text; P: picture; E: experimental group; C: control group; R: right; W: wrong

| Author | Liu and Chuang | Hung | Liu and Hou | Ho et al. | Chen and Wu |
|---|---|---|---|---|---|
| Year | 2011 | 2014 | 2011 | 2014 | 2012 |
| Issue | Learning from material with text and illustrations | | | | |
| Material | Text+picture | Text+picture | Picture+labels | Text+pictures | Text+picture |
| Topic | Earth science (wind, atmospheric pressure) | Biology (bee communication) | Earth science (plate tectonics) | Earth science (greenhouse effect and global climate change) | Math (geometry proofs) |
| Participants | Undergraduate (nonscience major) | Grade-6 | Undergraduate and above (science major) | Undergraduate and above (mostly nonscience major) | Undergraduate and above (not familiar with the subject) |
| Number of participants | 8 | 6 | 36 | 13 | 31 |
| Participant variables | | | PK (H/M/L: 10/17/9) | PK (H/L: 6/7) | |
| Material variables | | | | | Coloring (within subject) |

| Author | Liu and Chuang | Hung | Liu and Hou | Ho et al. | Chen and Wu |
|---|---|---|---|---|---|
| Year | 2011 | 2014 | 2011 | 2014 | 2012 |
| Total fixation duration | T > P | | Label: H > L<br>Illustration: H < L | T > P<br>T: H > L (sec 2)<br>P: H > L | T > P;<br>T < P (per pixel)<br>E < C (initial comprehension time) |
| Total fixation count | T > P | T > P | Label: H > L | (Reinspection)<br>T > P<br>T: H > L (sec 3)<br>P: H > L | |
| Mean fixation duration | | T > P | No difference | | |
| Mean saccade length | | T < P | | | |
| Transition pattern | Refer to the visuals when there was text describing the kinematics of the system | | Transitions between labels as well as between labels and plates: H > L | High PK: text and diagram, between diagrams; low PK: rare | |

| Author | Jian and Wu | Jian et al. | She and Chen | Liu et al. | Yang et al. |
|---|---|---|---|---|---|
| Year | 2012 | 2014 | 2009 | 2011 | 2013 |
| Issue | Learning from material with text and illustrations | | Comparing presentation modes in multimedia material | | Real classroom |
| Material | Text + picture | Picture | (animation versus simulation) + (text versus narration) | Picture + (text or voice or both) | PPT + instructor |
| Topic | Neuroscience | Mechanics (flushing cistern) | Biology (mitosis and meiosis) | Earth science (types and causes of thunderstorms) | Earth science (extinction of dinosaurs) |
| Participants | Undergraduate and above (not familiar with the subject) | Undergraduate (nonscience major) | Grade-7 | Undergraduate (nonscience major) | Undergraduate (science major) |
| Number of participants | 42 | 40 | 24 | 16 | 21 |

| Author | Jian and Wu | Jian et al. | She and Chen | Liu et al. | Yang et al. |
|---|---|---|---|---|---|
| Year | 2012 | 2014 | 2009 | 2011 | 2013 |
| Participant variables | | | | | PK (H/L: 10/11) |
| Material variables | Arrows (between subject) | Numbered arrows (between subject) | (animation versus simulation)+(text versus narration) (between subject) | Text or narration or both (within subject) | |
| Total fixation duration | T>P | E ~ C<br>first-pass fixation duration:<br>E>C | P: A-N>A-T<br>P: S-T>S-N<br>P: S-T>A-T<br>P: A-N>S-N | All:<br>PT>PTV,<br>PT>PV,<br>PTV ~ PV<br>T: PT>PTV<br>P: PT ~ PTV | Slides with<br>PT>P<br>in one slide:<br>T>P<br>T: H>L<br>P: no difference |
| Total fixation count | | | | All:<br>PT>=PTV,<br>PT>PV,<br>PTV ~ PV | |
| Mean fixation duration | | | P: A-N>A-T<br>P: S-T>S-N<br>P: S-T>A-T | All: no difference<br>T: PT>PTV | Slides with<br>PT<P<br>in one slide:<br>T<P |
| Mean saccade length | P: E<C | E<C | | | |
| Transition pattern | Majority: transiting between text and illustration at the beginning;<br>E: more likely to inspect the illustration before reading;<br>C: more likely to finish reading the text before inspecting the illustration | E: followed the sequence;<br>C: compare same components in both diagrams | | | H: more transition among AOIs |

| Author | Tsai et al. | Liu and Shen | Lin and Lin | Lin and Lin | Chen et al. |
|---|---|---|---|---|---|
| Year | 2012 | 2011 | 2014b | 2014a | 2014 |
| Issue | Problem solving | | | | |
| Material | Picture+question | Iconic versus symbolic | Picture+question | Picture+question | Text versus picture |

| Author | Tsai et al. | Liu and Shen | Lin and Lin | Lin and Lin | Chen et al. |
|---|---|---|---|---|---|
| Year | 2012 | 2011 | 2014b | 2014a | 2014 |
| Topic | Earth science (factors causing landslide) | Math (propositional problems) | Math (geometry: similar triangles) | Math (geometry: similar triangles) | Physics |
| Participants | Undergraduate (computer engineering) | Grades-3 and 5 | Senior high school students | Senior high school students | Undergraduate (science major) |
| Number of participants | 6 | 37 | 63 | 63 | 63 |
| Participant variables | Performance (successful/ unsuccessful: 3/3) | Grade (G3/5: 19/18) | Performance (successful/ unsuccessful) | Performance (successful/ unsuccessful) | |
| Material variables | | Iconic and symbolic presentation (within subject) | | | Text versus picture (within subject) |
| Total fixation duration | Chosen > rejected; relevant > irrelevant | G3 > G5 | Longer for difficult items and unsuccessful solvers | For difficult problem: picture > output | T > P |
| Total fixation count | | | Higher for difficult items | For difficult problem: picture > output; question area: more fixation and look-back (unsuccessful solvers) | (Reinspection) T > P R > W positive correlation with accuracy |
| Mean fixation duration | | Symbolic > iconic | | | T < P R > W positive correlation with accuracy |
| Mean saccade length | | | | | T > P P: R < W P: negative correlation with accuracy |
| Transition pattern | Successful: irrelevant → relevant; unsuccessful: relevant → irrelevant and back to the question | G3: single transition pattern; G5: changed their transition pattern among problems | | | |

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# Chapter 14
# Public Communication of Science and Technology in Taiwan

**Chun-Ju Huang**

**Abstract** Science and technology has a prominent influence in the modern world. From the transition of the little science to the big science, there are many different factors involved in the development of science. How to improve the public understanding of science is going to be an important issue for most societies and cultures, especially in Taiwan, where technological industries play an important role in the economy by combining both negative and positive effects.

Based on in-depth studies and careful literature review, this chapter explores the relationships among science education, science communication, and social studies of science in Taiwan. According to the implication, and compared with the new trend of international studies, this chapter aims to build a new developmental diagram depicting public communication of science and technology in Taiwan. These results would likely provide a solid base from which the different academic groups may communicate, interact, and thus benefit from its usage.

## 14.1 Introduction

> …The incineration plant in Changhua County was suspected of burning industrial waste that contained iodine yesterday. The purple smoke induced panic in the neighborhood. It was the third time this had happened during the past eight months. The people's representatives and the environmental groups demanded a (more) thorough investigation. The plant was requested to stop burning the material immediately and to investigate the cause of the waste…
> (*The Liberty Times*, 20130531-C3)

This was an exhaust emission incident that occurred at an incineration plant in central Taiwan. It was also one of many numerous socioscientific issues that had happened worldwide. In the wake of such a technological issue, this news helped people not only experience scientific knowledge about the environmental issue, but also allowed them to understand the various problems that resulted from the

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incident. The ranges of problems were directly related to the aspects of society, economy, energy, environmental protection, and people's livelihood. From the most basic analyzed level, it was worth taking the time to reflect on the factors behind incineration plants that had contributed to air pollution, the types and contents of waste, the waste-processing procedure in incineration plants, and the possible social cost caused by the processes. With further reflections, people would be able to consider the possible impact on their everyday lives if the waste disposal plant was not there. They would also be able to understand how to manage the town's waste without waste disposal plants, and imagine how chaos might ensue if garbage trucks were not available to collect garbage for just one week. More constructively, the inquiry could be upgraded to address how to deal with garbage efficiently on a daily basis and suggest possible alternatives for garbage reduction. These would hopefully lead to a better lifestyle. Such daily science news would be closely related to the knowledge of such scientific events.

Reflecting on the above problems in the context of schools' science education in Taiwan, would students be capable of comprehending and judging such "authentic problems" while learning the scientific concepts about the environment and energy? Science education in schools focuses on the acquisition of stable scientific knowledge; however, with the rapidly changing society, mass media would be the most important information platform for students to connect with the latest science development sustainability. Mass media is playing a role of the "skin of culture", and as the skin, it has mediated people on how to perceive the new knowledge worldwide (Kerckhove 1995). In terms of public communication of science and technology, the mass media did not simply mediate the scientific information but also shaped it (Dimopoulos and Koulaidis 2002). In other words, the media did not simply provide a piece of news information directly related to science, but further guided people on how to comprehend and monitor the report. The media coverage with inadequate reports should be largely responsible for the citizens' "scientific illiteracy" (Bucchi and Mazzolini 2003). Taiwan, a small island, has been confronting a lot of socioscientific controversies that have been generated from high technology and energy-consuming industries. The public has to constantly pay a high cost for dealing with such problems. Therefore, it is an important mission for science communication, with the mass media being able to deliver qualified scientific messages that citizens could comprehend, to provide the citizens with appropriate scientific literacy for participating in the decision making of socioscientific issues.

Past research on science education showed that in-school science was used to be regarded as formal science learning, and off-school science as informal science learning. With the prevalence of communication technology, the line between formal and informal science learning has become vague. As such, the role of the mass media in science learning must no longer be neglected. Both international and domestic science education research have begun to pay salient attention on the emerging trend of science communication studies induced by the importance of the mass media. By reviewing the global development of science communication research and comparing this with Taiwan's history of science popularization, this chapter has attempted to establish a new developmental diagram depicting the public communication of science and technology in Taiwan.

## 14.2 The Global Trend Movement of Science Communication

### *14.2.1 Approaches of Science Communication Models*

Science communication in academia has been a rapidly developing subject in Europe and the USA over the past two decades. This is possibly due to the increasingly complex interdisciplinary disputes within the technological society. When the relationship between science and the public was still being interpreted with science popularization in Taiwan, the research had already gone through various phases throughout Europe and the USA. These phases included "scientific literacy" between 1960 and mid-1980, "public understanding of science" between 1985 and mid-1990, and "science and society" from mid-1990 onwards (Bauer et al. 2007). Such phases were generated from various social and cultural changes in different contexts. In such a rapidly changing era, the relationship between the public and science was constantly changing the quality that resulted in the transformation of research angles on science communication.

These developmental phases marked an emphasis on science communication in Europe and the USA, thus becoming an important academic research field. During the process, science changed from the affairs of scientists in laboratories to the common affairs related to the public, as modern science left "bite-size science" for "big science" (Price 1963; Galison 1992)[1]. Scientists needed to persuade the public to ensure their funding, and because of that communicating directly with the public became critical. Such requirements became more obvious when many researchers were led to explore the problem of public understanding of science and to construct a good relationship between science and the public. Several science communication models appeared in the changing process.

1. The Deficit Model
   The model was formed in the consideration that there was not a sufficient number of people within the population who understood enough about science, and would therefore be able to support the scientific budget and development. Such an idea and research originated from scientific communities, where the scientists

[1] "Big science" refers to team type and large economic-scale scientific development pattern, and "little science" refers to individual and small economic-scale scientific development pattern. Such terminology was proposed by Price in early 1960, when he largely calculated the number of scientists, scientific magazines, and scientific papers in the history and found that there was index growth in science industry scale in about 200 years and it doubled every 15 years. In other words, science has turned from "little science" into "big science"

showed themselves as being concerned about the public lacking the fundamental scientific knowledge and intended to replenish the knowledge gap—or in other words, the “deficit” (Miller 1983; Royal society 1985). It was assumed that once the gap was filled the public would also support science. Nonetheless, acquiring scientific knowledge in this approach was treated as the major task, and the situations where the public used scientific knowledge in their everyday life were neglected, and therefore the effectiveness of this approach was limited. Also, it had been found that members of the public did not necessarily appreciate science more even if they were better informed about it. Consequently, although it was not a very successful approach, rhetorically it was still alive in many science communication activities. (Trench 2008)

2. The Contextual Model
   It was claimed in the contextual model that the individual was not an empty container when facing information, but that people always possessed relevant knowledge and experience, depending on the environment and the cultural framework. The relationship between the public and science was dependant on different situations and conditions concerning their requirement and understanding towards science. In the contextual model which guided science communication strategies, different methods would be developed for distinct situations and requirements in order to deepen the public impression and knowledge concerning science. Such an approach compensated for the shortage of the deficit model, allowing the public to acquire or sense the required knowledge. However, this model has been criticized for being merely a more sophisticated version of the deficit model, because laypeople might often have no social freedom or power to use available scientific knowledge in the way they were assumed to have by experts (Wynne 1995). In this case, even though the contextual model integrated several theoretical sources of social psychology, the interpretation and guidance were still dominated by the scientific community.
3. The Lay Expertise Model
   This model was deduced from the research field of social studies of science. Based on the introspection of experts’ knowledge, it advocated the ideas developed from lay knowledge or lay experience (Irwin and Michael 2003). In this model, scientists were regarded as being too overconfident of their knowledge by ignoring the accidental or uncertain factors when they were reliant on their knowhow in different situations. The knowledge contributed based on laypeople’s experience about specific contexts was usually much more helpful than the decontextual knowledge derived from the scientific expert. The lay expertise model focused more on criticism of the deficit model and put the emphasis on the epistemic relevance of local knowledge and lay expertise. Compared with other science communication models, this approach was criticized in that it still did not develop a practical way to promote the public understanding of science.
4. The Public Engagement Model
   When compared to the criticism-oriented lay expertise model, the more advanced public engagement model attempted to integrate the public ideas in discussions about public issues (Brossard and Lewnstein 2011). This model was mainly built

on the commitment of democratizing science and generated various public participation strategies, including consensus conferences, citizen juries, deliberative democracy, and science shops. Transferring the control of science from elite scientists and politicians to the public, through empowerment and political participation, was the common feature in this approach. The model was also named as the dialogue model in the UK, which emphasized bringing the public into scientific issues, but not by simply yielding control (Miller 2001). Nonetheless, such a model was still criticized that it merely stressed on the science process but ignored the contents, and merely served a small number of people and, sometimes, for having an "anti-science" bias (Brossard and Lewnstein 2011).

Comparing the changes in such science communication models, they presented different emphases and advantages/weaknesses depending on the conditions. However, the frequent communication and interaction between science and the public have become indispensable.

### *14.2.2 Topics of Science Communication Studies*

Science, as a product of human culture, covered a broad range of topics. With the changing approaches in science communication models, research on science communication has been developed for almost two decades. The journal *Public Understanding of Science*, published since 1992, was not only the earliest but also a major journal of science communication, its planned topics presented landmarks in this field. The topics covered in this journal include[2]:

- Surveys of public understanding and attitudes towards science and technology
- Perceptions of science
- Popular representations of science
- Scientific and parascientific belief systems
- Science in schools
- History of science education and of popular science
- Science and the media
- Science fiction
- Scientific lobbying
- Evaluative studies of science exhibitions and interactive science centers
- Scientific information services for the public
- Popular protests against science ("anti-science")
- Science in developing countries and appropriate technology

Such topics covered the overall academic research in science communication and are the typical classification for relevant academic researches. Moreover, *Knowledge: Creation, Diffusion, Utilization*, renamed as *Science Communication* in 1994,

[2] http://www.uk.sagepub.com/journalsProdDesc.nav?prodId=Journal201663&ct_p=title&crossRegion=asia (2013.6.19)

was another representative journal. The editor, LaFollete (1994), indicated in the announcement of the changed version that:

> *Science Communication* responds to the challenges posed by the ambiguity, complexity, diversity, and variety of modern communication within, by, and about the social sciences, natural and physical sciences, mathematics, engineering medicine, and similar technical fields.
> (LaFollete 1994)

*Science Communication* still emphasized the interdisciplinary approach in submission statements and considered *communication within research communities, communication of scientific and technical information to the public*, and *science and technology communications policy* as the major topics for submissions[3]. These two advanced academic journals virtually defined science communication as a broader science education. The relevant topics stressed on the meaning and methods of communication science beyond the classroom and focused on the interdisciplinary characters of those topics. In the beginning of the 1990s, the emergence of such two academic journals marked a new research field, as well as a new era, that related directly to science communication. The perspectives and the development also made a prodigious impact on the development of traditional science education.

## 14.3 Challenges of Science Communication in Taiwan

### *14.3.1 Many Urgent Problems Awaits Resolving*

Equating to the international research development in science communication, an urgent need for further discussions in this field in Taiwan was revealed. From the related literature review, the inspection could be done in various categories. First, categories of *Science and the Media* mostly focused on scientific topics of medicine and food (Hsu 2005; Chiu 2009) or global warming (Yang and Hsu 2012), whereas other types of scientific knowledge were usually ignored. Moreover, the questions were related to how the media produced science information, how the media cultivated professional science communicators, what abilities and characters the science communicators needed to possess, how journalists interacted with scientists, and the types of interactions between scientists and journalists. These questions correlated the media and science into a deeper relationship, yet was seldom investigated in Taiwan.

Second, *Perception of science* was another research category that was commonly investigated in Taiwan. Particularly, abundant research about the public's perception in health and medical problems has been accumulated, such as the viewers' attitudes, responses, or influence on medical reports (Hsu et al. 2006; Lin et al.

[3] http://www.uk.sagepub.com/journalsProdDesc.nav?prodId=Journal200892&ct_p=title&crossRegion=asia (2013.6.19)

2005) and the reading comprehension of the readers towards science news (Huang and Jian 2008). Such research mostly focused on medical topics rather than much broader scientific topics; most of the target participants were undergraduate students. The wider range of readers, such as housewives, laborers, and minority groups, were not included. Regarding the types of media channels, other than newspapers and TV news, diverse science communication channels such as religious channels, talk shows about health, and home shopping channels were insufficient. Those channels reflected that the special media environment in Taiwan was worth further discussion.

Third, the research on the category of *Audience Education and Public Participation* contained an investigation on science promotion (such as science exhibitions and museums) (Wang 2005) and the applications of science media to students' learning scientific concepts (Huang 2006). Other research focused on the possible public participation models that were aimed at the technological, economical, and environmental conflicts in the Taiwanese society (Chiou 2002; Chou 2004; Lin and Chen 2005). The public participation in science must be practiced on the basis of the public comprehending and understanding all/most of the relevant issues. Problems such as how to assist citizens in forming the concepts and opinions about science and technology through public science education, and how to develop a suitable public technology participation model for Taiwan required much further investigation.

Finally, regarding the phase of *Macro Picture of the Public Understanding of Science*, Hsieh (2005) described the macro picture of science communication in Taiwan based on an empirical data review. Tsai et al. (2010) conducted a large-scale survey on scientific literacy of Taiwan's citizens. The empirical data accumulated in such results was favorable for the big picture in science communication, but it still lacked an overall and in-depth academic infrastructure. With the coexistence of the positive and negative effects of science in modern societies, the reflection towards technology development was going to be a popular issue globally. Nevertheless, only popularization and simplification of science were considered as the major strategies for improving science communication in Taiwan. With the lack of a macro statement about the interaction among science, the public, and the media, a consistent guidance for science communication in Taiwan was hardly able to be established. Such a situation also limited the practice of any action that usually stayed on the superficial level. Further problems such as how to simplify science appropriately, what were the critical factors that determined suitable science for the public, and how did the media affect science and vice versa still needed clarification based on the macro-theoretical level.

The above problems required urgent solutions before science communication matures in Taiwan. However, such problems were complex and interdisciplinary that the co-diagnoses and collaboration among different academic communities were imperative.

### *14.3.2 Boundaries Among Academic Communities: STS Research as an Example*

The academic research on science communication in Taiwan was emerging, even though it was comparatively slower than in Western countries, and especially the guidance behind science promotion that mostly remained on the science popularization idea that was based on the deficit model. In contrast with the rapidly developing science communication in Europe and the USA, the sluggish movement in Taiwan was partially caused by the barriers raised among the academic communities. Since science communication was a newly risen academic field with interdisciplinary features, it required a perspective view from a wider scope of various domains. For instance, the academic fields of science education, mass communication, and social studies of science and technology are highly related. Nonetheless, the interdisciplinary cooperation is extremely insufficient amid these fields in Taiwan.

With the example of Science, Technology, and Society (STS) research in Taiwan, two academic communities, the *science education* community and the *social studies of science and technology* community, were simultaneously concerned about the effects of technological development on society, and having more citizens participating in and discussing science. However, even when committing to similar aims, these two communities seldom exchanged or referred to the mutually relative academic research outcomes (Huang et al. 2008). From the literature review of STS research in Taiwan, the *science education* community focused more on the agenda of the curriculum development, following the US Project Synthesis reports in the 1970s (Huang 1995; Wang 1995), and the research direction of Professor Robert Yager of Iowa University, who regarded STS as a science teaching method or instruction design idea. On the other hand, Taiwan's *social studies of science and technology* community orientated STS as the integration of history of science, sociology of science, philosophy of science, and culture studies of science, and emphasized in providing a more diverse and complete understanding of science from each distinctive academic field.

The past research had discussed the parting between such two academic communities in Taiwan (Huang et al. 2008). In Fig. 14.1, the development of the *social studies of science and technology* community is shown on the right, starting with Merton (1938), who proposed the abbreviation "STS". Kuhn's (1962) philosophy of science followed Merton's work and affected the establishment of the "Society for Social Studies of Science" (4S), the theoretical development of the "Strong Programme" (Bloor 1976), and the actor–network theory (Latour 1987). Following such a path, the notion deeply affected the development and the theoretical basis of Taiwan's *social studies of science and technology* community.

The path of Taiwan's *science education* community is shown on the left, which followed the process of the US's STS curriculum movement. Since the USSR successfully launched Sputnik in 1957, the US science curriculum reform was induced, including Project Synthesis (1977) and the STS curriculum movement guided by National Science Teacher Association (NSTA) (1982). The research topics in Tai-

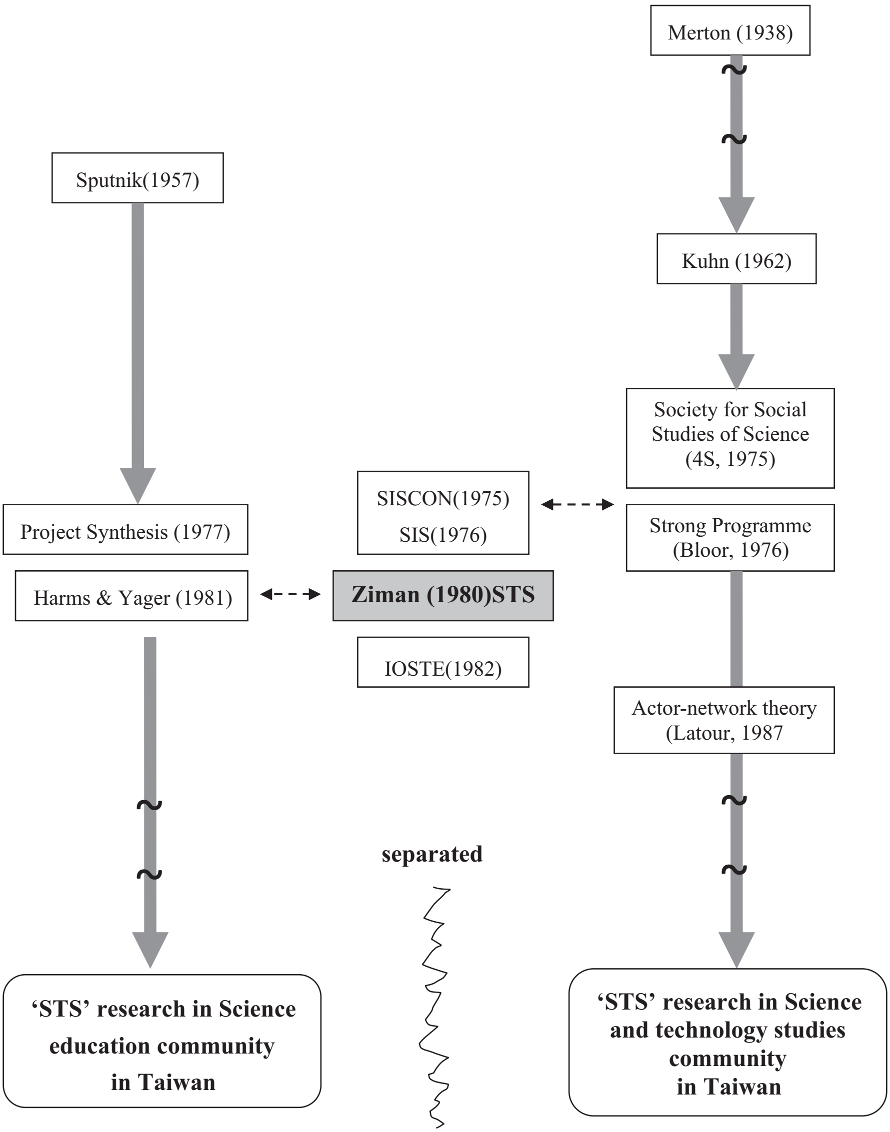


**Fig. 14.1** Different STS research approaches existed in two Taiwan's academic communities. (revised from Huang et al. 2008)

wan's *science education* community, therefore, covered science instruction, science learning, curriculum development, and the teacher's professional development under such guidance. The two such academic communities were often connected in the development in Europe and the USA. For example, SISCON (1975), SIS (1976), and Ziman (1980) in the middle of Fig. 14.1 played roles in connecting these two academic communities' STS research. With the boundaries found among the academic fields, the evolution of STS research in Taiwan fractured into two irrelevant academic communities with a clear gap between them.

The separated academic communities could hardly face these complicated problems independently in a modern society, the situation of STS research was one of the examples. Tasks of science communication that usually covered the social contexts of scientific events, scientists, mass media, audience, and relative organizations are complicated enough to coordinate between different fields for solving problems. Complications such as these are involved in the knowledge of science, sociology, mass media, psychology, education, and even economics and politics. Scholars of the sociology of science could understand the social effects of science and technology through macro perspectives, but could not investigate the psychological problems of the public. Scholars of mass media are familiar with the operational aspects of the media, but found it much harder to master the intrinsic natures of science and technology. Scholars of science education might well understand how precisely students learned science "in classrooms," but are not so aware of the public demands on science "in daily life." The complexity of such problems cannot be solved with knowledge gained from of a single angle, but rather the collaboration of scholars from various fields.

Institutes on science communication research in Europe mostly originated from the *social studies of science and technology* field, and then expanded to mass communication and science education (Huang 2012a). The origin of development within each country may well have been different, but the interdisciplinary interaction might be necessary for promoting science communication to be mature. It is considered as the most important direction for endeavor in Taiwan.

## 14.4 Steps to Improve Public Communication of Science and Technology in Taiwan

The difficulties and challenges of science communication are primarily coming from the transformation between "public communication of science" and "communicating science to the public." Science and technology were regarded as the "imported culture" for an in-depth image of Taiwanese, where a lot of complex factors, such as national dignity and self-esteem, could influence the effects of science communication. It was also one of the reasons why Taiwan still embraced the simplest deficit model to improve science communication, in contrast with the diverse models being employed in Western societies. In fact, these models were not mutually exclusive, as most communication situations could be described as the composition of different models (Bucchi 2008). Applying the simple and linear approach is no longer appropriate to the wider agenda that science communication is now addressing.

In addition to developing corresponding promotional strategies, educators and mediators of the public science communication in Taiwan should further define distinct steps at different stages. Based on the previous literature review and empirical discussions, “being correct,” “being popular,” and “being reflective” are proposed as the three progressive steps for promoting science communication in Taiwan.

### *14.4.1 Being Correct*

When scientists generate scientific knowledge or events, the basic requirements for science communication should be able to accurately deliver the relevant information. Such premise seems to be merely the practice of the deficit model and formal science education; nevertheless, it is the first step for appropriate science communication in Taiwan.

In the Western world, the quality of science in the mass media was also often criticized by scientists, researchers, and scholars (Bucchi and Mazzolini 2003). Regarding the media environment in Taiwan, the situation was of inferior quality. The tough and twisted competition that resulted from a declining media environment had caused the media to be unwilling to invest any resources for science communication. Furthermore, Taiwan’s education system divided students onto different tracks very early, and as a result, most journalists with a social science and humanities background have a distinct lack of scientific literacy. In addition, a small number of journalists with a science background were more likely to present other weaknesses, such as writing science being too difficult or accepting scientists’ ideas too easily (Han 1990). Moreover, Taiwan’s media heavily relied on science news from overseas; however, compilation of original reports and the domestic reports resulted in distortion of facts (Huang 2012b). The science news produced in such background material was often criticized as ignoring the scientific facts, emphasizing on irrelevant points, politicization, and lack of scientific contents (Hsieh 1992).

The sensationalized and distorted science news appeared far too often. For instance, Cheng (2003) analyzed a science report related to oysters. The news reported that the latest scientific study showed that the probability of Taiwan’s oysters that caused cancer was 500 times higher than that of American oysters. The real situation stated by the scientist, however, was that the threat will materialize if people eat 139 g of oysters every day for 30 years. The report misled the public by endorsing the fact that eating oysters would immediately induce cancer. Similarly, Chen (2003) pointed out the distorted report of “SARS saliva penetrating N95 masks” had fomented an atmosphere of distrust in Taiwanese society. A newspaper complied a medical research news entitled, “Looking at beautiful girls, men live for five years more,” which was discovered to be an unproven rumor on the Internet (Wang and Fang 2004). Another newspaper, holding a perspective that contradicted the principles of physics, reported that the Shinkansen trains in Japan could completely stop in three seconds after an earthquake (Tseng 2006). Such mistakes were published in Taiwan more often that they should have been.

If science educators or communicators were responsible for reporting appealing stories about science, they should first construct a story without misunderstanding science. If not, the following inference based on the stories would certainly appear to create greater problems, and the positive intention for communicating science would be reduced. Newspapers, broadcasts, TV, and magazines are important "hybrid forums" for reporting science news (Callon 1998) and these are not only the instant channels for public consumption of science but also a more efficient platform for scientists to learn about other scientific domains (Clemens 1986; Bucchi 1998).

### *14.4.2 Being Popular*

"Science popularization" usually referred to conveying scientific knowledge in simple, interesting, and attractive ways. After having completed "formal science education" in schools, most citizens in Taiwan would disconnect from science. Even though Taiwanese students obtained outstanding achievements in many international competitions and evaluations of science (like PISA 2009, 2012), they still showed very low confidence in learning science (Lee 2012). The "high achievement but low confidence" phenomenon mirrored the low willingness to access science "autonomously" when removing the pressure of an examination from everyday life.

Popular culture was considered as one of the sensitive probes in estimating the popularity of science in daily life. If science was popularized within society, it could be observed from the role science played in various types of popular cultures. The presentation of popular culture, including TV, movies, novels, video games, pop music, and animation, is regarded as the closest cultural type to laypeople's lives. With the example of pop music, Artichoke[4], an American band based in LA, released two albums in which the songs were named after scientists in alphabetic order (each album told the stories of 26 scientists); Chien-shiung Wu (吳健雄), a Chinese Physicist, was also included. Radiohead, an alternative rock band in the UK, wrote the song, *Supercollider*, talking about the large Hadron Collider experiment in Europe. The science magazine *Scientific American* praised the Icelandic singer and musician Bjork for her artistic portrayal of Iceland's geological nature that rests between two tectonic plates (Jabr 2012). This geological fact was the theme of the song and music video, "Mutual Core," in which geological activity was used as a metaphor for the volatility of an intimate relationship. As such, those pop music lyrics directly pointed to the core of scientific activities, which have not been touched, as yet, in Taiwanese pop music (Huang 2013).

The promotion of science is not merely a top-down relationship between science and the public, but that the public would construct their own demands and understanding of science based on distinct situations and conditions, just as what has been indicated in the contextual model. For this reason, various types of informal science education are also the means of science popularization. Taiwan invested heavily in science museums, scientific exhibitions, science festivals, and scientific games to provide the public with multiple channels to interact, communicate, and be better able to understand science. However, the connection between science and people's

[4] http://artichoketheband.com/

daily lives were still not very fluent, and the actions taken to encourage citizens to be concerned about public scientific issues were relatively few. For example, "science shop" had been promoted by the European Union for several years. Its idea obligates that science must be close to the public, just like any shop that provides a service in the community. "Science shop" could integrate science into local situations through "selling science," such a selling action does not aim to make a profit, but rather to satisfy citizens' needs for scientific knowledge. The action could also assist in fostering the public awareness of science in society. For instance, the intervention of science and technology could and has helped improve the lives of the disabled, the elderly, and young children in different communities. "Science shop" is one of the possibilities beyond the typical science popularization actions and has been considered, on a practical imagination level, for promoting science communication in Taiwan.

The action of science popularization must be rooted in everyday lives, as it does not necessarily provide an ultimate science consensus for every issue, but nevertheless is needed to open a dialogue among various social worlds. Lemke (1990) regarded learning science as learning to "talk science," i.e., employing scientific language to read, write, present, and solve problems. By comparison with talking science "in schools" being the major aim for science education, enhancing the public to naturally talk about science in "daily life" would be the primary task for science communication at this stage.

### *14.4.3 Being Reflective*

According to Stocklmayer and Gilbert (2002), cultivating the citizens with public understanding of science will benefit national development, economic growth, public policies, individual decision making, daily lives, perceptions of risks and uncertainties, and understanding contemporary thoughts and culture. In addition, people need appropriate scientific literacy to face more socioscientific issues caused by technological development (Millar 1997; Sadler and Zeidler 2004). How to negotiate and resolve such issues is not simply a big challenge for society, it also reveals how mature a democratic society has grown to be.

Socioscientific issues are gradually increasing in Taiwan, including the construction of nuclear power plants, the risks of radiation from base stations, and environmental pollution, as well as the impacts of cloning technology, nanotechnology, digital communication, new types of energy sources, and so on. Such issues drove the public to not just simply praise science but also to denunciate the side effects and/or the negative impacts of technological development on their lives. As with the previous descriptions in the lay expertise model and the public engagement model, the possible solutions should rely on the public's participation and feedback from such issues. For this reason, a reflective science communication action will assist the public in appropriate rethinking and reconstructing the effects, influences, and controversies of science.

In face of such complex socioscientific issues, the media in Taiwan usually appears to promulgate one of the two extreme approaches when presenting the issues, either the “science education approach” with great esteem for science, or the “social movement approach” adopting almost “anti-science” intention. The former admired the objectivity and neutrality of science, whereas the latter was against any phases of technologic developments. Such exaggerative and naïve science communication actions cannot assist the public in experiencing and judging restrictions and uncertainties of these issues fairly. Millar (1997) concluded several characters of socioscientific issues, including scientists who usually did not have a consensus for issues, relative data that was still incomplete or uncertain, events or situations containing numerous uncontrollable factors, and issues that cannot be determined by scientific experiments. Suitable science communication actions are required, leading the public to consider such uncertainties, while increasing their attention span for them to participate in the issues.

As socioscientific issues were complex and hard to resolve, many scholars in Taiwan proposed promoting deliberative democracy, consensus conference, and deliberative polls to expand the citizens’ participation in science and technology policies (Lin and Chen 2005). Cultivating the public to be concerned about socioscientific issues must be based on the reconstruction of civic consciousness towards science. A science communicator, with critical and reflective thinking, could help these scientific issues to be no longer classified as being outside of the public policy-making domain in a democratic society.

Three landmarks for improving public communication of science and technology

| Steps | Definition | Major action field |
|---|---|---|
| Be correct | Being able to express the scientific knowledge truly and accurately | Science news (newspaper, broadcast, TV, magazine…etc.) |
| Be popular | Being able to convey scientific knowledge in simple, interesting, and attractive ways | Science in popular culture (novels, books, films, comics, and music…etc.), informal science education settings (museums, science festival, science coffee, science shop…etc.) |
| Be reflective | Being able to assist the public in appropriate rethinking and reconstructing the effects, influences, and controversies of science | Deliberative democracy, consensus conference, deliberative polls…etc. |

The three-phased steps are practiced in different fields, but they are not considered as one-way correspondence or mutually exclusive. If science news could master the accuracy of science first, prior knowledge of the audience could be further taken into account and reconstructs as a readable and understandable report. When facing major socioscientific issues, the correlations among society, economy, politics, culture, and science must also be considered in reports to achieve "reflective" science news. If any science communication actions, practiced in various fields in Taiwan, are considered as being of the three-staged landmarks, it would gradually be presented with enough maturity to be connected with the rest of the scientific world.

## 14.5 Conclusions

Communication practices in science were mainly developed in relation to two broad processes, the institutionalization of research as a profession with higher social status and increasing specialization, and the growth and spread of the mass media (Bucchi 2008). This situation identified the reason why science communication was gradually emphasized worldwide. In addition to the steady development of the *Public Understanding of Science* journal and the *Science Communication* journal in the past two decades, the open access journal, *Journal of Science Communication*, was also established in 2002, that aimed to challenge and add dialogue in the world of social studies of science that stressed on the importance of the communicative processes into science's development, and the dynamics of contemporary knowledge societies.

This tidal wave on science communication also impacted the traditional research on science education. For example, in the publication preface of the *Cultural Studies of Science Education* journal in 2006, science education was defined as a cultural, cross-age, cross-class, and cross-disciplinary phenomenon. It further emphasized that the journal aimed to be a bridge between science education and the social studies of science, public understanding of science, science and human values, and science and literacy (Roth and Tobin 2006). Such descriptions not only expanded the coverage of science education but also connected science education with the public and culture.

Furthermore, the expansion of science communication research has also influenced several important journals of science education. For example, the *International Journal of Science Education* was divided into two different parts in 2011: Part A, which continued with the original principles and scale of research in the traditional science education field; and Part B, that was divided into master topics of "communication and public engagement" in science that included three main purposes:

1. To bridge the gap between theory and practice concerning the communication of evidence-based information about the nature, outcomes, and social consequences of science and technology.
2. To address the perspectives on communication about science and technology of individuals and groups of citizens of all ages, scientists and engineers, media persons, industrialists, policy makers from countries throughout the world.

3. To promote rational discourse about the role of communication concerning science and technology in private, social, economic, and cultural aspects of life.

Another publisher of the *Journal of Research in Science Teaching* called for a special edition of "Bridging science education and science communication research" in 2014. The submission descriptions emphasized that there are several similar topics for "the public understanding of science" in science education and science communication, however, only a few exchanges of ideas were made in between:

> "…two disciplines concern themselves with the study of public knowledge of science: Science Education (focusing on K-12 students, higher education and informal learning environments) and Science Communication (focusing on interactions between the scientific community and other publics). Regretfully, there is very little dialogue between these disciplines. Science educators sometimes view science communication as a marginal subcategory of informal science education, while many science communication researchers frown at the thought of studying science communication from an educational perspective… "(Baram-Tsabari and Norris 2013)

This research trend appeared in international journals and the academic topics resulted from the urgency of public science communication. The international trend not only explained the importance of interdisciplinary integration but also served the needs of science educators whose research interests had to be expanded beyond the realm of school science (Ogawa 2011). In the past few decades, Taiwan's science education has accumulated an abundance of valuable research results to become the solid base for enhancing science communication. Dunwoody (2010) mentioned that a science communication scholarship is inherently multidisciplinary, if not interdisciplinary. It is expected that mediators and instructors in Taiwan have perceived the inherent interdisciplinary features in science communication, and then move forward by following the three-phased steps through identifying the essential questions and breaking the barrier among academic communities.

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# Chapter 15
# Comments on Section 3: Innovative Technologies for Science Learning and Instruction in Taiwan: A Global Perspective

**Joseph Krajcik**

**Abstract** The incredible breakthroughs in science, technology, and engineering over the past 25 years have brought about unprecedented new opportunities to explain complex phenomena, harness natural resources, and improve the quality of life for individuals throughout the globe. Advances in communication technologies have united people across the globe. However, these and other scientific, technology, and engineering developments give rise to a myriad of global issues. Global warming, severe and unpredictable weather patterns, pandemics, uneven distribution of health and dietary attention and supplies, loss of species diversity, and pollution of our waterways and air serve as examples that have arisen from living in a scientific and technological society. Science education can play an important role in preparing citizens to design solutions to these problems. Through science education learners can develop deep understanding of the big ideas of science, learn to collaborate and communicate with one another, and develop capabilities to apply scientific ideas and practices in new situations to find solutions to problems. The use of innovative technologies in the teaching and learning of science can provide unprecedented opportunities to allow students to use ideas to find solutions to problems, explain phenomena, and explore new areas to learn more.

The incredible breakthroughs in science, technology, and engineering over the past 25 years have brought about unprecedented new opportunities to explain complex phenomena, harness natural resources, and improve the quality of life for individuals throughout the globe. Advances in communication technologies have united people across the globe. However, these and other scientific, technology, and engineering developments give rise to a myriad of global issues. Global warming, severe and unpredictable weather patterns, pandemics, uneven distribution of health and dietary attention and supplies, loss of species diversity, and pollution of our waterways and air serve as examples that have arisen from living in a scientific and technological society. Science education can play an important role in preparing citizens to design solutions to these problems. Through science education learners

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can develop deep understanding of the big ideas of science, learn to collaborate and communicate with one another, and develop capabilities to apply scientific ideas and practices in new situations to find solutions to problems. The use of innovative technologies in the teaching and learning of science can provide unprecedented opportunities to allow students to use ideas to find solutions to problems, explain phenomena, and explore new areas to learn more.

The use of various forms of innovative technologies, including interactive tablets, smart phones, and network technologies, in science education has captured the imagination of teachers, designers, and researchers to improve the quality of teaching and learning of science. Innovative technologies provide functionality that allows students to analyze data, build models, use simulations of unseen worlds, and solve complex problems. The flexibility, interactive power, networking capabilities, customization capacity, and multiple representation capabilities of innovative technologies can help to change the structure of the science classroom (Krajcik and Mun 2014) and the instructional practices of teachers. The interactive capabilities and the functionality to capture, display, and analyze data make computers ideal for engaging students in science. Unfortunately, even with these interactive capabilities, computers in classrooms are often not used as tools to engage students in exploring and making sense of science. The potential to promote student learning will be realized when technologies are used in ways to support the exploration and sense making of ideas that can't be accomplished without their use.

The five chapters in Sect. 3, *Innovative Technology for Science Learning and Instruction in Taiwan*, of Science Education Research and Practice in Taiwan illustrate the development and research that has occurred around innovative technologies in Taiwan. The chapters present summaries of research as seen in *Innovative Technology-Assisted Science Learning in Taiwan (Chap. 10)* to design-based research as seen in *Development and Evaluation of Technology-Infused Learning Environment in Science (Chap. 11)* to stretching possibilities of exploring how students learn science as seen in Neuroscience (*Chap. 12*), *Eye Tracking Methodology and Application in Science Education (Chap. 13)*, Public Communication of Science & Technology. As such, the chapters present insights into the use of innovative technologies as well as research methodologies to explore students' learning. The chapters document how researchers in Taiwan have become a part of the global presence exploring the potential of innovative technologies. In this commentary, I briefly highlight some major points made in each of the chapters. I end by presenting some remarks for future research studies focusing on learning technologies.

## 15.1 Chapter 10: Innovative Technology-Assisted Science Learning in Taiwan

In this chapter, Tzu-Chiang Lin and Chin-Chung Tsai describe the background of technology-assisted science learning research in Taiwan and review the findings from various research studies published about technology-assisted science learning by Taiwan researchers from 2003–2012. Broadly speaking, Lin and Tsai equate technology-assisted learning as the use of various e-learning environments, including virtual reality, mobile learning, ubiquitous learning, augmented learning, or game-based learning.

The chapter summarizes the technologies used in science learning, the methodologies used to study various technology interventions, and the research areas explored by Taiwanese researchers. Lin and Tsai chose to examine only those articles that appeared in SSCI journals, focused on Taiwanese participants, and included both e-learning and science education. With clearly defined criteria, the manuscript presents a detailed account of the prominent work that has occurred in Taiwan with the use of innovative technology in science education. Interestingly, they report that researchers from Taiwan participated in over 10% of the studies focusing on the use of technology for educational purposes and, as such, in terms of publications related to technology Taiwan is the third most prolific country. This is an amazing statistic considering the size of Taiwan. From a policy perspective this shows that the Taiwanese government's investment in e-learning has shown results.

One interesting finding that Lin and Tsai report is that the research has shifted from examining the effectiveness of e-learning environments to teaching and learning practices with innovative e-learning environments. Such a shift is critical because the field needs to learn how to use innovative technologies to support students to engage in and make sense of science. Two additional findings that they mention attracted my attention. First, researchers in Taiwan focus primarily on examining affective perspectives and achievement in e-learning environments and on how to develop e-learning environments. The second finding is a shift from technological application to support science learning to mobile technologies to support and strengthen "traditional" web-based learning.

Lin and Tsai suggest other possible new methodologies for exploring issues related to e-learning in science education, such as social networking analysis, eye-tracking analysis, and text-mining. Based on their analyses, I would like to encourage Lin and Tsai discuss what might be the most fruitful research questions that need to be explored to help promote the teaching and learning of science through the use of technology. One area that stems from their work is that more careful studies need to be explored on how to design mobile learning environments that promote students in exploring and making sense of phenomena.

## 15.2 Chapter 11: Development and Evaluation of Technology-Infused Learning Environments in Taiwan

Ying-Shao Hsu and Hsin-Kai Wu's chapter reports on their research work in the Technology-Infused Learned Environment (TILE) research and development team in Taiwan. The TILE research team takes a design-based research approach to iteratively design, develop, and revise technology learning environments to promote student engagement and learning in science. What I find so critically important is that design-based research allows researchers to uncover and refine important principles that support student learning and engagement. TILE includes the following features: (1) the visualization of scientific concepts and principles to promote conceptual understanding, (2) linked-multiple representations and web-based sharing tools that promote collaboration and communication; and (3) innovative and advanced technologies that enable teachers to use digital resources and support students in authentic scientific investigations. The iterative design-based research of Hsu and Wu has allowed them to refine these ideas and encapsulate them in products that enhance student learning. As they state in the conclusion of their chapter, the use of iterative cycles of design and development promote the designs of technology-infused learning environments and provide insights into refining principles for guiding future designers and science researchers.

Hsu and Wu report on a number of findings that result from their research. However, three findings stand out. First, a student-centered orientation to designing technology enhanced learning environments that incorporate contextualized environments that connect to students' prior experiences, and engages students in sense making through exploration and modeling can support students in developing conceptual understanding that can be used to explain phenomena and design solutions to problems. Second, metacognitive scaffolding embedded within technology can support students in a variety of scientific practices such as creating, testing, and revising scientific models. Perhaps more significantly, students with lower metacognition showed significant improvements in their inquiry abilities. Third, integrating a decision-making framework into technology learning environments can support students in making scientific decisions about complex socioscientific issues.

What I find so important about these three findings is that as a global community we need to know the design principles that can support students in making use of knowledge to find solutions to problems and explain complex phenomena, support students in learning new ideas and engaging in scientific practices, and use decision-making techniques. Hsu's and Wu's chapter illustrates how researchers and designers can incorporate various innovative features to promote students' capability of using knowledge to find solutions to problems, explain phenomena, and make decisions.

## 15.3 Chapter 12: Innovative Science Educational Neuroscience: Strategies for Engaging Brain Waves in Science Education Research

Chia-Ju Liu and Chin-Fei Huang take us down a new and potentially provocative road to explore science learning and teaching by considering what we can learn from neuroscience research using neuroscience techniques. Their chapter uses technology to study student learning. Without the breakthroughs in technology development, neuroscience research would not be possible. Liu and Huang present a detailed overview of neuroscience and neuroscience research and discuss possible opportunities for science education. Techniques such as electroencephalograms, event-related potentials, and functional magnetic resonance imaging (fMRI) are described. Although findings from neuroscience research related to science education are nascent and not as yet applicable to science classroom interventions, basic research into these areas hold the potential to promote learning across a diversity of learners in actively constructing knowledge. Other areas of research in neuroscience such as attention, memory, emotions, and reading comprehension are more advanced. As they report in their chapter, some work has been done in neuroscience and science education, particularly with respect to chemical education.

As the authors describe science education and neuroscience is an interdisciplinary field that integrates science education, psychology, and biological. From my knowledge of the field, only a few researchers globally are conducting neuroscience research with science education. Because of the remoteness of the findings to classroom interventions, one might ask why this field is important. Perhaps the answer is too obvious and too simplistic but, as Liu and Huang suggest, understanding the characteristics and limitations of the human brain is critical in understanding how to promote learning. What this chapter presents is a blueprint of a bridge that can link neuroscience research and science education. As Liu and Huang suggest building this bridge could provide new insights on how to promote the teaching and learning of science in classrooms. As such, their work presents new avenues to explore the learning of science.

As mentioned above, some research work has been conducted in using neuroscience research techniques in the area of science education (Huang and Liu 2012 as reported in Liu and Huang, this volume). Huang and Liu found that while both high- and low-achieving students used similar mental rotation strategies to identify 3D chemical structural formulas, they used different mental rotation strategies to identify 2D chemical structural formulas. Huang and Liu's study provides biological evidence that mental rotation affects the identification of chemical structural formulas. Moreover, the study demonstrates the potential neuroscience research techniques could have on improving the teaching of science.

What I see as the important point of this chapter is that researchers in science education need to investigate this new and potentially viable area of research. Although only in its nascent state, the findings from neuroscience research for learning holds promise for the teaching and learning science.

## 15.4 Chapter 13: Methodology and Application of Eye- Tracking Techniques in Science Education

Like Liu and Huang, Miao-Hsuan Yen and Fang-Ying Yang explore new methodological areas for research in science education. Yen and Yang present a detailed account of eye-tracking methodology and provide a careful delineation of the major ideas in eye-tracking research. Although a relatively new area of research in science education, eye-tracking research is more advanced and developed than neuroscience research in science education. Researchers in geoscience and chemical education research have made use of eye-tracking findings to design better ways to focus students on various representations. (See for instance the work of Stieff et al. 2011). Findings that result from using eye-tracking methodologies have great potential for informing instruction. For instance, one major finding that Yen and Yang make is that low and high achievers may differ in their abilities to comprehend the illustrations in printed materials. The instructional implication of this finding is that teachers need to support learners in how to read various types of illustrations. This aspect of science teaching is often overlooked. Although high achievers might determine how to read illustrations on their own or seek support from more knowledgeable others, low level learners seldom have such resources at their command. As Yen and Yang discuss, eye-tracking techniques have the potential to reveal learning processes and problem solving strategies related to students using science content.

Yen and Yang discuss that learner's eye movements with respect to location, duration, and number of gazes in predefined areas of interest together with transitions between areas, show the degree of attention learners have while reading texts. Eye-tracking techniques combined with measures of student learning can help science education researchers determine why some learners succeed in reading text integrated with graphics and various illustrations and why other learners do not succeed. Another instructional implication that stems from the research reported in their chapter is that arrows and color-coding can help guide and focus a learner's attention on important aspects of various illustrations and charts. Their synthesis of the research on eye-tracking shows that such techniques are critical in guiding and focusing learners' attention. Given the importance of images, diagrams, graphs, illustrations, and multiple representations to explaining scientific phenomena, the findings of eye-tracking research seem critical for science education. Various studies report that successful learners tended to fixate on relevant areas longer than unsuccessful learners. The implication of this finding is that we need to scaffold learning to focus on relevant features of representations. Given that disciplines such as chemistry, geoscience, physics, and biology rely so heavy on representation to communicate, eye-tracking research has the potential to improve the teaching and learning of these disciplines.

## 15.5 Chapter 14: Public Communication of Science and Technology in Taiwan

The chapter by Chun-Ju Huang looks at technology through a different lens than presented in the previous chapters in this section. Huang focuses on examining technology as a tool that has impacted the spread of science ideas that has blurred the distinction between formal and informal science education and as a vehicle that has given rise to socioscientific issues. As such, this chapter brings into focus the important role that mass media and public communication of science plays in science learning in Taiwan and globally. Huang argues that because of the prominence of science and technology in Taiwan, communication and interaction between science and the public is necessary for a democratic society to thrive. Although

Huang's argument focuses primarily on Taiwan, the argument presented is valuable for all countries.

Huang is concerned with how to assist the Taiwanese citizens in developing appropriate concepts and opinions about science and technology through public science education. Given the critical role of understanding science and technology for all individuals to make informed personal and public decisions, a focus on how to support the public in developing more useable knowledge of science and technology is critical.

The work of Huang is valuable because he puts forth a framework for examining and further understanding public science education. The framework shows a building from science knowledge expressed accurately and thoroughly, to conveying science knowledge in an accessible and interesting manner, to supporting the individuals in reflecting on science knowledge, especially the effects, influences, and controversies of science. Given how rapid science is changing and the sophisticated level of understanding that is necessary to engage in public discourse, a framework that can help promote the public understanding of science is critical. The framework, because of its focus on reflection, can support the public in more open discussion of scientific and socioscientific issues. This framework can serve as a viable model to develop public science education in Taiwan, and throughout the globe but needs further investigation.

**Concluding Comment** The five chapters in *Innovative Technology for Science Learning and Instruction in Taiwan*, of Science Education Research and Practice in Taiwan provide strong support for the claim made by Lin and Tsai (this volume) that science education research involving technology is prolific in Taiwan. As the five manuscripts illustrate, Taiwanese researchers have focused on synthesizing the literature (Lin and Tsai); designed, developed, and tested new innovative technologies to use in classrooms to promote science learning (Hsu and Wu); used new learning technologies to study how students learn science (Liu and Huang, and Yen and Yang); and because of the advancements of science and technology, how to promote public understanding of science education (Huang).

The work of Hsu and Wu reflects how new technology applications can be developed to support the teaching and learning of science. I would like to see even more researchers in Taiwan focusing on designed-based research to develop and test innovative uses of technology to promote teaching and learning across the science disciplines and throughout K—16 education. For instance, given the strength of science education and design and development of technology in Taiwan, I would like to see researchers focusing on designing special applications to support learning in building and revising models, constructing evidence-based explanations, and analyzing complex data sets. Such applications could serve as exemplars for other educational systems throughout the globe that hope to engage learners in scientific practices and the use of knowledge to explain phenomena and design solutions to problems.

I also find the chapters on eye-tracking (Yen and Yang) and neuroscience (Liu and Huang) as providing new methodologies for examining how students learn science. Such findings from such innovative research methodologies can result in the development of new instructional techniques. Because eye-tracking research has a longer history than neuroscience research applied to science education, new applications are beginning to emerge from eye-tracking research, like the importance of supporting learners' attention to important and salient features of representations. Because science and technology are not a luxury, but essential for all individuals to understand and be able to use, the framework that Huang proposes on the public understanding of science could serve as a model for others throughout the globe interested in promoting science.

Learning technologies can help to change the teaching and learning of science; however, the role that the science teacher has in the classroom will remain prominent. Science teachers play a critical role in scaffolding students learning and although new teaching strategies will be necessary, the use of learning technologies requires active teaching and monitoring from teachers. Lin and Tsai (this volume) also describe the important role played by teachers. Because of the important role of teachers, I would like to see future studies that focus on the role of teachers. Research is needed that explores and refines the teaching practices that can promote student learning in e-learning environments.

Although new innovative technologies can help to meet important learning goals, the design and development of technologies for learning are only one component of what is needed to improve teaching and learning. Curriculum materials and teaching practices serve as critical components in the learning environment. The integration of technology with appropriate curriculum and instruction can support students in engaging in science, experiencing phenomena and ideas that can't be accomplished without them. More research, however, is needed in how to design these integrated learning environments.

The scope of the work in *Innovative Technology for Science Learning and Instruction in Taiwan* not only shows the scope of work produced in Taiwan on science education and technology, but also the creativity and leadership of its researchers. The science education research community in Taiwan can help to further push forward the field's understanding of how to effectively use technology to promote the teaching and learning of science, providing unprecedented opportunities to allow students to use ideas to find solutions to problems, explain phenomena, and explore new areas to learn more.

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# Part IV
# Curriculum and Teacher Professional Development

Ever since Shulman (1986) proposed the concept of pedagogical content knowledge (PCK), a big revolutionary wave has swept over teacher professional development research. Taiwan was not immune from this wave. A great amount of research was carried out to uncover what difficulties teachers have in developing their instructional skills and knowledge to transform students from naive to experienced learners. Tuan et al. (Chap. 16) identify several issues relevant to the quality of teachers in teaching science. Along the same line, Su et al. (Chap. 17) also discuss the interrelation among curriculum, teaching, and learning in science and align the goals of curriculum for instruction. They argue that although designing curriculum modules facilitates school teachers' understanding of curriculum and teaching and learning, teachers are usually concerned about the limitations of time and resources in practice.

Kao et al. (Chap. 18) extended their research to indigenous students' learning via their culture. This approach echoed the call for learning in context. Culture and social impacts influence the perceptions of science among learners who have been marginalized in the general society. Liu (Chap. 19) emphasizes the importance of integrating science curriculum with socio-scientific issues and science, technology, society, and environment to extend students' points of view of science and urges teachers to develop controversial issues for discussion in school practice.

De Jong commented that factors of science education reform and teacher professional development are tied closely and influenced by the culture, in particular, Confucian culture, in Taiwan. He also drew some comparisons of science curriculum reform and teacher learning between Western countries and Taiwan to shed light of our understanding of this field. The last section of the book is organized from the international perspective.

# Chapter 16
# Taiwanese Science Teacher Education Research-Capturing the Spirit of PCK

**Hsiao-Lin Tuan, Kou-Hua Wang and Huey-Por Chang**

**Abstract** In 1994, when the new Teachers Education Law was enacted, the teacher education system in Taiwan was decentralized. Multiple channels were opened for teacher preparation. Technology-supported e-learning environments and infrastructure were well developed and the accompanying science teacher education research focused on the standards of science teaching among preservice teachers, the standard-based teacher education programs' outcome, the certification standards of preservice and intern teachers, and the impact of mentoring system on internship science teachers. We found that the pedagogical content knowledge (PCK) spirit influenced a majority of teacher education research in Taiwan. This chapter discusses the science teacher education research in Taiwan over the past 20 years and explains the influence of the National Science Council (NSC) and Ministry of Education (MOE) on science teacher education research and policy, preservice science teacher education research (including internships), and in-service science teacher education research in Taiwan. Finally, we derive some conclusions on the science teacher education research over the past 20 years in Taiwan.

## 16.1 Introduction

Looking at the science teacher education research in Taiwan over the past 20 years, two agents have played an important role in promoting science teacher education research, namely, the National Science/Council (NSC) and the Ministry of Education (MOE). In addition to these two agents, science teacher educators who have received their doctoral degrees, mainly from the USA and domestic universities, have also promoted the research in Taiwan. Taiwanese culture capital and the theories, especially pedagogical content knowledge (PCK) advocated by the Western countries (Shulman 1986), have been dominant among Taiwanese science teacher

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educators and have shaped the characteristics of research in this field over the past 20 years. In this chapter, we present a collection of papers related to science teacher education sources collected from National Science Council (NSC) Monthly, National Science Council Research Report, Chinese Journal of Science Education, and master and doctoral thesis in science education field, etc. The authors used their own experiences as well as of other science teacher educators who had participated in NSC-proposed research projects during the past 20 years while organizing and selecting the reports presented in this chapter. The following sections discuss the influence of the NSC and MOE on science teacher education research and policy, preservice science teacher education research (including internships), and in-service science teacher education research. Finally, we derive some conclusions about the science teacher education research over the past 20 years in Taiwan.

## 16.2 The Influence of the NSC and MOE on Science Teacher Education Research and Policy

In 1982, the NSC established its science education division to promote and offer financial support for science education research in Taiwan. In the initial years, the NSC's funding addressed research in students' science learning. It was not until 1990 that the NSC started to put stress on science teaching and science teachers' quality in Taiwan. From 1990 to 2000, research projects in science teacher education increased dramatically and the publication of such research also increased (Guo 1999). For instance, in 1990, there were only 13 research proposals funded by the NSC. By 1998, the number of funded proposals increased to 61. In terms of publication, from 1990 to 1994, less than 0.3 papers were published per researcher. From1995 to 1997, there were 0.4 papers per researcher on average.

In 1990, the NSC started to pay attention to preservice science teacher education research. The NSC sponsored three normal universities to establish teaching laboratories for secondary science/math teachers. The purpose of promoting this kind of research was to establish microteaching laboratories using high-technology equipment for assessing preservice science teachers' character, and to investigate strategies for preparing preservice science teachers (Guo 2001).

In 1991, to assess science teaching, the NSC proposed a series of case studies to uncover the characteristics of exemplary science teachers' teaching. In this area of research, the NSC invited the US science educators Dr. Ken Tobin and Dr. Jim Gallagher to introduce interpretative research methods for exploring the features of classroom science teaching. This research methodology influenced subsequent science teacher education research by promoting the use of case studies or the combination of qualitative and quantitative research methods to uncover the features of good science teaching in classrooms (Guo 2001).

The year 1994 was a critical year in Taiwanese science teacher education, when the Taiwanese government enacted the Teacher Education Act (TEA) which initiated multiple types of teacher education. The TEA allowed other universities, in addition to teachers' colleges and normal universities, to prepare K-12 teachers and make changes in recruitment, training, and employment of teachers. Before 1994, the Taiwanese government adopted protectionist and centralized philosophies into governing teacher education. The government supported nine teacher colleges and three normal universities in preparing primary and secondary school teachers. Senior high school students who passed the entrance examinations of the nine teacher colleges and three normal universities were financially supported by the government. After finishing the 4-year teacher education programs, they needed to complete 1-year internship to receive certification, and were then assigned to different public schools based on their GPA. Cheng (2006) mentioned that the old normal education law lacked a screening system. After 1994, the new teacher education system changed from a centralized to a decentralized system. All the qualified teacher education programs can educate preservice teachers. These teacher education programs usually last for 2 years with 26 (for secondary teachers)/40 (for primary teachers) credit hours of secondary/primary teacher education related courses, respectively. After preservice teachers finish 26/40 credit hours, they receive primary certification. After they finish half-year internship, they need to pass certification to receive secondary certification. Once they are qualified, they will need to search for teaching jobs themselves. The new teacher education system provides many ways to control teacher quality, such as the primary and secondary certification systems, quality internships, and quality teacher education programs. This new reform made the teaching profession more accessible and attractive during the 1990s. However, the increased number of preservice teachers and the decreasing number of newborns has resulted in competitions and challenges in teacher preparation in recent years. Nevertheless, to improve the quality of teachers, the Taiwanese government (NSC) has continuously made efforts to support research for improving teacher education.

In 1995, to coordinate with the MOE's multiple teacher education system the NSC proposed integrated projects to study a "multiple teacher education system with a science and math teachers' certification and preparation model" in the areas of primary and secondary certification, internship, and assessment (Guo 2001). Many science teacher educators from the nine teachers' colleges and three normal universities participated in these studies. Cheng (2006) stated that the funded proposals included 8 integrated projects and 37 individual projects, most of which started in 1995 and finished by July 1998. These projects were as follows: survey and analysis of Teaching competency's survey and analysis (2 junior high (JH), 1 elementary school for science majors (E(s))), subject matter knowledge (SMK) assessment (2 JH, 1E(s)), teaching competence evaluation (10 JH, 2 E(s)), certification tools for qualified teachers (4 JH), evaluation of internship experience (2 JH), teacher preparation model (1 Elementary school math (E(m))), laboratory teaching competence assessment (1 JH (biology(b))), science process skill assessment (1 E(s)), attitude toward science assessment (1JH(b); 1 E(s)), attitude toward nature of science (1 E(s)), understanding of students' cognition (1 E (m)), teacher's reflection (1 JH (physical science (ph))), and a comparison of senior high school teachers' cognition and performance (1 JH(ph)). All the teacher certification studies focused on the junior high school and elementary school levels only.

In 1996, the NSC noticed the importance of a 1-year internship in prospective science teachers' teaching quality. Therefore, they proposed a new direction for teacher education research in a proposal called "Establishing a distance mentoring system for science/math projects." In this proposal, the NSC focused both on how to use the Internet to improve science and math intern teachers' internships and developed the possibility of designing a distance mentoring system to facilitate in-service teacher's professional development (PD). Guo (2001) found among six funded integrated projects, including a biology internship mentoring system, a web system for mentoring physical science teachers, an elementary science teachers' mentoring system, distanced mentoring for internship teachers with information majors, life science majors, and vocational school teachers. The majority of studies addressed distanced mentoring methods for internship teachers (Guo 2001).

In 2006, the NSC and MOE created integrated research projects for secondary and elementary science/math teacher education in Taiwan (NSC 2006). Both the NSC and MOE tried to promote the MOE's policy of "Teacher Education Quality Enhancement," and expected qualified teachers. All teacher education programs were professional and standard based. They used this policy to maintain good teacher education programs and to also close unqualified teacher education programs. The NSC and MOE tried to recruit all the science teacher educators to conduct research for preparing qualified science/math teachers for elementary and secondary school. The qualified teacher education programs included preservice science teacher education, bachelor's degree and master's degree programs as well as in-service science/math master-degree programs for gifted teachers. Both the NSC and MOE wanted to see how science teacher educators prepare preservice science teachers and develop assessment strategies and criteria for assessing teachers' professional competence (Guo 2001). Since then, both agents have also proposed many research agendas to promote the quality of elementary and secondary science teachers in accordance with new curriculum reform.

## 16.3 Preservice Science Teacher Preparation Research in Taiwan

Improving the quality of teachers' preparation has been one goal of teacher education in Taiwan since the TEA was enacted in 1994. In this section, we discuss the research projects that have been implemented in preservice science teacher preparation in Taiwan, including investigations on preservice teachers' beliefs, teaching standards, preparation programs, and learning to teach.

Misconceptions of Taiwanese preservice teachers about science topics have been the subject of research for a long time. These misconceptions include topics such as the moon (Dai and Capie 1990), weather (Su 1999), oxidation and reduction (Wang and Huang 1999), air (Chou 2001), gas particles (Huang 2003), and various other selected science concepts (Dai 2003). Many of these studies indicate that preservice teachers do not have sufficient scientific knowledge and have misconceptions about various science topics. Van Driel and Abell (2010) also indicated that researchers are interested in understanding science teachers' understanding of content.

Some researchers have investigated preservice teacher's knowledge and its relationship to practice. Lederman and Chang (1997) investigated preservice science teachers' pedagogical and SMK structures. Their findings showed that Taiwanese junior high school preservice teachers tend to include pedagogical concerns and components within their SMK structures. This is because Taiwanese junior high school preservice teachers possess strong subject matter backgrounds. Lai (1997) suggested that preservice teachers have developed their own science PCK before taking science method courses. Do Taiwanese preservice teachers have a satisfactory level of scientific literacy? Chin (2005) investigated the level of scientific literacy among first-year preservice teachers in colleges in Taiwan. He found that the basic scientific literacy of first-year preservice Taiwanese teachers in colleges was at a satisfactory level. In addition, the preservice teachers displayed the highest literacy in health science, STS, and life science. Literacy in the areas of the nature of science and earth science was rated the lowest.

Further research focused on the development of teacher education programs and science teaching standards are addressed below. She (2004) restructured the courses in physical science methods by using constructivist approaches and required all prospective teachers to carry out action research during their 1-year full-time teaching internships to apply what they had acquired to actual teaching. Results showed that constructivist approaches affected teachers' beliefs and their initial choice of science teaching approach. Moreover, successful experiences with action research reinforced their beliefs and made them more willing to employ constructivist science teaching approaches in their teaching practice. Wang (2006) conducted a 3-year project to develop science and math teacher professional development standards and to modify the teacher education program. A modified Delphi technique was used to develop the professional indicators for elementary mathematics teachers, science teachers, and mentors. Findings suggested that the core standards involved four domains: rationale, content knowledge, teaching and assessment, and professional development. Under each domain there were 1 to 25 standards depending on the features of the discipline. Chang et al. (2008a) conducted a 3-year study to invite preservice biology teachers to attend it, and they were interested in following courses focusing on nature of science (NOS): Methods, Advanced Methods, and Internship. Researchers were interested in understanding howthese courses influence preservice teachers' NOS and their ability to design curriculum. In addition, researchers were also interested in using research findings to revise the above courses. Chin (2009) used the Delphi method to collect data from 32 science teacher educators from normal universities, teacher colleges, and regular universities through three continuous questionnaires. They established 57 indicators to evaluate science teacher education programs at the secondary level in Taiwan. Findings indicated that most of the science teacher educators all addressed the selection process for preservice teachers and their attitudes and competence of their teaching. They also discuss the teacher education program, the organization's internship experience and the nature of supervision, preservice science teachers' attitudes, and the teacher's competence in teaching science after finishing their teacher education program courses. Finally, they evaluate how teacher education recruited qualified professors teach. The last research area involves how preservice and intern science teachers in Taiwan learn to teach. Tuan (1994) indicated that after taking 1 year of practicum courses, preservice chemistry teachers' views of chemistry were simplified but their knowledge of teaching became more complicated and focused more on students' characteristics and learning styles. During the internship year, the preservice teachers gained an awareness of the importance of PCK in improving science teaching in the future. Factors influencing preservice chemistry teachers' PCK development were their preference, reflection ability, and deprived teaching repertoire. Tuan (1996) investigated the development of PCK of three preservice chemistry teachers in Taiwan during 1-year practicum course. She found that the three chemistry intern teachers increased their integration of pedagogy knowledge (PK) and SMK into their thinking on teaching after 1-year practicum course. They also gained knowledge of students' personal and learning characteristics. Factors influencing these teachers' PCK development were the teachers' own reflections and ability to take action which is the same as Tuan's (1994) findings. In addition, practicum teachers' actual classroom teaching experience and their own preferences in relation to PK, SMK, and PCK also influence their PCK development. Tuan and Kaou (1997) also followed one chemistry-major teacher from her preservice teacher education program to a 1-year internship experience to explore the case teacher's PCK development. Findings indicated that in the authentic school setting, the case teacher automatically developed her knowledge of students, viz., PK and PCK which supported the previous study (Tuan 1996). Lin (1995) investigated the progress of 15 beginner chemistry teachers in regard to teaching techniques taught in a preservice teacher education program. Findings revealed that the beginner chemistry teachers were able to improve significantly in teaching techniques such as asking divergent questions and giving appropriate wait time to students after questioning. However, almost no progress was made on teaching techniques such as: (1) using analogies to explain theoretical concepts; and (2) initiating classroom discussions. The quantitative results of the study indicated that a typical beginner science teacher tended to ask students to memorize scientific content knowledge and formulas. Tuan (1996) investigated the development of PCK of three preservice chemistry teachers in Taiwan during a 1-year practicum course. She found that the three chemistry intern teachers increased their integration of PK and SMK into their thinking on teaching. They also gained knowledge of students' personal and learning characteristics. Factors influencing these teachers' PCK development were the teachers' own reflections and ability to take action, as well as actual classroom teaching experience and their own preferences in relation to PK, SMK, and PCK.

Tuan and Kaou (1997) followed one chemistry-major teacher from her preservice teacher education program to 1-year internship experience to explore how she developed her PCK. They coded the case teachers' teaching to see the patterns of her PCK development. Findings indicated that in an authentic school setting, the case teacher automatically developed her knowledge of students, viz., PK and PCK.

Another area of preservice science teacher education research is to investigate teachers' NOS, beliefs, and epistemology. Chen (2006) surveyed 302 preservice participants' concepts of NOS, and she found that preservice participants have common conceptions and conflicting thoughts about the NOS. Liu and Lederman (2007) examined the views of the human relationship with the natural world and understandings about the NOS held by preservice elementary teachers in Taiwan. The results pointed to the interplay between these teachers' sociocultural beliefs and NOS conceptions. People with different world views may have differing views about science. This makes it important to incorporate sociocultural perspectives in science instruction and introduce the contemporary concepts of the NOS to science learners. Lee et al. (2012) compared the epistemic beliefs of ethnic Chinese preservice teachers from Taiwan, Singapore, and China. Findings revealed that with respect to beliefs about the nature of knowledge and learning, the preservice teachers from Taiwan and Singapore held relativist epistemological beliefs in contrast to the multiplist epistemological beliefs of preservice teachers from China. With regard to beliefs about learning, preservice teachers in Taiwan tend to believe that ability is innate or fixed, unlike teachers from Singapore and China.

Lin and Chen (2002) indicated that preservice chemistry teachers attain a better understanding of NOS through intervention with the history of science, especially in the domains of the nature of creativity, the theory-based nature of scientific observations, and the functions of theories.

Tsai (2006) examined the effects of science education courses on a group of Taiwanese in-service and preservice teachers' views toward NOS. Teacher preparation courses included the philosophy of science, the instruction to students' alternative conceptions and theories of conceptual change, and some classroom activities for science education. The findings revealed that both in-service and preservice teachers, to a certain extent, changed their views toward the NOS on completion of the courses. Many of them reinterpreted and reconstructed their views about science during the courses, and their views became constructivist oriented. Tsai suggested that the instruction related to student alternative conceptions and conceptual change theories was more helpful than direct instruction about the philosophy of science in changing teachers' views about science.

Lin et al. (2007) investigated two science intern teachers' learning experiences during 1-year internship using a qualitative research method. They found that the intern teachers' personal practice theory (PPT) came into conflict with their mentors' PPT, but it created good opportunities for intern teachers to transform these conflicts into their own teaching knowledge.

The latest area of preservice science teacher education research is related to technology and modern science topic—nanoscience. Chien et al. (2012) developed a framework, called MAGDAIRE, to transform preservice science teachers from passive users to active designers of technology. They found that MAGDAIRE suggested the framework significantly improved the preservice teachers' technology competency levels. Moreover, MAGDAIRE facilitated the preservice teachers' critical reexamination of the affordances of technology for their teaching practices from the views of subject matter selection, motivation empowerment, information presentation, activity design, and pedagogy transition.

In addition, how does nanoscience influence the education of teachers teaching science to both junior and senior high school students? Shih et al. (2012) addressed that the inclusion of nanotechnology in science curriculum has long been present in modern countries. For instance, the contents and standards of nanoscience teaching for K-12 students have been established in the USA. In the past decades, we have also devoted extensive efforts to enhancing students' interests in learning nanoscience in Taiwan. A variety of activities such as science fairs, science camps, and creative projects have been employed to promote students' understanding of nanoscience as well. The outcomes of these activities have frequently been considered successful. To enable systematic education reform, especially in science education, we need to offer nanoscience curriculum to both preservice and in-service teachers. Therefore, researchers, teachers, and professors in the fields of nanoscience and technology were invited to select, organize, and design the nanoscience curricula suited to the needs of university students and in-service teachers. Topics such as introduction to nanoscience, the nanoscale, properties of nanomaterials, measuring and synthesis of nanomaterials, and nanomaterials and life have been emphasized in curriculum development. Given the highly interdisciplinary nature of this exciting future technology, teaching strategies and methods should also be taught to preservice and in-service teachers. By way of appropriate teaching, teachers may transmit their SMK of nanoscience to their students.

### *16.3.1 Summary*

Based on the above literature review, preservice science teacher education research has been promoted by NSC from 1990 till now. More than 20 years of research has been undertaken to establish the standards for science teaching, science teacher education programs, and certification criteria. But these standard-based research did not influence the outcome of science teacher education nationwide. Followed by standard-based research, teacher education researchers also conducted research in the area of preservice science teachers' PCK development, misconceptions, NOS, and beliefs. In the recent years, research also focused on teachers' technology and nanoscience competency. These trends were very similar to the US science teacher education research agenda (Borko et al. 2010; Van Driel and Abell 2010; Yager and Simmons 2013). For instance in Salish project, science teacher education projects also focused on teacher preparation, new teacher knowledge, beliefs, performances, and student learning outcomes (Yager and Simmons 2013). Van Driel and Abell (2010) found that science teacher educators investigated teachers' prior content knowledge, NOS and beliefs about science teaching and learning, and PCK development. However, their teacher education studies were more influenced by National Science Education Standards (NSES) (NRC 1996), while Taiwanese science teacher education had to work from scratch to establish standards and design the teacher education program all by themselves.

## 16.4 In-service Science Teacher Education in Taiwan

After the teacher education system was decentralized in 1994, in-service teacher education research has received increasing attention from NSC and MOE. In 2008, MOE helped three normal universities establish in-service teaching programs to encourage in-service teachers to promote their teacher PD. The three approaches to in-service teachers' PD are: (1) A degree-program to encourage in-service science teachers to attain a master's degree in the areas of education, teaching, or educational administration. (2) A certification-program to encourage in-service teachers to improve their teaching skills, and choose a second major. (3) An in-service workshop with local schools cooperating with each county's bureau of education, offering courses that would meet the needs of local school teachers. In general, science teachers have to take a certain number of credit hours per year (the number varies in each county) to prove they are continuing their PD. However, there is no regulation requiring in-service science teachers to take courses in particular areas to enrich their teaching competence.

According to our review of literature, science teacher PD programs can be classified into the following areas: enhancing teachers' constructivist teaching competency, inquiry-based teaching competency, and technology competency. Below, we discuss these areas of studies in general and focus on the details of one of the studies in each category.

Enhancement of teachers' constructivist teaching competency was emphasized from 1995 to 2005. During this period of time, constructivism was introduced to the Taiwanese science education community. Meanwhile, our public school curriculum reform was also highly influenced by constructivism. Thus, many science educators were anxious to introduce constructivism as well as constructivist teaching to teachers. Related research projects focused on how to help science teachers grasp constructivist teaching in elementary and junior high school science classes (Guo et al. 1997). Another way to enhance constructivist teaching was embedding constructivism and pedagogy into in-service teacher education programs.

A typical in-service program reform study was conducted by Guo et al. (1997). Experienced science/math teachers who passed the entrance examination and enrolled in the in-service science teacher education program at one education university were required to take the following courses: special topics in science education, teaching methods, science courses, science assessment courses, master's seminar, master's thesis courses, etc. Within these courses, Guo et al. (1997) embedded constructivist theories, constructivist related teaching and learning (e.g., conceptual change, students' misconceptions, portfolio, and two tier tests) into special topics courses, teaching strategies, and assessment courses. After taking these courses, each teacher had to find out their own teaching problems, and use action research to solve them. Meanwhile, researchers collected participants' feedback after taking courses offered by the end of each school year to identify the problems within this in-serivce teacher education program. They found solutions to these problems and revised the program in the following year. Since the majority of in-service course instructors also served as participants' advisors, they know how to encourage their advisees to conduct action research and transform their traditional science teaching into constructivist teaching. Towards the end of the 3 year project, many action research results and case studies were produced by participants (Lee et al. 1994; Fan and Guo 1995; Yen 2001). Wang (2000) embedded concerns based adoption model (CBAM) theory and a social constructivist teaching model to help elementary school science teachers change their science teaching. Findings indicated that teachers' change in their conceptions of teaching do not necessarily lead to changes in teaching practice; teachers encountered more difficulties while translating constructivist theories and science content knowledge into classroom practices as they lacked proper science content knowledge and PCK. Yen (2001) used students' perceptions of teachers' knowledge (SPOTK) (Tuan et al. 2000) to examine how one elementary science teacher incorporated ideas of constructivism into her teaching. Findings revealed that after the case a teacher accepted and practiced constructivist teaching and her changed beliefs about constructivist teaching did not influence her PCK. Her pedagogical knowledge and assessment knowledge developed independently and did not grow in a congruent way. Teacher needs to know more about student-centered teaching representations to implement successful constructivist teaching.

These studies showed that teachers' successful teaching experiences were hindered by their changing beliefs on the NOS. Teachers' original beliefs, scientific knowledge, the demanding pace of the curriculum, both teacher and students' values about teaching and learning, and adequate support for teachers, were the factors influencing the practice of constructivist teaching. However, having abundant teaching experiences can facilitate the implementation of well-designed constructivist lesson plans.

Guo and Chang (2002) carried out 3 years of the enhancement of science and mathematics teachers' professional growth through the development of instructional modules for a 9-year integrated curriculum. In this integrated project, six collaborative action research studies were carried out over a period of 3 years. Science teacher educators worked collaboratively with in-service elementary and junior high school science or mathematics teachers in small groups, aiming at helping teachers develop integrated instructional modules to be used in teachers' own classrooms while also assessing these teachers' PD, and facilitating their growth. Through this kind of research design, science teacher educators can both study teachers' PD and educate teachers. Findings indicated that participating teachers continued to grow in their beliefs, PCK, and instructional skills. The curriculum modules these teachers designed won many awards in various national contests. Moreover, these teachers have become leaders in their schools.

Since 2002, the 9-year continued curriculum reform that focused on the spirit of inquiry has greatly influenced the Taiwanese society. Since teachers play an important role in the successful implementation of the curriculum reform, science teacher educators have addressed the development of science teachers' inquiry-based teaching competence.

Tuan et al. (2008) implemented a 3-year inquiry-based teacher PD project to reform the in-service science teacher education program and to promote inquiry-based teaching competence among science/math in-service teachers. Tuan et al. (2008) followed Guo et al. (1997) design of the teacher education program. Tuan et al. added constructivism, social constructivism, and the nature of inquiry into the special topics of science education. In the teaching method course, the instructor introduced above theories to support inquiry-based teaching and showed teachers how to infuse PCK into inquiry-based teaching. In the assessment course, the instructor introduced various kinds of assessment that can be used in inquiry-based teaching. In the science courses, science inquiry activities were offered by scientists who invited teachers to participate in science inquiry activities to learn about both the nature of inquiry and content knowledge. Technologies applied in science teaching showed how technology can be used in inquiry-based teaching. Finally, teachers were encouraged to use action research to transform their current teaching into inquiry-based teaching. Tseng et al. (2012) assessed the effectiveness of the above program and found that the 55 in-service science and math teachers enrolled in the program showed significant progress in their inquiry teaching efficacy; science teachers showed more significant progress than did math teachers. Although all teachers gained significant improvement after taking courses each year, the third year led to more significant increases in scores than did the first 2 years, because teachers were conducting their own action research focused on how to implement inquiry in their classes. This kind of action research experience helps science/math teachers build up solid inquiry teaching efficacy. Chen and Chang (2008) investigated a chemistry teacher who participated in a 3-year long PD project emphasizing inquiry-based teaching. Findings indicate that the case teacher thought inquiry-based teaching includes the processes of observing phenomena, designing and conducting experiments. The teacher referred to this as the "reconstruction model." Students showed their enjoyment, learned scientific concepts, and abilities when engaging in inquiry-based instruction. The case teacher indicated that he acquired confidence and support from his students and was willing to continue to implement inquiry-based teaching in his classrooms. Tseng et al. (2013) explored the perceptions of 10 experienced junior-high science teachers in relation to their learning experiences with inquiry teaching, and constructed a process for PD through inquiry teaching. Findings indicated that teachers' inquiry-based teaching PD could be classified as: teachers' positivistic beliefs shifting to a naturalistic view point about science teaching, having various teaching strategies and planning ability, solving conflicts between teaching beliefs and teaching practice, academic learning experiences enhancing teachers' changes, scaffolding teams, and teachers' own beliefs and successful inquiry teaching experience support teachers in conducting inquiry teaching. They also identified three critical factors affecting the success of teachers' inquiry-based teaching PD. These are teachers' reflections on teaching, rigid beliefs about inquiry-based teaching, and scaffolding from research teams. These findings reveal that teachers' beliefs influenced their PD; in addition, teachers' PCK repertoire also influenced how they put inquiry into practice. Findings also showed that teachers act like students. That is, they need constant support to transform their traditional teaching into inquiry-based teaching. Finally, teacher's ability in reflecting their teaching influences their understanding of inquiry and their implementing of inquiry-based teaching.

Science teachers' views about the NOS, practice of inquiry teaching, and PD have received considerable attention in Taiwan when it comes to teaching science to both secondary and primary students. Research indicates that beliefs could influence teachers' practices (Van Friel and Abell 2010). Therefore, it is important to examine the relationship between teachers' views of the NOS and their instructional practices related to the NOS. Another question is whether science teachers can provide a learning environment consistent with the progress of scientific knowledge that facilitates student learning about the NOS and other science content. Finally, it is important to investigate how to facilitate in-service teachers' ability to provide students with inquiry-based instruction. A Taiwanese version of inquiry-based teaching was recommended by Chen et al. (2007). They pointed out that science teachers generally do not implement inquiry teaching in their classes because of the restrictions of instructional schedules, the physical environment, school culture, and the national examination in Taiwan. In their study, several science teachers were invited and assisted in understanding and implementing inquiry teaching through a PD program. A model that was determined to be appropriate for implementation in actual science classrooms was established. This model is called infused inquiry teaching (IIT). The IIT model was further verified to be suitable for infusion into the formal curriculum in Taiwan. This model has seven characteristics, including: (1) meaningful learning of inquiry for students, (2) questions used to focus on inquiry, (3) guidance to verify students' ideas, (4) communication and connection to science conceptions, (5) assessment of students' learning performances, (6) incorporation of collaborative learning into inquiry, and (7) writing about inquiry. Through the process of PD, these science teachers felt confident and satisfactory about their inquiry-based teaching in science classes.

It is worth discussing how scientific inquiry teaching promotes students' science learning. In a 2-year study conducted by Chang et al. (2011), they reported that the enhancement of students' understandings of scientific concepts as well as competency of scientific inquiry has been a perennial and universal topic. This study began with the establishment of scientific competency in the concepts of electricity and magnetism for both elementary and secondary school students. Then, the learning goals of science classes were constructed on the basis of learning goals. In turn, the curriculum design was executed to pursue students' learning goals. Meanwhile, the development of different instruments such as scientific literacy, problem solving, critical thinking, scientific explanations, and scientific understandings were completed and used to assess students' learning outcomes. In the first year, action research was adopted to assist science teachers in recognizing significant ideas within science education as well as the essence of inquiry teaching and cooperative learning. Curriculum emphasizing students' inquiry and communication abilities was developed. To systematically examine the effect of using the new curriculum, a quasi-experimental research method was adopted in this project. In addition, classroom observation was applied to find out what science teachers actually did in their classes. The results of these analyses demonstrated the relationships between teacher's classroom practice and students' achievements in science learning. The possibility of putting scientific inquiry and communication teaching into actual classrooms was also discussed.

Guo et al. (2011) recruited the majority of elementary and secondary science teacher educators in Taiwan to conduct learner-centered PD programs. In this project, all science teacher educators treated teachers as learners, established professional learning communities jointly formed by universities and nearby schools to facilitate teachers' PD, and used students learning outcomes as one of the indicators of science and mathematics teachers' PD. Various PD were produced by this block project, which included various in-service teacher education programs, courses, instructional strategies, activities, materials, and assessments.

Chang et al. (2010) conducted a 3-year joint research project under MOE and NSC to develop a 5-year preservice math and science teacher education program and master-degree offering an in-service science teacher education program for gifted science and math science teachers. The teacher education program emphasized teachers' practical knowledge and PCK. Findings indicated that participants understood and liked the idea of a 5-year preservice program. However, they were concerned about the additional number of credits they had to take in their teacher education program. For the in-service program, participants revealed strong motivation to participate in continuous education, and gained more confidence in the education of gifted math/science students. Concerns revealed by teachers were course arrangement, thesis requirements, and time constraints. As for the program coordinator's perspective, regulations of MOE, administration operations, and instruction resources were seen as critical to the success of the program.

Technology-infused teacher education programs are the third direction of teacher PD programs in Taiwan. Fan et al. (2011) developed an assessment system (Web-based Assessment and Test Analysis) that focused on improving assessment of teachers' Internet literacy. They invited 47 secondary in-service mathematics and science teachers in a summer program for 36 h within 6 weeks and found out that the participating teachers' assessment knowledge and teachers' assessment perspectives showed significant improvement after the training model.

Another study done by Wang and his research team developed a collaborative PD project that includes features of collaboration, authentic classroom teaching, feedback, and reflection through a network camera system (NCS). The PD group consisted of a novice chemistry teacher, a university professor, and the researcher. With the support of the group, the novice teacher was asked to develop three inquiry teaching units, including density, vibration, and refraction. When the novice teacher taught these units in her class at a junior high school in a rural area, the professor observed the teacher's teaching through a NCS from the university. After instruction, the professor gave feedback to the teacher by using the system. The findings indicate that the teacher's perspectives about teaching and practice changed through this strategy. This suggests that the system can be used in teacher PD (Shih et al. 2010). This kind of distance teaching helps in-service teachers as well as preservice teachers see how they can get together to discuss teaching performance in the class. In addition, technology-infused teacher education programs can also allow experts to join teachers' discussions from a distance. This kind of vivid discussion can facilitate teachers in acquiring teaching competence through classroom observation.

Another kind of technology-infused teacher professional program is to establish a PD on the Web where individual teachers can go to observe themselves. For instance, Yu et al. (2010) incorporated conceptual change and self-efficacy to establish a mentoring assisted inquiry-based teaching (MAIT) PD program. In MAIT, teachers would upload their original inquiry-based instruction videotapes to the Web. They also watched video clips of scientists' explaining their scientific inquiry processes and video clips related to experienced science teachers' teaching inquiry-based instruction. Teachers learned what inquiry-based instruction is through the Web. Finally, these teachers need to present their inquiry-based lesson plans and their inquiry teaching performance. Results showed science and math teachers' conceptions of inquiry and the nature of inquiry increased significantly after one semester of courses. In addition, their competence in guiding inquiry and assessing students' understanding and expectations of their own teaching outcomes were significantly increased.

### *16.4.1 Summary*

Based on the literature reviewed in Taiwanese in-service science teachers' education, they can be classified into the following areas: teachers' constructive teaching, PCK development, inquiry-based teaching, teachers' NOS, beliefs and epistemology, school-based PD, and technology infused into teacher PD. These research topics are similar with science teacher education literature (Borko et al. 2010; Van Driel and Abell 2010; Yager and Simmons 2013; Wallace and Loughran 2012). In addition, many science educators tried to revise current in-service teacher education programs to long-term systematic support of PD for in-service science teachers. As Borko et al. (2010) addressed that the features of the high quality of PD are long-term, cycles of experimentation and reflection, inquiry-centered, and finally helping teachers to collaboratively develop their professional knowledge. In-service science teacher education studies described in this section seems to match these criteria of high quality of PD. Another uniqueness of this area of studies is that many in-service teachers need to conduct action research in their own class. These in-service teachers produced many action-oriented master or doctoral thesis, and many in-service teachers build in depth of PD through action research. Borko et al. (2010) found out many science teacher education programs request teachers to conduct action research, journal writing, or lesson studies to report and reflect their PD. In Taiwan, our science teachers tended to use action research to report their PD development. Taiwanese science teacher educators also used systematic and various resources to assess the outcome of PD programs which is highly advocated by Hawley and Valli (2000). However, due to the small sample sizes of the studies, findings from individual studies cannot generalize to make nationwide suggestion for our in-service science teacher education field. These phenomena is the same as teacher education literature (Borko et al. 2010)

## 16.5 Conclusion

The above literature review revealed that science teacher education research in Taiwan has been influenced by two major institutions: NSC and MOE. When the new "Teachers Education Law" was enacted in 1994, Taiwanese teacher education system was decentralized. Multiple channels opened up for teacher preparation. Due to the teacher preparation policy change, preservice science teachers focused on establishing standards for science teaching, for science teacher education programs, and for certification criteria (Cheng 2006; Guo 2001). Researchers used Shulman's (1986) PCK and/or teacher's knowledge in developing their teaching standards or evaluation criteria for recruiting qualified science teachers.

After the government shortened the required internship period for preservice teachers from 1 year to a half year in 1996, researchers shifted their focus from preservice teacher education to in-service teacher education and teachers' PD. NSC joined with MOE and established teachers' competence PD programs and assessed the outcome of these programs. In this area of study, researchers examined the impact of short workshops or long-term degree-offered in-service teacher education programs on in-service teachers' PD. The content covered in these workshops or programs included the NOS (Chang et al. 2008b), PCK, inquiry (Tuan and Wen 2008), assessment (Lin 2004; Wang and Wang 2008), social scientific issues, and applying technology in science teaching (Wang et al. 2005) these topics are very similar to science teacher education research agenda (Borko et al. 2010; Van Driel and Abell 2010; Yager and Simmons 2013; Wallace and Loughran 2012). In general, researchers assessed teachers' pre- and postconceptions of the above science teaching concepts and infused these concepts with PCK to enhance teachers' teaching competence. Some researchers followed teachers' classroom teaching to check the outcomes of teachers' PD on teachers' classroom teaching and students' learning outcome which is highly advocated by Borko et al. (2010).

Analyzing the research methods used in the science teacher education research field, we found the following patterns: When assessing in-service and preservice teachers' teaching standards or science teacher education programs standards, researchers have tended to use the Delphi method. That is, surveying experts in science teacher education field three to four times to reveal teachers' science teaching competence standards.

For assessing the impact of various mentors' on internship teachers' PD, researchers have used case studies to describe the nature of mentor/mentee interaction and, describe and classify the aspects of mentee's PD. Again, PCK was used as the theoretical foundation for researchers to draw on and to present the nature of teachers' PD, these findings were matched with Wallace and Loughran (2012) that PCK dominated studies on teachers' learning to teach.

As for investigation of the impact of workshops or teacher education programs on in-service teachers' PD, the research methods varied. For short-term workshops, researchers used both quantitative and qualitative research methods to conduct pre- and postassessment of in-service teachers' conceptions and/or perceptions of their own science teaching. In addition, researchers interviewed these teachers or collected participants' assignments or journals to confirm their quantitative findings. For this type of research, the quantitative findings have usually shown significant differences before and after workshops. However, it is not clear whether or not teachers take the teaching concepts or strategies they have learned into their classrooms.

In addition to the above research methods, science teacher educators have used case studies to capture case teachers' PD throughout long-term in-service teacher education programs. This kind of research approach not only assesses impact of teacher education programs on teachers' conceptions of their teaching competency, but also identifies which components of teacher education programs facilitate such changes. Some researchers have also followed teachers into their classrooms to examine changes in teachers' teaching performance and their students' learning outcomes (Tuan et al. 2008; Tuan and Wen 2008). Usually, participating teachers and their students have made significant learning progress through this kind of long-term teachers' PD (Chen 2012; Tein 2012).

As mentioned above, in-service teachers enrolled in in-service teacher education programs are required to write a master's thesis, therefore, many action research theses have been generated through this kind of program (Chen 2012; Tein 2012). These teachers did not only learn new teaching competence, but also learned how to engage in reflective thinking and carry out research methodologies. Some of them have become master teachers in their own schools, while others have continued to earn PhD degrees in the science education field. We found that long-term teacher education programs cultivate future leaders in the field of science education. Action research is also a good way to assess effective science teacher education programs (Guo et al. 1997; Tuan et al. 2008) or science teacher initialized school-based science curriculum reform (Lin et al. 2013). These PD programs match with Borko et al. (2010) suggested that high quality of PD should be long-term and school-based.

In addition to the above factors, science teacher education research in Taiwan has also been influenced by trends in international science education research. For instance, 20 years ago, when science teacher education research focused on microteaching, science teacher educators tried to establish many microteaching labs to educate future science teachers. Later on, as research started to focus on teacher's PCK, researchers tried to uncover how teachers' PCK develop during their enrollment in preservice or in-service teacher education programs, and how to create teacher education preservice or in-service programs to facilitate teachers' PD.

The notions of constructivist, social constructivist, and reflective practitioners were behind these teacher education programs and research (SchÖn 1983). For example, science teacher educators became aware that individual science teachers construct their own knowledge of teaching. Thus, it is better for teachers to work as a group to discuss teaching, and teacher educators serve as mentors to scaffold or facilitate teachers in learning science teaching. Meanwhile, teachers need to constantly reflect on their own teaching to transform their traditional teaching into reform-based teaching. The concepts of reflective thinking are embedded into many courses offered by the teacher education programs, such that teachers are used to reflect on what they have learned to understand new teaching concepts. The above research focus on teachers' PCK, teachers' reflection ability and teachers' conceptual change after enrolled in PD, these trends are similar in science teacher education research in US (Van Driel and Abell 2010).

In addition to the above theories or philosophies, we found that the PCK spirit has influenced the majority of teacher education research in Taiwan over the past 20 years. PCK also influenced science teacher education research and program design in the USA (Abell 2008; Gess-Newsome 1999). Although PCK originally refers to the blend of teachers' content and PK (Shulman 1986), many researchers have broadened the definition of PCK. For instance, Van Driel and Abell (2010) defined PCK as knowledge of student learning of science, knowledge of science instructional strategies, and knowledge of science curricula and science assessment. Loughran et al. (2008) used a content representations (CoRes) and pedagogical and professional-experience repertoires (PaP-eRs) conceptualization to describe PCK. Tuan (1996) reviewed PCK literature and defined PCK as the combination of macro- and microaspects. For the macroaspect, PCK is the integration of content, curriculum, students' understanding, context, and PK domains. When teachers participate in a program for a long period of time, they blend these separate domains of knowledge together to develop their PCK. This definition can explain why preservice and in-service science teacher education programs in Taiwan have followed the spirit of the macro aspect of PCK in conducting their preservice, in-service, and teaching certification studies. Many in-service and preservice teacher education programs have been held at normal universities and teachers' colleges in Taiwan. In this kind of school system, the majority of science courses are offered by scientists who understand their preservice teachers' needs in teaching science. Therefore, their science teaching fits with teachers' needs. When science teacher educators want to reform teacher education programs, the majority of professors who emphasize pedagogy, or come from the science field know that their students' goals are to become good science teachers. Therefore, these professors teach science content, pedagogy, and PCK to these teachers to increase their level of understanding. In addition, each science subject has a PCK course to offer, for example, teaching methods for chemistry, biology, and physics. This kind of environment facilitates the macro aspects of teachers' PCK development.

As for the microaspect of PCK, topic teachers can demonstrate their understanding of content knowledge and transfer this content knowledge to students. This aspect of PCK offers a direction for science teacher educators to promote PCK competence in science teachers' PD. In addition, this definition can integrate new teaching concepts such as NOS, inquiry, and SSI to meet the competence needs in these areas. As Abell (2008) reviewed 20 years research in PCK and advocated future research needs to assess the teachers' PCK performance in the class. Tuan et al. (2000) further developed an instrument for students to check their teachers'

PCK, called SPOTK, consisting of knowledge of science content, knowledge of teaching methods, knowledge of teaching representations, knowledge of students' understanding, and knowledge of curriculum. This instrument has been used by many teachers, examining their PCK development from their students' perspectives, with very good results.

Future science teacher education research probably will be highly influenced by technology-infused competence. In an e-learning environment, many competences change and teachers' PD must also be updated. However, one thing that will not change is the spirit of PCK.

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# Chapter 17
# Design to Understand Curriculum: Epistemic Practices, Teaching, and Learning in Science

**Ming-Chin Su, Che-Ming Tsai, Hui-Chi Chang, Wen-Hua Chang and Chen-Yung Lin**

**Abstract** Current science curriculum emphasizes the knowledge, skills, and epistemic practices of science. Scientific practices usually involve asking questions, developing models, investigating, constructing explanations, and negotiating meanings. Students are not only expected to acquire more relevant science knowledge, but also to develop the ability to think and reason about phenomena and, furthermore, to take actions and solve problems. However, science teachers utilizing published textbooks and focusing on coverage and neglecting the epistemic practices aspect of science curriculum would restrain the enactment of reformed curriculum. This chapter draws on the paradigm of understanding curriculum and gives examples to illustrate to what extent Taiwanese science teachers enhance their understandings of curriculum, teaching, and learning in science through designing science curriculum modules. We also compare and contrast the approaches of designing professional developing programs in literature and those emerging from the case teachers' design experiences. Furthermore, we illustrate how teachers' knowledge about curriculum, teaching, and learning in science interacted with each other and mediated teachers' learning process. This chapter helps readers understand the trend of curriculum reform in Taiwan, as well as ways science teachers learn under the reform context.

## 17.1 Introduction

Echoing the calls of needs in national development and public expectations, the goals of curriculum in Taiwan were revised to develop core competences that a modern citizen should possess (Ministry of Education 2008a). In the reformed curriculum, leaning subjects are regrouped into seven major learning areas. Moreover, school teachers were encouraged to implement learning areas following the principle of integration and adopting team-teaching approaches. The major contents of the science and technology learning area, for example, are designated to include the learning of substances and energy, the world of living organisms, the earth environment, ecological conservation, and information technology. The science and

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technology learning area will also focus on knowledge and skills of science and research, developing attitudes such as respect for all forms of life and love for the environment, and developing the ability to utilize information, as well as applying the knowledge and skills to everyday life, which is equally important.

In the guidelines of the science curriculum (Ministry of Education 2008b), the basic competencies in science and technology were formalized into eight key components of science practice: process skills, content knowledge of science and technology, nature of science and technology, development of science and technology, scientific attitudes, intellectual habits of thinking, application of science knowledge and inquiry process, and design and manufacturing. The guidelines also address the principles of selecting and compiling instructional materials, curriculum implementation, pedagogy, and assessment of student learning. In a nutshell, the guidelines highlight the reformed curriculum as school-based, competency-based, empowerment of teachers, and learner-centered. The ideal of the reformed curriculum is to keep with the global trends of educational reform (Ministry of Education 2008a). For a long time, school teachers followed a centralized curriculum and mandatory curriculum materials. Hence, the Taiwanese teachers perceived that the ideal of the reformed curriculum is challenging for them to operate in the schools.

From the literature on professional development of science teachers, it is found that focusing singularly on building knowledge base, training teaching strategies, or developing appropriate beliefs, is limited in moving in-service science teachers toward the goals of teaching science in accordance with students' previous understandings (Chen et al. 2008; Guo et al. 1997). In order to enhance the participant teachers' teaching effectiveness, a sustained support is necessary for teachers to successfully implement student-centered teaching strategies. Chen et al. (2010) suggested an intensive workshop in summer combined with school visits during school terms and reflection-on-action strategies. Moreover, literature in the past 15 years reveals that improvement of science teaching practice usually comes from teacher-initiated teaching actions in classrooms. Science teachers may work together to determine teaching topics (Hung and Chen 2011), frame the content structure (Chang and Lai 2001; Chiou et al. 2003; Hsiung et al. 2001; Kao 2006; Tseng and Chen 2005), sequence teaching activities (Chang 2001; Hsu and Hsu 2012; Tseng and Hsu 2006), design assessment instruments (Lu and Huang 2007), and analyze each teacher's teaching performance (Lin et al. 2013).

In the abovementioned studies, science educators collected data including, content knowledge structure, pedagogical content knowledge, understanding of science curriculum, educational goals, personal rationale of science teaching, personal goals of learning science, teaching performance, artifacts, and/or assessment strategies, and analyzed their data to identify the participant teachers' professional growth in terms of his/her beliefs, relative knowledge, teaching performance, or students' learning outcomes. These findings were used for making comparisons among groups of students from various teachers or identifying professional growth. Case science teacher's professional growth in domains of relative knowledge, beliefs, or teaching performance through taking and reflecting upon actions and public sharing of action results were illustrated and discussed in some empirical research (Guo et al. 1997; Lin et al. 2013; Tseng and Chen 2005). Their findings indicated that taking actions collectively, collecting information and reflecting upon teaching events, and sharing action experiences are promising in promoting professional growth of in-service science teachers. Yet the teachers' trajectory of professional growth was not examined in depth.

Science teachers are active learners. They make sense of the routines and events in their professional life and take actions accordingly, thus to establish themselves as a member in the professional learning community. Exploring science teachers' trajectory of professional growth can inspire science educators to develop effective programs for science teachers. Therefore, this chapter aims to propose an approach to explore teachers' trajectory of professional learning in terms of their knowledge of the role of epistemic practice in science curriculum, knowledge of science learners, and knowledge of science teaching, particularly focusing on science teachers' professional development through designing curriculum materials.

## 17.2 Context

Reflecting upon the scope, sequence, and coordination of the entire curriculum, the Ministry of Education of Taiwan has commenced a 9-year Curriculum Reform. In the new curriculum framework, more emphases are on integrating subject matters and building a student-centered learning environment (Ministry of Education 2008). Since 2002, all subject matters in junior high schools are regrouped into seven learning areas and the curriculum goals are reoriented to build all students' ten domains of basic ability. According to the policy, the traditional layer-cake type science curriculum (Biological Science-Physical Science-Physical Science plus Earth Science) in junior high schools is combined with living technology. Recently, the curriculum reform was extended to the senior high school level.

In addition to the announcement of the reform curriculum guidelines, the Ministry of Education funded schools to integrate advanced technology or frontier science research topics into school-based science curriculum (Lin et al. 2013; Hung and Chen 2011; Tseng and Chen 2005). From the pilot projects, it was apparent that most of the specialized science teachers in the secondary schools were hindered by their experiences of lecture-based teaching style.

In order to assist school teachers to face the challenge of recent curriculum reform, some science educators started from teaming teachers and training them in developing curricular modules through providing professional development programs. Eventually, science teachers were expected to be equipped with sufficient understandings about the nature of learning and teaching, and the ideal of reformed curriculum.

As indicated in literature, Loucks-Horsley and Stiles (2001) pointed out that the overall design of a professional development program has to consider four critical inputs—context, knowledge and beliefs, critical issues, and strategies for professional learning, if the program is intended to meet the particular needs of the teachers and students. In the same document, they reported 15 strategies in designing professional development program, including immersion (immersion in inquiry into science and math; immersion in the world of scientists and mathematicians); curriculum (curriculum implementation, curriculum replacement units, curriculum development/adaptation); examining practice (action research, case discussions, examining student work and student thinking and scoring assessments); collaborative work (study groups, coaching and mentoring, partnerships with scientists and mathematicians in business, industry, and universities, professional networks); and vehicles and mechanisms (workshops, institutes, course, and seminars, technology for professional learning, developing professional developers).

In an early research project funded by the National Science Council, Guo et al. (1997) planned a 3-year university and school collaborative professional development program based on the four-step planning cycle, set goals-plan-do-reflect suggested by Loucks-Horsley and Stiles (2001). The researchers invited junior high schools' teachers to attend knowledge-building workshops and then helped the teachers by forming teams to develop curriculum modules. In a follow-up survey study, Chang et al. (2002) claimed that junior high school science teachers' attitudes toward the curriculum reform were altered positively after attending professional development workshops. The participant teachers self-reported their improved understandings of the goals and rationale of the curriculum reform. However, the teachers also notified a need in learning to design learning activities for promoting students' learning outcomes, as well as adapting the published curriculum materials and establishing learner-centered learning environment.

Enlightened by the literature (Guo et al. 1997; Chang et al. 2002), we embraced the rationale that teachers are active learners and continuously shape their own professional growth. Coenders et al. (2008) also suggested that science educators should invite teachers as their codevelopers and support them to enact the designed curriculum. They argued that this will provide teachers an active learning experience in which teachers would strengthen and develop their pedagogical content knowing.

Nevertheless, very few studies in Taiwan had explored teachers' growth through this type of collective effort. We therefore inspected and reflected upon the strategies listed by Loucks-Horsley and Stiles (2001) to design a program to facilitate participant teachers' professional development. For the case teachers reported in this chapter, the strategies selected included workshops, curriculum development/adaptation, examining students' work and thinking, and study group.

## 17.3 Methods

In the professional development program, we first arranged a series of presentations to build participated teachers' knowledge about the reform policy and rationale, constructivist teaching approaches, sample modules, curriculum developing models to develop modules, cooperative learning approaches, use of technology, and so

**Table 17.1** Information about case science teachers

| Participant | Years of experience | Background | Expertise |
|---|---|---|---|
| Charles | 4 years of teaching in junior high schools | Bachelor in chemistry<br>Master student in science education | Self-regulated learning |
| Dean | 10 years of teaching in senior high schools | Bachelor in earth science<br>Master in physics<br>Doctoral student in science education | Misconception |
| Dick | 3 years of teaching in senior high schools | Bachelor in biology<br>Master student in life science | Socio-scientific issues in science education |
| Eve | 16 years of teaching in a junior high school | Bachelor in biology<br>Master in science education<br>Doctoral student in science education | Media in science education |
| Hank | 12 years of teaching in junior high schools | Bachelor in biology<br>Master in science education | Multimodal writing |
| Linn | 30 years of teaching in junior high schools | Bachelor in biology | Project-based learning |

on. Some expert teachers with rich experiences in managing interactive learning environment were invited to share their teaching strategies, teaching materials, and curriculum developing and enactment experiences.

Thereafter, teachers formed groups according to their available time and interests. The researchers and teachers in each group determined some possible topics of science curriculum modules. Each group planned a schedule of group meetings for analyzing textbook content, setting teaching goals, sharing progress, and receiving suggestions. Finally, based on mutual agreement, a science teacher in each team was invited to implement the curriculum module. The case teachers reported in this chapter are listed in Table 17.1. Currently, about 70 % of Taiwanese science teachers have a master's degree in science, science education, or education. Another 15 % of science teachers are studying for their master or higher degree in science, science education, or education.

During team meetings and the teachers' enactment of the curriculum module, graduate students and one science educator acted as consultants and participant observers in each teacher team. Science educator and graduates also supported the teachers by collecting feedbacks from curriculum developing documents, student artifacts, teacher and student interviews, or inviting comments from outside science educators and school faculties. The teachers reflected upon the collected quantitative and qualitative information after implementing the curriculum modules. In Table 17.2, the developed curriculum modules are listed and a brief description is provided.

Throughout the module developing duration, the science educators continuously provided workshops or presentations based on the teachers' needs in order to update information about the curriculum reform, and elaborate contemporary theories of

**Table 17.2** Examples of teacher-developed curriculum modules

| School | Activity title | Subject | Teaching time | Features of learning activities |
|---|---|---|---|---|
| A | Self-assessment of expository writing | Physics | 8 times, 20–25 min each time | Students self-assess their understanding of core concepts and provide written explanations |
| B | Solar cell | Physics | 4 h | An add-on advanced technology integrated module |
| C | Socio-scientific issues | Biology | 8 times 25 min each time | Select two socio-scientific issues related to the core concepts of each chapter |
| D | Science news instruction | Biology | 3 times, 45 min each time | Enrich the core content covered in the textbook. Carry out at the end of each chapter |
| E | Multimodal writing embedded science instruction | Biology | 10 h | Modify the lab activities provided in each chapter of the textbook |
| F | Immersion approach of argument-based inquiry | Biology | N/A | Embedded in the whole semester |

learning and teaching science (such as notions and more examples of constructivist teaching approaches, exemplary cooperative learning practice, professional learning community). In addition, the teachers had opportunities to engage in regular and collaborative interactions through multiple communication modes, including web-based forum, face-to-face meeting, social network websites, and informal gatherings. Science educators tried their best to attend and collaborate with the teacher teams whenever it was possible.

The case teachers kept their individual or collective teaching portfolio. They shared their works with science educators and other school teachers to receive feedbacks. The reasons for building teaching portfolio are as following:

1. Under the curriculum reform, teachers are expected to develop their own teaching materials and provide evidence for school evaluation procedure. Focus on building portfolio is an appropriate strategy since every teacher should do it for teacher evaluation and professional development. This approach is also considered in line with the constructivist notions that learning should be based on previous experiences and needs.
2. A teaching portfolio is more than accumulation of teaching materials. Helping teachers in developing instruments and collecting evidence through the action cycles of examine-plan-action-reflect, is expected to have a function of stimulating reflection and increasing teaching effectiveness.
3. Based on the point of view of situated cognition, the teachers are expected to demonstrate professional development with regard to their knowledge, skills,

and beliefs. Their teaching portfolios can be used as physical tools providing visualized evidences in guiding teachers' discussion and reflection.

4. The teaching portfolios can be used as examples to invite team members' participation as well as templates for other teachers to adapt for their usage.

Data from six cases were collected through multiple techniques. Data sources include meeting journals, e-mails, classroom anecdotes, artifacts, online discussion logs, and interviews transcripts. The teachers were interviewed on their knowledge and beliefs of science teaching, their knowledge and beliefs of students' science learning, and their knowledge of science curriculum and curriculum reform.

While analyzing data, we first generated thematic understandings about teacher performance through repeated comparing and contrasting among data from different sources. Afterward, we analyzed the results of assessment or tests to screen out teaching content and corresponding teaching segments in order to interpret the influencing factors in each teaching anecdote.

## 17.4 Findings on Trajectory of Teacher Learning

As indicated in the literature, the efficacy of curriculum reform rests upon the teachers' knowledge related to the development and implementation of curriculum. In general, we found that the teachers' understandings and appreciations of the curriculum reform and curriculum framework were enhanced. Their knowledge of applying various teaching modes, assessing students in authentic situations, and developing or adapting problems- or core concept-centered curriculum modules, are enhanced as well. The results from analyzing a sample of selected videotape clips (procedures described in Sun 2000) showed that teacher performance was improved in terms of teaching content, teaching behavior and assessment, student behavior, and access of resources (Chang 2012, NSC technical report). The case teachers' presented their teaching research in several international science education conferences in year 2011–2013. In this chapter, we focus on presenting the case teachers' learning trajectory throughout the developing process. We first describe the case teachers' acquired understandings about the principles of designing curriculum modules, followed by sketching the case science teachers' enhanced knowledge of epistemic practice, teaching, and learning. Finally, we reflect upon the approach and give suggestions.

### *17.4.1 Contextualized Understanding of Curriculum Design Principles*

According to the regulation policy, all school teachers were required to attend workshops about reformed curriculum. These case teachers were experienced in teaching science in secondary schools. Therefore, at the very beginning, we expected the case teachers were knowledgeable about curriculum design principles.

As stated in the curriculum guidelines, teachers are issued the responsibility to provide curriculum adapted to students' needs, levels of academic ability, interests, and experiences. Teachers have flexibility to reorganize curriculum based on daily life, local, or social issues, as well as referring to the listed themes and subthemes in the guidelines to integrate content knowledge in different science disciplines. Inquiry-based instructional approach and several interdisciplinary topics are also illustrated in the guidelines for teachers' references. Moreover, utilizing historical cases that exemplify the scientists' discovery process are recommended to enrich students' understanding of the nature of science knowledge, scientific inquiry, and science enterprise.

However, with the exception of Linn (who had been a lead teacher in the local educational authority for several years), we found that the other case teachers only held a literal understanding of the curriculum design principles addressed in the curriculum guidelines when they agreed to join in. They routinely designed and carried out daily teaching activities mainly to cover the textbook. Before joining the design teams, they had very limited experiences in designing curriculum modules.

We observed that, in the teacher teams, the case teachers had ample opportunities to discuss the design principles during their group meetings. On occasions they made any decision on the teaching topic, set teaching and learning goals, or determined the teaching duration and timeline, the team members would remind each other from time to time to focus on the goals. They spent time on analyzing science content and searching for teaching resources, such as, science news, socioscientific issues, manipulation materials, video clips or other media aids, expository text materials, etc., to fulfill their teaching needs. However, we also noticed that they often raised the issue about the limitations of available teaching time. Rather than exploring the possibility of extending the scope of teaching content and alternative approaches to carrying out the lessons, the teacher members in four out of the six teams would express their thoughts and suggestions, but were not able to spend more time on brainstorming optional possibilities.

Nonetheless, there were instances where Dean and Linn showed their understandings of design principles that differed from the other four case teachers.

In Dean's group, teachers continued to discuss two possible teaching approaches: teaching for comprehension and project-based learning. The former approach was more like the way Dean had been applying in his classes. Another teacher, Jeff, had rich experiences in applying project-based learning approach in secondary schools for more than 10 years. The group of teachers mapped the teaching content and developed an innovative curriculum on "the solar cell and energy policy." They developed an understanding of the curriculum as a hypothesis to be tested. They decided to compile two different curriculum modules of learning materials, one for comprehension and the other for project-based learning. Dean introduced the solar energy device located in the school campus into the comprehension curriculum materials. The team organized two different school sites to implement the two modules.

> These photos are about our school. This device in the photos could produce energy in the photovoltaic curriculum modules. And that is the monitoring system. We can obtain information about how much energy it produced. I would like to discuss with students about the device and the application of solar energy at our school.

Dean expanded his understanding of curriculum designing principles beyond focusing on the decontextualized content in textbooks through his designing experience of the two parallel modules. In the following school year, Dean further extended this designing experience, and posted a call for students to initiate action projects in the school. Students from different grade levels applied to receive a limited amount of funding for planning and conducting their action projects. After the successful experience, Dean continued to collaborate with other teachers in the high school and offered an elective course for students and teachers to get involved in developing sustainable campus. Consequently, Dean and his colleagues established a school-based curriculum development model.

Linn is an active senior science teacher with plenty experiences in compiling curriculum materials. She had abundant human resources to support her in instructional design. Her involvement in the teaching team exemplified another pattern of learning trajectory. Linn frequently received enquiries from science teachers with different background in science disciplines. Although she was new to argument-based inquiry, her expertise in carrying out project-based learning and courageous disposition of trial-and-error led her to be able to integrate written argumentation tasks into her lessons with ease.

Linn approached teachers in different schools through face-to-face meetings, web-based forums, and online professional communities. She enthusiastically learned from language teachers about facilitating students in creating picture books, and learned from junior science teachers about utilizing technology to improve her teaching. She also studied other teachers' experiences and combined her own understanding and experience in project-based learning to design argumentation-oriented learning tasks. She actively took in these rich external resources and dynamically supported herself in advancing her knowledge of curriculum designing principles. Her effort of breaking through her "conventional" ways of teaching science frequently encouraged other team members to apply innovative teaching strategies.

Charles, Dick, Eve, and Hank focused on adding elements of self-assessment for cultivating self-regulated learner, relating to socioscientific issues to expand students' understanding of science research, integrating science news media reports to cultivating students' competency of argumentative reasoning, and encouraging students utilizing multimodal representations to transform their understanding respectively. In contrast to the curriculum designing actions adopted by Dean and Linn, Charles, Dick, Eve, and Hank followed more traditional ways of designing curriculum modules. They identified goals, analyzed and determined the teaching sequence, designed learning activities and assessment tasks for each learning unit, enacted the teaching plans, and examined students' learning outcomes, in order to investigate the effectiveness of the curriculum modules.

Our analysis indicated that the learning trajectory of Charles, Dick, Eve, and Hank were more recursive and slow in nature. Although they were able to focus on core concepts of each chapter and adjust the level of difficulty of the content knowledge, they frequently expressed hesitance and frustration about adopting new teaching approaches due to their students' retarded and limited changes. They showed a higher degree of anxiety during the longer duration of teaching intervention, although their team members often gave positive words and developed a sense of integrity by giving emotional support. The teacher members in their teams got involved in detailed analysis of students artifacts before they further provided their feedbacks on teaching performance. Short of feedbacks from immediate student learning outcomes was another critical influencing factor on teachers' design and enactment of curriculum modules. This implied that positive student learning outcome could be one of the possible effective catalysts for changes in teachers' learning trajectory.

### *17.4.2 Knowledge of Epistemic Practices in Science Curriculum*

Based on the analysis of data, we identified that Hank showed the most noticeable growth of knowledge of epistemic practices in science curriculum through designing science curriculum modules. Hank constantly modified the lab activities for students to frame claims based on their manipulation, data transformation, and publicizing their knowledge. In interviews, he stated that "*Incorporating technology to enhance the learning environment saved more time for experimenting, however, what the teacher should do to utilize the extra time?*" From the worksheets, we recognized that his students had rich opportunities to pose questions, design experimental steps, and formulate science explanations in the format of self-generated multimodal representations. Moreover, Hank also improved his approach of guiding students to do independent studies by learning from the member teachers in the team. He reflected upon his teaching practice and accepted invitations to share his teaching approach in some other junior high schools. In the following school year, he was appointed to organize workshops for students to conduct independent studies. Teachers in his school approached him to learn strategies aimed to enable students to generate multimodal representations.

Linn was quick in designing learning tasks and establishing a learning environment for effective learning. However, she drew on teaching examples from language area that led her to spend more student learning time on reading informational books and recording observations. It was regretful that she was short of time to guide the students toward developing deeper understandings of the nature of knowledge and science process. Linn was aware of her failing in this aspect. She proposed a way for the students to give comments and suggestions on each other's artifacts after the activity. She also digitized some of the student artifacts, posted them online, and invited members from an online professional community to give her suggestions about improving the task.

Dean reached a noticeable higher level understanding of the nature of science knowledge through discussing about project-based learning within the team. Nonetheless, the limited teaching time prohibited him from actualizing the teaching plan. He would like to use real objects to arouse students' learning interest, in order to enrich students' understanding and application of solar energy in daily life. While enacting the curriculum module, his students received an information-rich introduction session on solar cells deployed in the campus, followed by the teacher's explanation in classroom, and an oral presentation on their position and reasoning regarding the provided information about fuel consumption data chart in the past years. His students did not have opportunities to conduct investigations beyond a cook-book type lab activity to elaborate their understanding about solar energy and energy policy. After enacting the curriculum module, Dean examined the students' learning outcomes and realized that curriculum implementation should address students' needs, rather than focusing on delivering rich subject matter knowledge. Some of the teaching content, such as, how a semiconductor produces electricity, can be omitted or can wait till students raise their need of the knowledge.

Eve, Dick and Charles focused more on developing conceptual understanding about facts rather than the process of constructing science knowledge. They seldom spent time on discussing the nature of science knowledge in social context, although Eve and Dick integrated socioscientific issues in their teaching. Occasionally, Eve and Dick encouraged students to think critically about the relationships between research procedure and findings, as well as their judgment of the issues. Since Eve relied merely on written form, and Dick frequently terminated the discussion with no decisive closure, it was short of solid evidence to reach a conclusion about their improvement in terms of their knowledge of epistemic practices in science curriculum.

### *17.4.3 Knowledge of Science Teaching*

Case teachers teaching in junior high schools were comparatively more willing to adapt the content to students' ability level. They were also more flexible in utilizing external resources to draw students' attention. We suspected that possessing rich subject matter knowledge would have hindered the teacher from developing a curriculum module for students to learn through authentic experience of generating science knowledge.

For example, the original concept map of instructional representation of Dean was complete and complex. It appeared that Dean had difficulties in simplifying the concept map to suit his students. Understanding about students' starting points is invaluable. Dean intended to apply comprehension approach, doing experiment, and discussion in his lessons. By means of discussion sessions within the team, Dean classified the content and refocused on students' learning difficulties after examining students' performance in preassessment.

Dean took the initiative in using the two different instructional strategies in order to resolve the conflicts of his belief of science teaching. Considering his limited knowing about project-based learning, Dean tried to learn more about instructional strategies of project-based learning from his team members. It is important to note that in the process of developing curriculum, Dean learned about project-based learning and was concerned about a shortage of teaching time for his students to complete the projects. He expressed his confusion about the nature of science teaching:

> Teacher Jeff, how will you do the activity for two periods? For me, it seems to take just thirty minutes to talk it over?

Dean changed his opinion after carrying out the two instructional strategies in a nonscience track class. He appreciated the effects of project-based learning and realized that covering the content is not the ultimate concern. Inviting students to engage in learning and developing a thorough understanding throughout the curriculum module, is the most prestigious and precious teaching principle. From the designing experience, Dean learned to diagnose students' prior understanding and increase the coherence of teaching content. Moreover, he noticeably became convinced of focusing on selected core ideas. Nonetheless, he was struggling with the application of student-centered strategies and the concern of time limitations for science-track students from time to time. The growth of knowledge of science teaching is not straightforward.

Dick, during his early teaching career, also taught in a senior high school. He was eager to try out the newly announced socioscientific issues oriented biology curriculum. He satisfactorily selected and brought in the issues, questioned the students, and engaged the students in sharing opinions about the issues. However, he was disappointed by the ineffectiveness of his teaching activity on enhancing students' conceptual understanding. He overestimated the available teaching time and mistook the goal of the issue-oriented instruction. Through the discussion and reflective conversation within the team, Dick realized that some complementary tasks, such as extensive reading and written argumentation, might have potential in promoting students' sophisticated reasoning. He also recognized the necessities of consolidating the students' conceptual understanding about the issues through procedural and metacognitive scaffolds.

Charles had been bothered by his under-motivated students. He had a feeling that some of the students were struggling and some were going to give up. However, he lacked strategies to diagnose and assist his students to develop a better conceptual understanding. He knew very little about how to adapt the teaching content in accordance with students' ability due to his inexperience in carrying out an interactive teaching approach. Charles taught in a school where the laboratory facility was limited and the administrative personnel preferred a quiet learning environment. Furthermore, students were alienated from the highly abstracted physics concepts. Demands of transforming physics law and principles into multiple representations had worsened the situation. Charles was in urgent need to develop his students' self-confidence. He learned the writing-to-learn strategies from other team members. After sitting in for several weeks, Charles decided to invite his students to self-rate their confidence on answering test questions and provide multimodal representations about the test items of their own selection. Charles was not feeling secured about his strategy. However, he was assured by the successful experience of his team members in applying writing-to-learn strategies. He sought for experienced peers to examine his students' artifacts. Under the strategic support of his peers, he sustained the instructional strategies for 8 weeks. During that period of time, his understanding of science teaching remained almost the same, except allocating part of the class time for writing. Charles was not able to articulate and share his action of and reflection upon carrying out the writing tasks during the 8 weeks of intervention.

Hank was not skillful in giving eloquent lectures. His science lessons were usually dominated by students' manipulating activities, writing tasks, small group discussion, presentation, and whole class discussion. When interviewed about what were the special features of his science teaching, Hank mainly referred to students' learning approaches, including identifying testable questions, designing procedures, transforming their understanding into different modes of representations, framing scientific explanations, and sharing findings and explanations in public. Hank and Charles are similar in lacking descriptions that signified their understandings of science teaching. However, compared to Charles, Hank was more decisive in terms of his teaching actions in taped teaching. His classes were equipped with a variety of equipment, including video camera, time lapse camera, notebook computers, mini projectors, and so on. His directions and explanation were simple and to the point. His students were fully engaged and well oriented.

In contrast to Charles and Hank, Linn is an expert of verbal expression. She was in shortage of terminologies to describe her knowledge of science teaching, but her vivid description of her classes and teaching tips, supplemented by student artifacts as illustrations, the audience can picture the atmosphere of active learning with ease. Unlike most of science teachers, Linn seldom referred to textbook during her teaching. Instead, she used a large amount of videos from the Internet to establish an interactive learning atmosphere in her classroom, and to make connections between content knowledge and daily life events. Her enhanced knowledge of science teaching during designing argument-based inquiry concentrated on the dialogic interactions between her and her students, as well as among her students. She paid more and more attention on the quality of evidences and the reasoning given by the students. She also agreed with the ideas of using writing tasks for students to integrating their understanding through different modes. She knew her students well and designed a series of prompts to guide students in organizing their thinking. In short, Linn insisted that teaching science is not to pass content knowledge to students, but to teach for understanding, integrating, and creating information.

### *17.4.4 Knowledge of Science Learning*

In the beginning of participating in the project, Dean seemed to know well the conceptual understandings and prior knowledge his students brought in. His confidence had been developed from teaching experiences over many years. But after pretest, Dean found that he overestimated the abilities of this group of senior high students. After teaching the curriculum module, Dean recognized that the students in the comprehension group lacked enthusiasm to participate. Worse still, students who were engaged throughout the lesson seriously lagged behind Dean's expectations. In contrast, students in project-based learning group developed noticeable progress in inquiry abilities. Dean related the different levels of participation to the inquiry abilities of students in different groups. Moreover, Dean pointed out students' misunderstanding shown in the process of manipulating materials. He had much to share about his surprised findings. We inferred from the case that a teacher's observations about students' mistakes seemed to play a considerable role in improving his knowledge of science learning.

> In the module of the PBL, when solar cars could run, students thought that maybe it needed more light. They asked another group to join them. So they had two halogen lamps with one solar car at the same time in order to increase the brightness of the light. Before adding the halogen lamp, students tried to move the lamp to find the right angle. They also shorten the distance between the lamp and the solar car in order to increase the brightness of the light. When we designed the curriculum, we arranged some activities to change the angle and distance of the light. In fact, students were able to perform the process of changing variables so as to enable the solar cars to move.

After posttest, Dean emphasized his realization that students' interest topics, aptitude background, and learning difficulties shall be taken into consideration while developing curriculum modules.

Dick analyzed his students' prior experiences and background knowledge on socioscientific issues before he delivered his issue-oriented instruction. His selection of issues matched students' interests and fully engaged the students. However, the questions he posted for students to think further were not clear. Students frequently got confused about the purpose of the after class tasks. Moreover, the majority of students were in need of training to formulate their arguments. From the student artifacts, Dick realized that some of the issues were totally out of the students' life experience. They could hardly imagine it, not to mention framing an argument about it. The socioscientific issues were complex in nature. Students required some initial understanding of policy in medicine, society, or economics prior to taking a stand. In addition, the students would need more time to consider points of view from both sides before clarifying their value and making judgment. Otherwise, students would waggle between the sides, or make uncivil and polarizing comments.

Eve focused on introducing socioscientific issues and writing argumentations in her seventh grade classes. She simplified the tasks and designed a writing template to afford the students to frame their arguments visually. She also found that students were interested in the topics, yet lacked connections between content knowledge and events and explanations in the news media reports. She held a view that teachers should guide the students to make connections actively and critically. Students were more interested in recent hot socioscientific issues. They might have learned certain viewpoints, yet were not acquainted with related scientific knowledge. The students would mistake claims as evidences, and as a result, make unsound decisions accordingly. Eve argued that: *explicitly teaching students the genre of news media report would help students get rid of making quick judgments and think thoroughly about the logical relationships between data and claims*.

Hank and Charles learned to address students' learning difficulties by encouraging them to transform their understanding into a variety of representation modes. Their students benefit from transforming understandings into multimodal representations. Moreover, by placing students' clarifications of scientific understandings at the center of science teaching, they were able to restore students' confidence in learning science. The member teachers in the team stimulated Hank and Charles to reflect upon the effects of planned teaching on students' learning. Although students' progress in providing explanations and improved conceptual understanding may not be apparent at first, eventually students showed satisfactory progress. While integrated with hands-on activities, effects of applying multimodal representations demonstrated a better learning result. As a result, Hank and Charles attributed students' competency in giving scientific explanations to their self-assessment of scientific understanding. However, they would like to examine the long-term effects of the strategy. Furthermore, they were deeply concerned that the students' enhanced competency in the approach was not closely aligned with that needed in the term examinations.

Linn stressed that she was surprised when her students were able to create a picture book about plant taxonomy within the limited class time. She also found that students with learning styles other than verbal preference performed better in this learning activity. She reflected upon her strategy and deliberated about why some high achievers in her classes did not perform as well as usual. She figured out that these high achievers could have learned as better as passive receivers, if she had encouraged them to manage their learning time actively. Linn tried to accommodate more open-ended reading and writing tasks for students to practice as independent learners. She was satisfied with her students' improved learning skills.

In general, students in the case teachers' classes can learn science through independent or self-regulated learning tasks. They might make mistakes or over-infer from available information. However, students eventually developed self-management and independent thinking skills.

## 17.5 Reflections and Suggestions

In this study, the professional development approaches were effective in enhancing teachers' understanding of curriculum designing principles. All the case science teachers developed richer subject matter knowledge. During developing curriculum modules, teachers' belief on the crucial role of content knowledge led them to lecture more and in-depth content knowledge. In the collective effort of curriculum developing teams, the case teachers would become aware of their belief in covering more science content. They also demonstrated searching for possible ways to overcome the barrier they encountered with great enthusiasm.

In general, designing curriculum modules was effective in promoting the case teachers to develop a more completed and adequate understanding of science curriculum, teaching, and learning. Either by developing one curriculum module, by developing two modules of two instructional strategies, or by actively taking in external resources and reflecting upon the student assessment results, the case teachers revised their belief as "piecemeal movers" or "jumpers." Consequently, the case teachers expressed an appreciation about the notions of student-centeredness in designing curriculum modules. In spite of their growth in all these aspects, the case teachers still concerned about the limitations of time and resources.

Drawing conclusions from our results, in order to facilitate science teachers to be more aware of their weak knowledge of formal science curriculum, teaching and learning, we suggest teachers employing two instructional strategies simultaneously in developing curriculum modules with their team members. That is, it is not necessary to facilitate the team members to pursuit a singular way of designing curriculum modules while they were in developing stage. The professional development approaches in this study have shown positive effects on promoting teachers' professional growth to a satisfactory extent. In addition to theoretical understandings of curriculum reform and science learning, the teachers know well about the value of student-centered learning. They are also capable of practicing these teaching strategies in real school context and reflecting upon the learning results in a collective manner.

We also identified some weaknesses in the teachers' action cycles. First of all, due to the rationale of our professional development program, we expected participant teachers to lead the process of developing curriculum modules. However, we frequently found that the teachers had considered reverting back to their old routines if they were not feeling secure about the new teaching approaches. We argued that secondary teachers possess adequate content knowledge, but still in need of affective and pedagogical supports.

Furthermore, we suggest that science educators and teachers should find ways to explore and assess the roles of prior learning experience and knowledge on students' construction of new understandings about science. Students' expectations about their science teachers and science lessons also played a crucial role. If students could not appreciate the teachers' teaching strategies and content, they may not value the learning experience. This will lead to the teachers' hesitancy in revising their knowledge of science curriculum, teaching, and learning.

Despite these noticeable weaknesses, the authors would still suggest to enhance teachers' professional expertise through action cycles of examine-plan-action-reflect when applying innovative teaching approaches and expanding the scope of the content to daily life related issues. Many of the science teachers themselves did not have open inquiry experiences in science disciplines, and were short of pedagogy in helping student learn through inquiry activities. Teachers teaming up and designing curriculum modules through the action cycle would be able to supplement these teachers with the needed curriculum inquiry experiences.

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# Chapter 18
# Integrating Paiwan Culture into the Design of a Science Curriculum, with Teaching Examples

**Huey-Lien Kao, Chih-Lung Lin, Ming-Chou Su and Chi-Liang Chang**

**Abstract** In this chapter, we first provide an overview on Taiwan's indigenous population, including the various tribes, their population distribution, as well as their cultural characteristics. Second, we review the state of Taiwan's indigenous science education in regard to the following aspects: indigenous education, indigenous science education research, factors affecting indigenous learning achievement, and indigenous e-learning. Then, we take one indigenous tribe, the Paiwan, as an example and describe the implementation of culturally responsive teaching in one indigenous school, starting with the SWOT analysis of the school, followed by the development of a curriculum for the professional development of the school's teachers. In addition, we describe how to design a science curriculum based on Paiwan culture. Finally, a culturally responsive science teaching model (CRSTM) is created.

## 18.1 Overview of Taiwan's Indigenous Status

### *18.1.1 Indigenous Tribes in Taiwan*

Taiwan's total land area is about 36,000 km$^2$ (14,400 square miles). It lies off the southeastern coast of mainland Asia, across the Taiwan Strait from China. It is an island on the western edge of the Pacific Ocean. To its north is Japan; to its south is the Philippines. Taiwan is a multiethnic society; around 2% of the population is aborigines (Lee 2009). Modern historians believe that the indigenous people of

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Taiwan arrived from southeast Asia 15,000 years ago. Their native languages are identified as having originated from Austronesian languages (Rubinstein 2007). They occupied both the coastal lowlands and the mountainous uplands until the arrival of the Dutch in the seventeenth century. Historical records indicate that an estimated 70,000 aborigines lived in small villages on the west coast of the island during the early years of Dutch occupation, but new migrants from mainland China quickly outnumbered the native settlers (Stainton 2007). The Han Chinese group eventually became the majority in Taiwan, whereas the aborigines became the minority.

Taiwan had a population of 23,332,705 in March 2013, out of which 528,799, or 2 %, are classified as aborigines. In 2013, the government of Taiwan officially recognized 14 indigenous tribes: Amis, Paiwan, Atayal, Bunun, Truku, Puyuma, Rukai, Sediq, Tsou, Saisiyat, Yami (Tao), Kavalan, Sakizaya, and Thao. However, there are other two indigenous tribes recognized in 2014. There are Hla'alua and Kanakanavu (Council of Indigenous Peoples (CIP), Executive Yuan 2014). Various ethnic groups have their own cultural characteristics, language, customs, and social systems. In teaching the nation's history, Taiwan's indigenous history and culture should be included for its unique beauty and treasures (CIP 2013a).

### *18.1.2 Population Distribution and Cultural Characteristics*

The geographical distribution of Taiwan's indigenous tribes is illustrated in Fig. 18.1, while their population (CIP 2013b) and cultural characteristics (CIP 2007, 2013a) are described in Table 18.1.

## 18.2 Taiwan's Indigenous Science Education

### *18.2.1 Indigenous Education*

In recent years, many countries have noted different points of view regarding multicultural education; these are of great concern in regard to indigenous education. One of the many multicultural education goals is to fight for equal educational opportunities for students from different ethnic groups; another goal is to inspire students to learn the knowledge, skills, and attitudes that can help them survive in their communities (National Research Council 2007). Indigenous education is one of the most important goals in Taiwan's current multicultural education system. Hence, the government has taken steps to reform the education system by launching many initiatives to revitalize indigenous cultures and give indigenous people a voice (Liu and Li 2007). Although school infrastructure and other hardware have generally been upgraded to the national level, indigenous education still faces many difficulties. For example, indigenous students exhibit maladjustment when they are

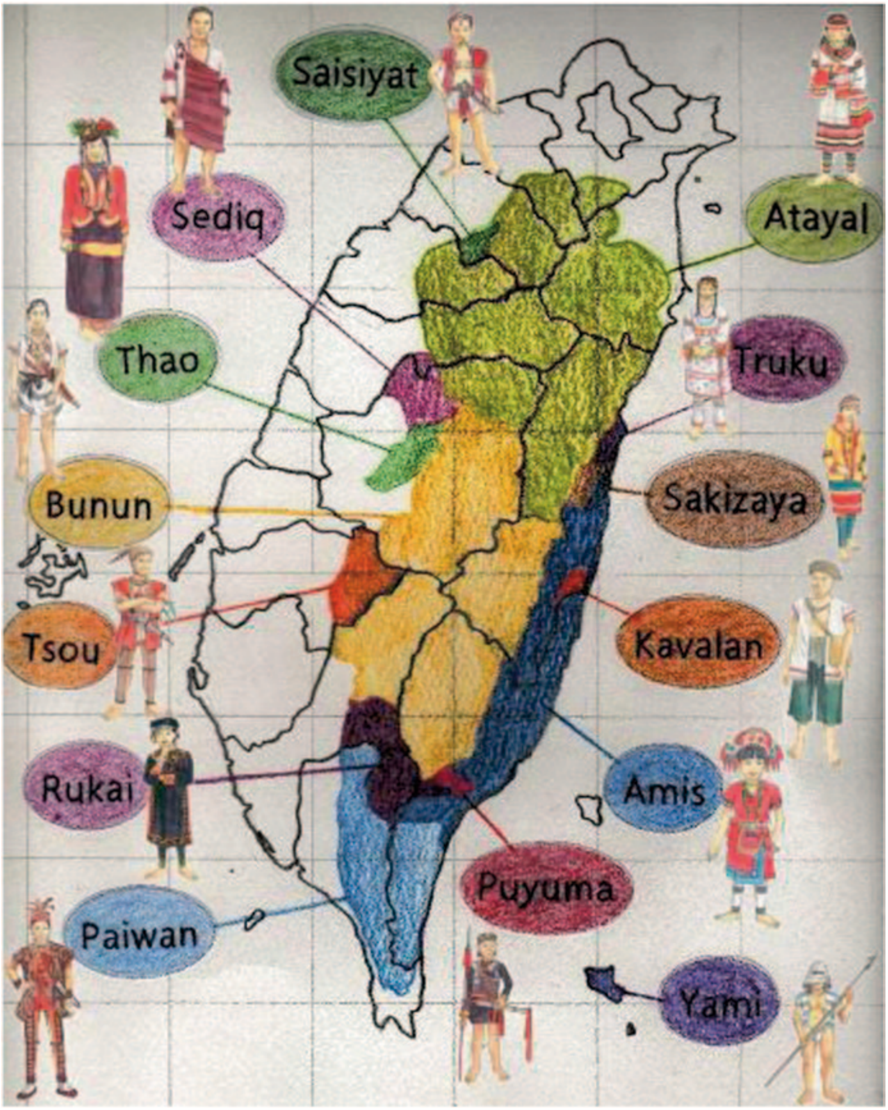


**Fig. 18.1** Taiwan's indigenous geographical distribution

integrated into the school system (Liu and Huang 2005; Tan 2002). Also, underqualified teachers and a high population outflow rate of the young to urban centers for employment, takes the tribes' intellectual elites out of the villages, leading to undesirable effects (Chen 2004).

Since Taiwan's indigenous tribes primarily live in the mountainous interior of the country, a gulf has emerged over the years between the tribes and the mainstream culture in terms of customs and languages. As formal education, regardless

**Table 18.1** Taiwan's indigenous population and cultural characteristics

| Tribes | Population | Cultural traits |
|---|---|---|
| 1. Amis  | 196,863 | They live along the east coast plains of Taitung and Hualien counties of Taiwan. The social institution of the Amis tribe is mainly based on matrilineal-oriented clans. They are also well-known for their dance and music during ritual ceremonies |
| 2. Paiwan  | 94,573 | Their clothing and embroidery have been influenced by the Han Chinese during the time of the Qing dynasty. Their embroidery and art works are seen in everyday items such as clothing, utensils, and woodwork |
| 3. Atayal  | 84,364 | The Atayals live in the central mountain range of northern Taiwan. In the past, Atayal men were known for their hunting and women for their weaving. Face tattooing of the Atayals has attracted much public attention |
| 4. Bunun  | 55,073 | Living in the high mountain ranges, Bunun's livelihood depends on hunting and the cultivation of millet. Therefore, their rituals center on harvesting millet and hunting animals |
| 5. Truku  | 28,864 | The Truku tribe shares similar cultural custom and traits with the Atayal: living in high mountains, hunting, and farming, and known for its strong fighting spirit. Stemming from a feud between the two tribes, however, the Truku language gradually became nearly unintelligible to the Atayal and vice versa |
| 6. Puyuma  | 13,041 | They are traditionally known for their assembly system, with strict training and responsibility delegated to each age group. Their popular "Hunting Festival" is derived from the rigorous training system for boys as they progress to adulthood |
| 7. Rukai  | 12,632 | The Rukai live mostly on the eastern and western sides of the central mountain ranges of southern Taiwan. They are known for the hierarchical structure of their society. The Rukai practice primogeniture where family property is inherited by the eldest son |

**Table 18.1** (continued)

| Tribes | Population | Cultural traits |
|---|---|---|
| 8. Seediq  | 8582 | The Sediq have a smaller and narrower distribution than the Atayal, mostly in Renai Township of Nantou County, with the Atayal to the north and the Bunun to the south. Similar to the Atayal and Truku tribes, the Sediq once practiced facial tattooing which represented the outstanding weaving skills of the women and great courage of the men |
| 9. Tsou  | 7063 | The Tsou inhabit the Alishan mountain ranges of Chiayi county. The village of the Tsou tribe has a men's house, called Kuba, which serves as a ritual center. The most important festival, known as Mayasvi, which honors the god of war, takes place on February 15th |
| 10. Saisiyat  | 6303 | The Saisiyat live in the mountain ranges of Hsinchu and Miaoli Counties. The social structure of the Saisiyat is patrilineal. Once every 2 years, the Saisiyat have a ritual celebration known as Pastaai or dwarf spirit festival |
| 11. Yami (Tao)  | 4365 | The Tao, as the Yami call themselves, live on Taiwan's Orchid Island. The Tao live by catching fish and growing taros and sweet potatoes. They distinguish themselves from other tribes in Taiwan through their architecture, flying fish festival, and ceremonies for launching new boats |
| 12. Kavalan  | 1334 | They have maintained their traditional songs which sound melancholic compared to the lively music of the neighboring Ami people. Traditional Kavalan ceremonies are related to farming and fishing activities, with the most important being the Palilin Ceremony of paying respect to ancestors, held before the Lunar new year |
| 13. Sakizaya  | 747 | In 2001, the Sakizaya began their effort to revive their culture and to bring back their traditional ceremonies, clothing, dances, and songs, including the unique "work song." The colors of their clothing are brownish gold, maroon, and black |
| 14. Thao  | 742 | In September of 2001, the Thao, once thought to be a branch of the Tsou tribe, were added to the ethnological classification of Taiwanese aborigines. The Thao, the smallest tribe of Taiwan, live near Sun Moon Lake of Nantou County. "Ulalaluan," the basket containing the ancestor spirit is hung in the corner wall of each household |

of the language or teaching content, is based on mainstream culture, indigenous students often encounter more difficulties in their learning compared to their majority peers (Tang and Chang 2009). The cultural disconnect between indigenous students and their schools not only added to difficulties in learning but also worked against educational success (Chung 2003; Lin 2003; Yen 2009). The implementation of aboriginal education meant assimilation into the dominant culture (Lee 2009).

Since indigenous cultures are unique, the government and the people of Taiwan, in appreciation, have worked to keep these cultures and languages alive since the 1990s (Hou and Huang 2012). In 1998, the government announced the implementation of the "Indigenous Education Law" to establish an indigenous education system with a high quality, create a new image of modern indigenous people, and improve their competitiveness; however, even after the implementation of the "Indigenous Education Act," indigenous students' learning achievement has remained low. Research shows that these minority students have continued to fail in Taiwan's public school system (Yen 2009).

### *18.2.2 Indigenous Science Education Research*

One of the current issues in science education studies is the enhancement of education within culturally pluralistic societies. In 1991, the National Science Teachers Association announced its position on multicultural education, stating that science education should help students from diverse cultures learn science and develop engineering and technology career-related skills. In Taiwan, general research on aboriginal education reform emphasizes indigenous education policy, schools, mother-tongue teaching, and local education, with less research focused on aboriginal science education (Fu 1999).

In recent years, the focus has gradually shifted to indigenous science education. Research shows that indigenous students are still underachieving in mathematics and science compared to Taiwan's majority Han students (Chien 1998; Fu 1999, 2003). Without question, aboriginal students are no less intelligent than the Han students and it would be absurd to ascribe aboriginal students' scholastic underachievement to intelligence (Su 2009). Yet, explanations commonly offered for this difference in mathematics and science academic achievement are often reduced to stereotypes of aboriginal students having "significantly lower conceptual reasoning ability" or "lacking abstraction ability." As a result, indigenous people are often perceived as incapable of learning concepts and abstract contents. People even used "lack of cultural stimulation" and "cultural disadvantage" to explain the reasons that indigenous primary and secondary school students show no interest in school work and find it difficult (Fu 1999).

### *18.2.3 Factors Affecting Indigenous Learning Achievement*

The authors review the literature to explore the factors affecting indigenous learning achievement. These factors can be divided into the following: indigenous school environment, and learning difficulties of indigenous students in mathematics and science.

#### 18.2.3.1 Indigenous School Environment

Since Taiwan's Retrocession, Taiwan's government has promoted the creation of more than 30 school incentives and counseling measures to provide educational opportunities to indigenous people. However, because of the objective environmental constraints in economy, traffic, society, etc., education resources could not be properly assigned. In addition, the education system has been unable to take into account the social and cultural characteristics of indigenous people and their needs. In the curriculum aspect, the eighteenth to twentieth clauses of the "Indigenous Education Act" in Chap. 5, relating to the curriculum, point out that "the curriculum development and teaching material selection at all levels of school in ethnic education for indigenous peoples should respect the views of indigenous people and invite indigenous representatives to participate in the planning and design." However, the implementation of this Act over the years, in all levels of school curriculum development and teaching material selection, are mostly provided by culturally removed text book manufacturers, and are rarely made by culturally aware individuals (Kao 2002).

#### 18.2.3.2 Learning Difficulties of Indigenous Students in Mathematics and Science

Excluding Symbolic and Abstract Concepts of Learning

Indigenous language structure and thinking patterns will use an analogy of specific things to illustrate abstract ideas which they encounter; this differs from those of Han students and Han culture which mostly use symbolic expressions. Indigenous children have superior geological organization ability with more concrete and visual concepts and fewer abstract concepts (Jiang and Pan 2010). Therefore, indigenous students in mathematics and science find it difficult to understand abstract concepts. Guo and Tan (2002) also found that indigenous children mostly like specific operations, personal observations, dynamic and lively context of informal learning, and visual image learning; therefore, they tend to exclude symbolic and abstract learning concepts.

Cultural Factors Cause Learning Difficulties

Many empirical studies demonstrated that the reason for Taiwan's indigenous students' inferior mathematics and science learning performance can be attributed to "cultural differences" (Hsu et al. 2013). Since the scientific revolution of the seventeenth century, western science and technology has progressed rapidly, influenced by changes in Western culture. Today, the scientific community's descriptions and explanations of natural phenomena are taught in schools worldwide, but often differ from those found in non-Western cultures. While cultural differences exist between East and West for Han students in Taiwan, the cultural gap is much wider for indigenous students in Taiwan because they have to learn mathematics and science in Chinese rather than in their native language. Li (2004) pointed out that there are many differences between the grammar of indigenous peoples in Taiwan and Chinese grammar. These students often experience difficulties learning in a second language. In addition, traditional indigenous cultures of Taiwan have language instead of words; thus, they cannot develop logic and reasoning through words. When encountering complicated mathematical problems, they will not be able to comprehend the meanings of the questions and solve the problems (Chien 1998); they also use "approximation" rather than precise numbers (Huang 2002) which hinders them in a severely competitive study environment in regard to the precision of mathematics (Hsu et al. 2013). In addition, due to cultural differences, there is a gap between indigenous students' concepts constructed in their daily lives and science concepts instructed in schools (Chi 2001). For indigenous students in Taiwan, it may constitute a double transcultural learning experience (Lee et al. 2012), even in aboriginal schools, there is a mother-tongue class per week. It is partially for this reason that indigenous students' mathematics and science achievements are in decline (Hsu et al. 2013; Lin et al. 2008).

In summary, aborigines' political, economic, and social disadvantaged status, coupled with a school education system that teaches only mainstream culture as well as a negative cultural environment, are responsible for low indigenous student achievement.

### *18.2.4 Taiwan Indigenous E-learning*

With the genesis of the Web 2.0 community cooperation and collective intelligence concepts, the model of e-learning started an era of e-Learning 2.0. In other words, the traditional model in current educational training units has started to decline. Conversely, the model of sharing and collaborating has blossomed (Executive Yuan, ROC 2008). The reason for this transformation is that e-learning offers the kind of instant, on-the-job learning that can eradicate the obstacles of time and distance. (Zhang and Zhou 2003).

In e-learning, students do not have to travel to a specific location. It is reported that companies using online training can expect an average of 50 % in time savings and 40 to 60 % in cost savings compared with conventional training (Khirallah 2000). More and more countries in the world are currently taking e-learning as an important strategy to enhance their knowledge competitiveness. Governments are eager to play a larger role in providing more effective learning environments and increasing learning channels by the use of information technology. Therefore, students can obtain the necessary learning content anytime and anywhere, greatly improving learning outcomes and enhancing national competitiveness.

To increase national competitiveness, promote industrial development, and elevate social welfare, Taiwan is making great efforts regarding the implementation of information education. Since 1997, the Ministry of Education has promoted information education infrastructure by spending 6.47 billion NT dollars on building computer classrooms, elevating internet use, and installing software within all primary and secondary schools. They hope to achieve the end goal of “every class having computers and every class having access to the Internet” (Yu and Lai 2010). In 2001, the Ministry of Education continued to promote its blueprint of information education, not only targeting the building of a high-quality information education environment but also emphasizing the vision of “every teacher being able to use computers in the classroom and access the Internet everywhere.”

Even if information education has been promoted for years, there is still a long way to go so that students can fully use information technology to enhance their learning and life skills. Teachers, like students, are still unable to fully use information technologies to enhance the quality of their teaching. Moreover, there is also a long way to go until we can provide teachers and students with equal opportunities of digital use in the classroom. However, according to a survey conducted by Research, Development and Evaluation Commission (RDEC) in 2005, the level of digitization in indigenous areas of Taiwan is almost the lowest among all groups compared in the survey, including those using computers and the Internet, as well as the ability to use digital information. The survey showed that for people above 12 years old in Taiwan, 70.1 % had experiences using computers; among indigenous people, only 62.7 % had experiences in using computers, 7.4 percentage points less than the averaging rate (RDEC, Executive Yuan, ROC 2006).

Having this in mind, the implementation of the “e-Learning National Science and Technology Plan” was to assess and improve research to reduce digital divide, especially for the indigenous tribes. In 2003–2007, to promote the first phase of the “e-Learning National Science and Technology Plan,” CIP intended to effectively preserve the original indigenous traditional culture, and proposed a 3-year project, the “Taiwan Indigenous e-Learning Center Program.” They hoped to enhance the competitiveness of Taiwanese indigenous people, and construct an indigenous e-learning model to achieve universal learning goals (Executive Yuan, ROC 2008).

Indigenous e-learning center programs are used mainly to promote and perform three important works: “reducing the indigenous digital divide,” “constructing an indigenous e-learning network,” and “showcase indigenous culture.” According to the digital divide survey report by RDEC in 2007, indigenous individual, households, and overall digital performance scores ranked significantly lower compared to Han Taiwanese over the age of 12, with gaps between 6.4–11.5 points. The performance score of households, being 11.5 points behind that of the Han, formed the biggest gap, and highlighted the need to enhance the information environment at homes in addition to including information literacy among indigenous groups; there is still much room for improvement. The overall digital performance score of the Bunun (45.3 points) and other indigenous (45.4 points) scored the highest; Paiwan scored relatively poor with a score of 40.3 points. An analysis found that more remote towns, more people with lower digital performance scores.

For students, the materials of indigenous science education not only include traditional textbooks but an e-learning platform on the Internet also provides more interactive ways of science learning. E-learning is the future of science education. According to the Ministry of Education's statistics, digital resources in language domains includes 10,265 sites, mathematical domains 2976 sites, nature and life technology domains 5351 sites, community domains 7151 sites, arts and humanities domains 5425 sites, health and sports domains 3300 sites, integrated activity domains 4323 sites, and living domains 1676 sites (Executive Yuan, Republic of China 2008). The numbers of e-learning resources are growing at a rapid rate, but many of the e-learning platforms are not suited for indigenous students. The number that can be used for digital material is inadequate, which is a great pity. Therefore, the future development of indigenous science education should be based on scientific knowledge of traditional culture, infusing culture into the curriculum courses. In addition, transforming scientific knowledge into digitized materials can permanently preserve the indigenous wisdom and share with more people in the future.

## 18.3 The Teaching Module Design of Pek-msim

As mentioned before, indigenous students are still underachieving in mathematics and science. Many mathematics and science education researchers have called for culturally-responsive curricula to be taught in all math and science classrooms (Abrams et al. 2013). In 2009, Taiwan's National Science Council (NSC) implemented indigenous science education programs, with the end goals being the popularization of indigenous science education and promoting the competitiveness of indigenous people. The NSC encouraged science educators to combine government and traditional tribal teaching resources in planning indigenous culture-based learning activities in the fields of mathematics and science (NSC 2009).

Having this in mind, since August 2009, the authors implemented an NSC-supported program for developing culture-based Paiwan Elementary and Kindergarten Mathematics/Science Instructional Modules (Pek-msim) to reduce learning differences between indigenous and nonindigenous students. By 2013, this program had been going on for 4 years. During these 4 years, the authors implemented culturally responsive teaching methods in W elementary school (School W) and designed a culture-based curriculum for indigenous school children.

From the 4-year study data, the authors finally created a culturally responsive science teaching model (CRSTM) (Fig. 18.2). According to Fig. 18.2, the whole

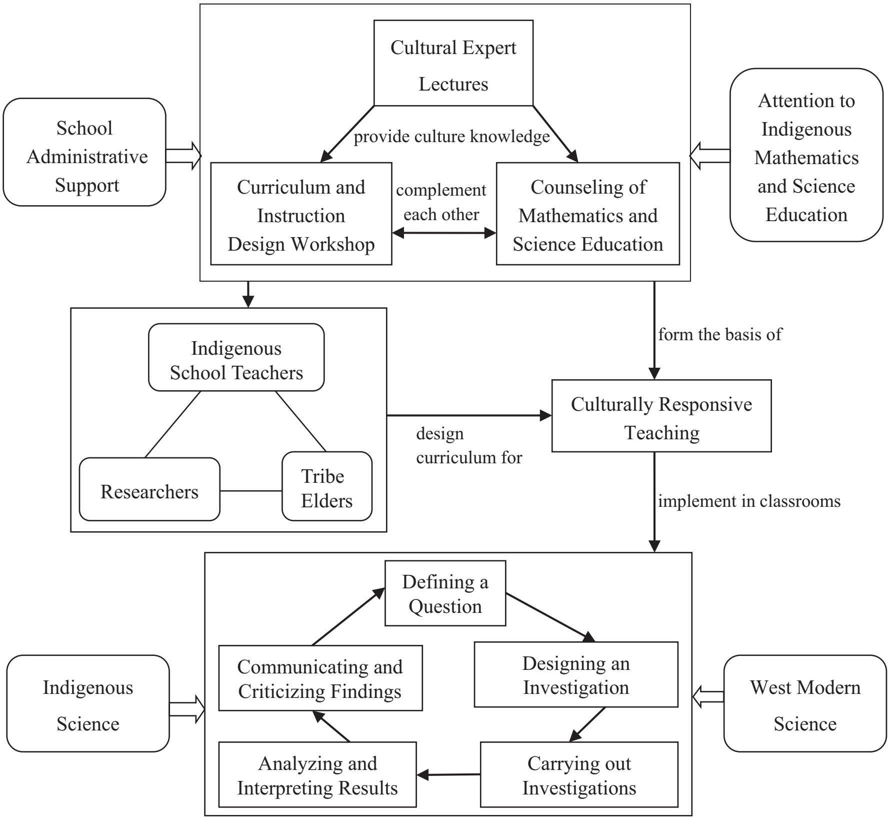


**Fig. 18.2** A culturally-responsive science teaching model (CRSTM)

structure of CRSTM consists of two phases. The upper half of the first phase consists of "cultural expert lectures," "curriculum and instruction design workshop," and "counseling of mathematics and science education." Their primary aim is to provide School W teachers with the knowledge and skills required to perform "culturally responsive teaching," in which these three are interwoven. First, the "cultural expert lectures" component provides culture knowledge to the other two components. This echoes Abrahams and Troike (1972) who stated that "if racial-minority students are to be taught effectively, teachers 'must learn wherein their cultural differences lie and… capitalize upon them as a resources, rather than… disregarding the difference…[and] thereby denigrating…the students'" (Abrahams and Troike, cited in Gay 2010, p. 28). Second, both the "curriculum and instruction design workshop," and the "counseling of mathematics and science education" also have a complementary function. Last, all three components need to be supported by the school administration as well as indigenous mathematics and science education teachers and researchers. While indigenous school teachers improve professionally, they should cooperate with tribal elders and mathematics and science educators to design culturally-responsive curricula.

The lower half of Fig. 18.2 refers to the process of culturally responsive teaching. The teachers render indigenous science and Western modern science (WMS), and let the students compare them and propose a question for doing scientific inquiry: defining a question, designing an investigation, carrying out the investigation, analyzing and interpreting results, and communicating and criticizing findings. This echoes Aikenhead (2001) who said that it offers an advantage to give indigenous students the ability to see the world from the indigenous and western perspectives, allowing them to choose the one that better fulfills their goals at any given moment. This cross-cultural teaching helps students gain access to Western science without losing sight of their cultural identity.

In the following paragraphs, the authors share some experiences about the study.

### *18.3.1 Implementation of Culturally Responsive Teaching in School W*

The authors adopted a collaborative action research plan and invited Paiwan tribal elders and teachers to participate in the study. At the beginning, the study analyzed the textbooks and concepts, and explored students' prior knowledge related to learning. In addition, to develop Pek-msim, the researchers collected traditional Paiwan science education knowledge, analyzed internal strengths (S), weaknesses (W), external environment opportunities (O), and threats (T) to Paiwan tribes and schools, and reviewed related literature. Then, the study implemented the Pek-msim to researchers and teachers in the classroom to explore problems, practices, and changes in regard to the impact of Pek-msim teaching. According to the above data, the research helped to revise Pek-msim and carry out teachers' professional growth and activities to extend Pek-msim to other indigenous schools. The following describes how the authors implemented a culturally responsive teaching method at School W.

#### 18.3.1.1 The SWOT Analysis of School W

Today's science education emphasizes that all students from different cultural groups should get equal opportunities in regard to science education. However, related problems will be encountered when integrating Paiwan culture into school curricula because of the influences of mainstream culture in science education, so the authors first adopted SWOT analysis to find the related problems. SWOT analysis was developed for studying social marketing in 1970. It aims to promote ideas and norms, and the change of behavior, rather than the sale of goods and services (Kotler and Roberto 1989).

The authors began to analyze geographic location, school size, school buildings, and teaching equipment along with teacher resources, school background, students, parents plus the administrative resources of School W for a SWOT analysis. Through the background content of a SWOT analysis, whether from the vertical dimension of School W, teachers, communities, government educational institutions, or from the horizontal links of the culture, economy or education, it was found that the difficulty in integrating Paiwan cultures to develop science education in School W was that the gap between science education and cultural awareness for indigenous students who are unable to understand science is inherent in the cultural differences. In addition, the long-term lack of involvement of expert teachers in science education has caused indigenous students to suffer low motivation in regard to learning math and science. The authors summarized the content of SO/WO/ST/WT in a cross analysis for developing science education in School W, as follows.

Strengths and Opportunities (SO)

School W has superior geographical environmental location with complete indigenous features, making it easy to develop into a distinctively beneficial school. Fewer students makes it likely to develop a more sophisticated teaching curriculum that can be created and used as a community learning center to share its resources with the whole tribe. Many teachers have mother tongue and counseling qualifications. School teachers are "the right man in the right place," making good use of their talents and actively participating in the development of school characteristics.

Weaknesses and Opportunities (WO)

School W is located in a remote area, and paid less attention to math and science education. In addition, the school lacked expert teachers in mathematics and science education over a long period of time. Traditional cultures need experts to help explain mathematics and science. With the intervention and assistance of enthusiastic mathematics and science experts, the school can strengthen cultural stimulation, and encourage students to learn science and math. In addition, students are made more curious by enthusiastic mathematics and science researchers. School W needs to work hard to overcome its weaknesses and takes advantage of this opportunity.

Strengths and Threats (ST)

It will be a challenge to the future researchers of culture integration to develop science education if the following issues cannot be effectively enhanced: indigenous understanding of scientific concepts, science education, and the integration of traditional cultural values.

Weaknesses and Threats (WT)

The disappearance of indigenous cultures and the value changes stemmed from global economization, and the neglect of traditional culture integration in the education curriculum, with consequences that will affect the daily life of indigenous people and also waste the school's educational resources. It is not only a crisis in indigenous areas but also the most important issue for the entire indigenous population in Taiwan.

Currently, indigenous areas are Taiwan's most culturally diverse and important areas, especially for animal- and plant-based education. We hope science education of indigenous areas can be popularized with a sustainable, knowledgeable, and multicultural attitude. Meanwhile aboriginal schools, communities, and academic research can be linked together with appropriate mechanisms without changing the original structure of education. The authors hope to engage in the integration of Paiwan culture into, and develop core values of, indigenous science education activities.

#### 18.3.1.2 Development of a Curriculum for Professional Development Based on the Design of Pek-msim (PD-d Pek-msim)

This section reveals how the authors developed and implemented a culturally responsive mathematics and scientific teaching method in School W to achieve the reduced indigenous mathematics and science learning gap.

In the initial period of the study, the authors contacted School W to establish relations with the Paiwan's school teachers to do the research, and show School W the researchers' real concern for the Paiwan's schoolchildren's improved performance in mathematics and science education. For example, one of School W teachers, Camak said:

> The "link" between aborigines and science and mathematics education is very small. Paiwan school teachers really need the research team's support and encouragement to really enhance the Paiwan science and mathematics education (interview with one of Paiwan's teachers).

Therefore, one of the objects of PD-d Pek-msim curriculum that the authors set up is to cultivate School W teachers to attend to Paiwan mathematics and science education. The dimensions and content of PD-d Pek-msim curriculum are summarized in Table 18.2.

The condition of PD-d Pek-msim curriculum is described in the following sections.

##### Cultural Expert Lectures

The "Cultural expert lectures" dimensions required that teachers understood scientific wisdom in Paiwan culture. However, School W's teachers in the first year of the curriculum design experience questioned the Pek-msim objectives:

> Indigenous school teachers and pupils have been trying to catch up with the mainstream culture; why should we allow them to return to the old tribal and backward learning mode? (Data from meeting with the teacher)

**Table 18.2** Dimensions and content of PD-d Pek-msim curriculum

| Curriculum dimension | Curriculum content |
|---|---|
| Cultural expert lectures | Paiwan traditional culture: Introduction of Paiwan culture, slash-and-burn culture |
| | Science wisdom in traditional culture: science wisdom in traditional culture, and with science curriculum |
| Curriculum and instruction design workshop | School W SWOT analysis, culture-integrated instructional module design, lesson plans presentation and discussion |
| Counseling of mathematics and science education | Mathematics and science instructional module design, culture-based mathematics and science instructional module design |
| Culturally responsive teaching | Classroom observations, video content analysis |

After listening to cultural expert lectures, the teachers now understand the scientific wisdom in Paiwan culture. The Han principal of School W thought that:

> Experts introduced cultural and scientific wisdom and thus helped teachers understand traditional knowledge along with how to design a culture-integrating curriculum (interview with the principal).

In spite of different cultural backgrounds of different ethnic groups, the above scenario is similar to the finding of Chinn (2011). She argued that:

> At the start of the workshop, teachers tended to critique indigenous knowledge as possibly erroneous, based on superstition and empty ritual, and serving only as a negative example in science. After the presentation of Hawaiian cultural perspectives, teachers began to openly acknowledge the value of indigenous and traditional practices in teaching environmental sustainability. (Chinn 2011, p. 91)

### Curriculum and Instruction Design Workshop

From the beginning of curriculum design, the indigenous teachers often expressed reluctance to participate in Pek-msim curriculum design. Therefore, the primary function of the "Curriculum and instruction design workshop" was to enhance the teachers' willingness to integrate indigenous culture into their teaching methods, and enhance curriculum design ability in mathematics and science for the teachers.

The indigenous teachers often questioned the meaning of integrating indigenous culture. For example, one teacher said:

> Do not be too deliberate in culture integration, because when aboriginal students grow up, they will need to take university entrance exams that will not test about aboriginal stuffs, for example, glass beads, wild boars. If we have to teach wild boars, when are we going to teach modern science and technology? (Meeting transcription data)

So in this curriculum stage, differences in educational philosophy that first caused problems were reconciled by the authors. Mainstream math and science educators started working alongside indigenous teachers to help create a unified teaching curriculum at School W.

### Counseling of Mathematics and Science Education

In this stage, the authors encouraged the teachers to participate in the "2009 Indigenous science education lesson plan selection." The authors used the PD-d-Pemsim curriculum to help indigenous teachers participate in selecting lesson plans, and strengthen their mathematics and science curriculum design ability. Fortunately, Camak, one elder Paiwan teacher, has a great passion and sense of duty. He encouraged three other teachers to join him in actively participating in the Pek-msim curriculum design for the "2009 Indigenous science education lesson plan selection," and won Advanced Honors.

### Culturally Responsive Teaching

The PD-d Pek-msim curriculum required teachers to implement culturally responsive teaching in their classrooms for a total of 8 weeks. The authors' requested the teachers to help students understand and become interested in mathematics and science courses, as well as to be willing to interact with teachers and "vuvu" (Paiwan elders honorific). In the teaching process, indigenous children responded well with the vuvu interactive learning process and further discussed relevant indigenous scientific wisdom's with their teachers. From the interviews with the teachers, we knew that this dimension of the curriculum had achieved the above goals. For example:

> Camak: Students who originally disliked mathematics and science courses have changed. Since the culture intervention, there is no longer a dull, absent light in students' eyes in regard to mathematics and science courses, but the teachers and students work together to find mathematics and science wisdom in indigenous culture. Students will also take teachers' instruction home to interact with vuvu. It is a triangular interaction relationship of teachers, students and tribal elders (Interview with the teacher).
> $IT_2$: We want students to actively participate in mathematics and science learning activities; teachers only play a supplementary role (Interview with one of the Indigenous Teachers, $IT_2$).

From the classroom observation, the authors also found that students were very earnest when participating in activities, and they thought that the activities helped them to understand scientific concepts. In addition, they thought these activities were very valuable. One of students said:

> At first, I thought it ["Paiwan King of Tops" lesson: it integrates toy-based games from traditional culture into the science curriculum] was a boring course, but when accompanying grandfather Luo to go to the mountain and bring back wood, I saw how he uses a machete to make the top, and my heart is surging that the ancestors had such a good skill originally.

> I really like this course which enhances my confidence in mathematics and science learning (Interview with one of the Paiwan students).

## *18.3.2 Example of Pek-msim Curriculum*

The following describes how the authors integrate the "slash and burn agriculture" of Paiwan culture into the textbook curriculum, which is dominated by WMS.

The "slash and burn agriculture" teaching activity draws from the "Mountains and Rivers of the Earth" unit in Taiwan's 9-year science and technology curriculum textbook. The unit objectives of "Mountains and Rivers of the Earth" have experiments designed to prove erosion, flow, and accumulation of water. In addition, it also cultivates the spirit of appreciation and care for the landscape, along with practical exploration attitudes and problem solving ability. Therefore, the authors included tribal vuvu and invited the indigenous students to create the "General Terraced Field Model" (Fig. 18.3: Left) and "Paiwan Soil and Water Conservation Model" (Fig. 18.3: Right) to satisfy the above textbook unit objectives. The difference between these two models lies in the construction and resources used in separating each hillside region, the left model by cement, and the right model by bamboo and simulated piling flagstone built of wood.

"Slash and burn" is a traditional mountain farming method of Paiwan peoples. This method comprises traditional wisdom developed by Paiwan ancestors over thousands of years. The "slash and burn" culture, which includes (1) selecting arable land, (2) cutting trees and clearing weeds, (3) burning trees and weeds, (4) using miscellaneous bamboo and shale in constructing retaining wall, and (5) proceeding with soil and water conservation according to the appearance of the mountain terrain. This fully demonstrates the clansmen's lifelong wisdom. In harmony with the natural ecology (Fig. 18.4), the tribe has never encountered the natural disaster of massive mudslides.

In the domain of Paiwan traditional life, whether in the tribal community or field, the ancestors' vuvu integrates the wisdom of the ecological engineering method into the daily life so it can protect the safety of the tribe and continue the production of crops, which was the lifeblood of tribesmen. Paiwan traditional crops, such as sweet potatoes, millet, and taro are mostly planted on steep hills. Since Paiwan people survive in harmony with nature, they have accumulated a great deal of life-related wisdom. A tribal grand elder said that Paiwan ancestors carried on "slash and burn" which is followed by the ancestors' ecological engineering methods of managing land and farming. Ecological engineering, defined as the design of sustainable ecosystems that integrated human society with its natural environment for the benefit of both, has developed over past 30 years, and rapidly over past 10 years (Mitsch 2012). In practice, there are two kinds of ecological engineering methods in Paiwan. One is piling stones horizontally (Fig. 18.5). The other is piling bamboos or firewood horizontally (Fig. 18.6). The procedures of these two methods are as follows: (1) prepare the soil to bare the surface; (2) pile stones in accordance with the terrain by the lateral pile construction method or fix a long piece of bamboo or long piece

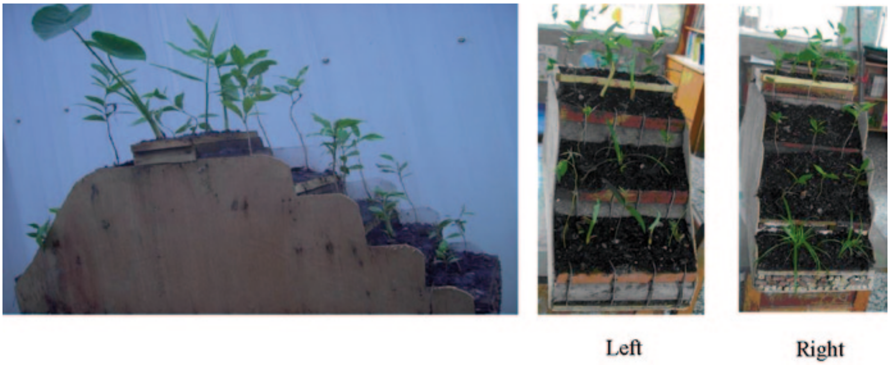


**Fig. 18.3** Soil and water conservation models

**Fig. 18.4** Using the natural terrain to cultivate taros *Left*: photographing from the bottom up. *Right*: photographing from the top down, by Lu Chih-Liang in Wutai Village, Pingtung County, Taiwan

**Fig. 18.5** Piling stones by a horizontal working method

**Fig. 18.6** Piling bamboos or firewood by a horizontal working method

of wood on the surface horizontally; and (3) keep an appropriate distance for each column down the line according to the terrain. The functions of these methods are as follows: to prevent and block the occurrence of mudslides, to help plants survive, and to retain soil nutrients.

After indigenous students experienced the above "slash and burn agriculture" practices, first, they themselves proposed questions: "Are mudslides really a problem?" Do Paiwan traditional areas have "mudslides?" Second, they formed the questions to explore: "Is a modern clay bank appropriate?"; "Is a traditional indigenous ecological engineering method better?"; "Which method is more effective?"

The above is some of a series of problem-solving steps, like Yager's (1991) three problem solving steps: (1) asking questions by students, (2) forming hypotheses and explanations, and (3) designing experiments and testing hypotheses. Therefore, to answer the above questions, the students conducted the experiment of running water down "the soil and water conservation model" (see Fig. 18.3). They used water to scour the model, starting from the top of the models. Then, they recorded and analyzed the data and found that the soil and rock of the hillside on the left model (Fig. 18.3: Left) is vulnerable to erosion. The model on the right (Fig. 18.3: Right), maintained by traditional Paiwan agricultural method, drains water naturally while retaining the soil, and the amount of erosion and flow being much lower than the left model.

## 18.4 Conclusion

Taiwan has 16 officially recognized indigenous tribes. Their cultures are extremely rich. However, empirical studies have shown that Taiwan's indigenous students' inferior mathematics and science learning performance can be attributed to "cultural differences." This echoes McKinley (2005) who said that "the failure of science education research during these times was in not taking culture, language, 'race' or colonization as major factors in any of the projects" (p. 230). Therefore, the authors developed a culture-based Pek-msim curriculum, implemented culturally responsive teaching at School W, and created CRSTM (Fig. 18.2).

As verified by research, culturally responsive teaching can really help indigenous students in mathematics and science education. However, one main problem of indigenous students is that they cannot fully understand the meaning of the questions, especially when they encounter a lot of symbols and word problems in application-based questions. They often are unable to link words with their life experiences, thereby affecting their willingness to learn, and resulting in a lowered learning performance. When indigenous children returned home, they still used their native language to communicate with their families; as a consequence, they used fewer mainstream culture words. This will naturally affect their language growth, limiting their classroom performance. In addition, because aboriginal schools are located in remote areas, it makes the schools' network communications more difficult.

According to the above situation, in 2013, Taiwan's NSC began implementing indigenous science education programs to enhance indigenous students' reading ability, develop indigenous mathematics, and science education teaching materials and build a digital learning platform. We hope that all of these efforts will be able to improve indigenous students' performance in mathematics and science.

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# Chapter 19
# Teaching Environmental Issues in Science Classroom: Status, Opportunities, and Strategies

**Shiang-Yao Liu**

**Abstract** This chapter highlights the importance of using environmental issues as a resource and a context for science education. A review of literature regarding socio-scientific issuesand science–technology–society–environment (STSE) education demonstrates a rationale for involving environmental issues in science education. It has been suggested that such instruction will effectively improve student decision-making and problem-solving abilities as well as civic participation. I intend to express the status of science and environmental education in Taiwan, and tensions between these two disciplines, by analyzing relevant studies in this regard. Strength and obstacles of incorporating environmental issues into science curricula are discussed. In the final part of this chapter, I present my recent research on teaching approaches that aim to engage students in learning environmental issues. Further studies on teachers' perspectives on environmental issues and their practical considerations in teaching such topics are recommended.

**Keywords** Action (oriented/orientation) · Controversial issue · Decision-making · Environmental education · Interdisciplinary (thinking/training program) · Issue-based (teaching/instruction) · Nature of Science · Reflexivity · Reflexive (action/judgment/learning/thinking) · Socio-Scientific issue · STSE education

To introduce the topic of environmental issues in science education, I shall reflect on my own experiences in the environmental education and science education departments under the colleges of science of two universities in Taiwan. I have such a great opportunity to work with many intellectuals in these two academic fields, but I have also been questioned about the differences between environmental education and science education. Should each field have a distinct disciplinary identity with a boundary between the two? This is a question I have been asking myself for 10 years.

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Before I was appointed to my first faculty position in the environmental education department, I did not have a clear image of what environmental education was about. In my observations over the past 20 years, environmental education in schools generally consisted of asking pupils to protect the environment and endangered species. It was either a form of pro-environment education or advocacy of biological conservation. As a biology major and science educator, I believed that teaching ecological concepts in science courses should have achieved the goal of environmental education. That changed when I read a chapter by Hungerford (1998). He refuted several myths about implementing environmental education, including the belief that science teachers are the best people to teach environmental education and that teaching science can solve environmental problems revealing the unrealistic view of this discipline that may hold.

In this chapter, I would like to share my reflections on this subject by introducing some articles. The first article that inspired me to bring the topic of nature of science (NOS) into environmental education is Ashley's (2000) "Science: an unreliable friend to environmental education?" I will discuss this article further in the following section. The second, and most important, reference is Bybee's lecture at the Paul F-Brandwein Institute (Bybee 2008), in which he reminded us of the potential for using environmental issues as a context for improving scientific literacy and also noted that the components of decision-making, participation, and forming action strategies are lacking in the current conception of scientific literacy. A series of studies on socio-scientific issues, initiated by Zeidler and discussed in his 2003 edited volume (Zeidler 2003), provide a rigorous basis for introducing local or global environmental issues into the science classroom, highlighting the fact that these issues can implicate discourse, debate, inquiry, and moral reasoning, as well as understandings of NOS.

The following sections begin with a brief historical review of environmental education and science education and then examine the relationships between them. A review of literature regarding socio-scientific issues and science–technology–society–environment (STSE) education demonstrates a rationale for involving environmental issues in science education; it will effectively improve student decision-making and problem-solving abilities as well as civic participation. A pilot analysis of empirical studies, published in local journals, on the incorporation of environmental issues into educational practices is conducted to portray the research findings that have been done in Taiwan. Further, following a discussion about various features of environmental issues and what literature recommends about involving materials related to environmental issues in science curricula, I will present some teaching activities I have developed through my research projects. In the final part of this article, recommendations on how to increase the possibilities of issue-based teaching in science classrooms are proposed in regard to teacher professional development.

## 19.1 Environment, Science, and Education

Environmental education first garnered international attention as a new field in education with the publication of the Belgrade Charter in 1975. It was described as a specific type of educational endeavor that aims to foster individuals' awareness of environmental challenges and their active participation in solving environmental problems. A later document, the Tbilisi Declaration, established a blueprint for contemporary environmental education stipulating that programs should use diverse learning environments, provide opportunities for learners to take ownership of their learning processes, and strive to facilitate concrete activities that would contribute to the resolution of environmental problems (UNESCO-UNEP 1978). Until now, these documents still provide the theoretical foundation of most important to environmental education, which is an emerging discipline. However, from the perspective of Smyth (2006), if one considers the objectives of environmental education in the context of a broader system of human–environment relationships, environmental education has emerged and been carried out without obstacles starting with ancient generation. It is no wonder why David Orr, a well-known environmental educator, argued that all education is environmental education while the purpose of education is about human survival (Orr 1991). Some other researchers then emphasized the action orientation that distinguishes environmental education from other types of education (Hungerford and Volk 1990; Jensen and Schnack 1997).

The discipline of science has been part of formal school curricula for more than 100 years in most Western countries. In the early twentieth century, science education was formulated to prepare future scientists with an eye toward promoting the nation's power. In recent decades, the main goal of the science education paradigm has shifted toward the education of future citizens. Reform perspectives for science education emphasize that school science teaching should not only transmit substantive knowledge but also encourage students to apply knowledge to solve problems and to actively participate as citizens in decision-making on science, technology, and environmental issues in their daily lives (Hodson 2003; National Research Council (NRC) 2012). As Bybee comments (2006), science education must connect with the needs of society. In the beginning of this century, the movement of STSE education in Canada had surpassed the STS framework (science, technology, and society, without an environmental component) that had dominated science education since 1980s. STSE education emphasizes the issue-based teaching approach to foster students' literacy in the context of ethical, individual, and social responsibility (Aikenhead 1994; Pedretti 2003). Adopting a similar perspective, Zeidler et al. proposed the inclusion of controversial socio-scientific issues in science curricula for their potential to develop students' functional scientific literacy (e.g., Zeidler and Keefer 2003; Zeidler et al. 2005). All of these scholars argued that scientific literacy enables citizens to make informed decisions and participate in the formulation of public policy on societal issues. Many of these issues are related to natural resources and global environmental change.

Traditionally, school science curricula have often presented science as a final answer to all of humanity's problems and as a quest for absolute knowledge. This framing in turn influences young people's perceptions about the purposes of scientific endeavors (Millar and Osborne 1998). People are fond of the convenience and efficiency that technological products bring to their lives but often fail to consider the potential environmental consequences of these products. Given this, Ashley (2000) asserted the need for an education incorporating the so-called "precautionary principle," which engages people in taking more responsibilities for their environment and encourages enhanced understanding of risk, uncertainty, and the limits of science. That is to say, aspects of NOS should factor into science and environmental education. Smyth (2006) also criticized the reductionist approach sometimes present in science, which he contended could impede people's systemic thinking on complex environmental issues. He then suggested the need to bring environmental and social systems together into a single conceptual framework. According to the framework, environmental educators could involve a wide range of themes from the sciences, humanities, and arts. In this way, environmental education has the potential to be more interdisciplinary in nature than science education, which indicates another distinction between the two disciplines in addition to the feature of action orientation.

Still, science plays a significant role in ensuring the effectiveness of environmental education. Action competence is often seen as an ultimate outcome of environmental education because it combines the processes and practices of education with the idea of developing the democratic citizenship skills and values necessary to deal with environmental crises (Jensen and Schnack 1997). Bishop and Scott (1998) noticed that an overemphasis on taking action has a tendency "to undervalue the place of science in the construction of knowledge and understanding of environmental issues" (p. 225). According to Jensen and Schnack's claim, an action must be targeted toward solutions of the problem that is being perceived as a situation demanding change. The action-oriented learning activities might address an understanding of the causes of the problem and a decision to do something to make a change. I would infer that without judgmental reasoning, an action may lack a rationale. Having sufficient knowledge and abilities to gather informative evidence serves as a prerequisite for one to diagnose the symptoms and to evaluate the effects of the problem. The debate is also directed to school science curricula that have been portrayed in a positivist light. Scholars called for a goal in science education of fostering scientifically literate citizens, given that scientific knowledge offers ways of learning that have the potential to bridge the gap between cognition and action (Posch 1993).

Research in environmental education has found that the teaching model, which assumes that possession of environmental knowledge and positive attitudes can guarantee positive environmental behavior, is detrimental (Hungerford and Volk 1990; Kollmuss and Agyeman 2002). Thus, an action-oriented teaching approach is preferred. Jensen and Schnack (1997) argued for the integration of relevant scientific knowledge and situation-specific knowledge in the evaluation of potential actions. In the field of science education, researchers also called for using socio-scientific issues to develop functional scientific literacy, which takes moral reasoning and character development into account (Zeidler and Keefer 2003). It is evident that both scientific literacy and action competence include a component that involves enabling learners to participate in decision-making processes regarding environmental issues with a scientific basis. Proponents of both tenets suggest changing the school curriculum to incorporate teaching materials that allow learners to explore the nature of the work undertaken by the scientific community. Therefore, environmental issues serve this purpose well.

## 19.2 Features of Environmental Issues

From the above review of literature, we can see that the common ground between environmental education and science education is to use environmental issues as a context for education. This section then addresses a terminological question regarding what we mean when we call something an environmental issue. I would prefer to distinguish "environmental issue" from "environmental problem" by giving a different interpretation to the respective terms. Environmental problems often appear in many textbooks as phenomena that have been examined by experts for their causes and effects as well as resolutions. Discussions of environmental problems are often didactic, aiming to inform people how serious the problem is and what must be done to solve it. For example, acid rain is an environmental problem. It is known that "acid rain" describes any form of precipitation that is acidic and is caused by the emission of sulfur dioxide ($SO_2$) and nitrogen oxide (NOx) that occur in connection with industrialization and the resultant air pollution. Its phenomena and negative effects have been known since the 1960s, and corresponding monitoring systems and regulatory policy has been established. Textbooks introduce the problem simply by defining the term, explaining the process of testing the pH value of samples; revealing damage to buildings, human health, and/or ecosystems; and suggesting solutions. Such teaching material provides less space for exploration of the problem because its contents are largely already well established. Even fewer opportunities are generated in teaching activities that discuss scientists' work in discovering the problem or ask why it took over 100 years for people to become aware of the problem after chemist Robert A. Smith first discovered it in the 1850s.

In using the term "environmental issues," I intend to emphasize the controversial nature of any issue related to nature resource conservation, environmental management, sustainability, and/or human survival in a broader sense. Drawing on the definition Zeidler et al. (2005) offers for "socio-scientific issue," a term that can be used to describe a variety of social dilemmas tied to science and technology, an environmental issue also embodies social and managerial dilemmas. Environmental issues are complex and often involve ill-structured problems, inconclusive scientific evidence, and multiple perspectives of different stakeholders (Bardwell 1991; Colucci-Gray et al. 2006; Hogan 2002). Exploration of environmental issues requires an understanding of natural systems, the relationship between the living and nonliving environment, and the scale of humanity's impact on the natural environment, as well as an ability to synthesize the biophysical and social aspects of the issues. Since the term "environment" may refer to everything surrounding us, an environmental issue must be relevant to our lives and must involve conflicts among the different perspectives that we form based on previous knowledge and experiences. Environmental issues can operate at the regional, national, or global levels. In a review of empirical studies, global environmental issues might include energy resources and global warming (e.g., Colucci-Gray et al. 2006; Sadler et al. 2004; Yang and Anderson 2003), while local issues might include conservation of species (Grace and Ratcliffe 2002), household packaging waste (Kortland 1996), wetland management (Jimenez-Aleixandre and Pereiro-Munoz 2002), and treatment of exotic species (Hogan 2002), among many others. Pedretti (2003) suggests that, when using controversial environmental issues in science classrooms, the issue should "present a point of departure for developing and exploring further inquiry, provide a rationale for the search for information, and more accurately reflect the multi-disciplined nature, discourse, and activities of the *scientific pursuit*" (p. 221) (emphasis added). If it is being used in the action-oriented environmental education, the issue itself could serve as a context for seeking a possible solution or action through discussing different values and beliefs implicated in the various alternatives. Adequate background information should be provided on the selected issue in order to facilitate students' review and analysis. To make the issue engaging to learners, some materials related to the issue can be retrieved from mass media, but the scope needs to be carefully defined. Ashley (2000) offered an example of environmental controversy regarding mad cow disease (formally named Bovine Spongiform Encephalopathy, BSE) in England 20 years ago. The BSE issue revealed the British government's failure to recognize the limits of science. From 2005 to 2006, the BSE issue, along with the issue of importing American beef, garnered public attention in Taiwan. At that time, I used the public focus on the BSE issue as a context for introducing what scientific evidence indicate about links between BSE and Creutzfeldt–Jakob disease (CJD) and extended the discussion to the relationship between imported livestock products and greenhouse gas emissions. I will describe this issue-based teaching in more detail later.

## 19.3 Related Studies in Taiwan

This section reviews related studies conducted by Taiwanese scholars in order to explore the research trends surrounding issue-based teaching and learning. To search international publications, I used keywords that included "socio-scientific issue" OR "environmental issue" AND "Taiwan" in academic search engines such as EBSCOhost, Web of Science, and Google Scholar, and then selected the empirical studies that primarily targeted Taiwanese subjects and explicitly used certain environment-related issues as teaching or assessment tools. Unfortunately, using the keyword "environmental issue" did not generate any articles that met the selection criteria because most of the studies with this keyword were merely assessing people's knowledge of, and attitudes toward, environmental problems. These studies did not mention any particular episodes of environmental issues or problems. Among the seven articles extracted, three studies employed the use of nuclear energy as the controversial issue (Wu and Tsai 2007;2011; Yang and Anderson 2003); two studies focused on the incidence of flooding and ground subsidence (Yang 2004; 2005); one study used the control of exotic species (Liu et al. 2011); and another article adopted four issues, including organic food, genetically modified food, DDT and malaria, and dispute over dioxins (Chang and Chiu 2008). However, the majority of these studies were primarily assessing people's decision-making and reasoning processes around the selected issues. The exception was Yang's study (2004), in which high school students were involved in STS-oriented instruction and their reasoning modes were observed through the intervention. The results showed that students do not use scientific thinking in environmental decision-making; instead, their reasoning modes are more driven by their personal epistemological perspectives. Yang recommended further research on the transfer skills from the scientific domain to the social domain. Considering the complexity of environmental issues, I instead emphasize interdisciplinary thinking, which can increase students' awareness of the diversity of information and help them to construct better integrated knowledge in the decision-making process (Liu et al. 2011).

For local publications, I focus on only two journals, the *Journal of Environmental Education Research (JEER)*, the official journal of the Chinese Association of Environmental Education, and the *Chinese Journal of Science Education (CJSE)*, which is sponsored by the Association of Science Education Taiwan. JEER is a newer journal than CJSE, having published its first volume in 2003. Both journals operate a strict review process and have high publication quality; thus, they can be considered representative journals in both academic areas. JEER publishes two issues each year, while CJSE publishes four to six issues. A total of 76 articles were published in JEER from 2003 to March 2013 and 250 articles in CJSE during the same period of time. The primary review effort involves searching for the studies concerning environmental issues in school curricula or classroom teaching. Screening of all of the topics turned up twenty-four articles related to teaching and learning in school education in JEER, but only four of them report on specific environmental issues used for assessment or instruction. Among these four articles, two explore teachers' perspectives on local environmental issues, such as exotic species (Tang and Liu 2008), construction of mountain cable cars, and construction of highways (Lee and Liu 2006). Of the remaining two studies, one considers animal welfare issue-based instruction in a high school (Wang and Liu 2009) and the other one involves a wetland conservation curriculum for elementary school students (Lin and Wang 2006). It seems that formal education is not of primary interest to JEER. The curriculum and instruction studies published in JEER are more concerned with the development of guidelines and indicators, and with conducting surveys to analyze teachers' and students' environmental knowledge, attitudes, and behavioral intentions. A relatively larger portion of articles is devoted to informal and non-formal environmental education, but they pay little attention to teaching or communication approaches. Consistent with Rickinson's observation in Western countries (2006), the environmental education community in Taiwan focuses too much on formulating the contents of environmental education and not enough on the quality of the learning process.

In CJSE, there have been ten articles from 2003 to 2013 that report on issue-based teaching and learning in compulsory and higher education. Two of these studies were conducted by implementing issue-based instruction with college students (Hsu 2003; Hsu and Gou 2009). The researchers followed the "issue investigation and action training module" created by Hungerford and Volk (1990) to design the college course. In the course, students worked in groups to analyze certain local environmental issues; the evaluation of student performance focused mainly on affective domain. One study reported on an inquiry curriculum for high school students involving the issue of alternative energy resources (Hung and Chen 2011). The results aimed to demonstrate the process of developing the curriculum and the curriculum's effectiveness in enhancing student understanding of the features of scientific research. A series of studies by Lin et al. focused on incorporating various socio-scientific issues into elementary science instruction (Lin and Huang 2009; Lin 2012; Su and Lin 2012). These issues included generic topics, such as genetically modified organisms (GMOs), as well as local events, such as high-speed rail construction, burning worship papers (for religious ritual) and $CO_2$ emission, and betel nut plants and mudslides. The primary assessment foci of Lin's studies were argumentation and moral reasoning abilities, the same foci used in a study with college students (Lin et al. 2010). The remaining three articles were related to teacher perspectives and roles in issue-based teaching (Lin 2006; Lin and Chin 2012; Liu et al. 2007).

From the review, we are aware that empirical studies of this type are few but increasing in the science education community. We also recognize that there are many barriers to using controversial environmental issues in curriculum development. Science educators may prefer generic issues such as dilemmas caused by genetic technology because the contents can be deemed relevant to the existing science curriculum. However, the scope of environmental topics inevitably extends to a wider sociopolitical realm such that the relative importance of the scientific content may be reduced. Such topics may challenge teachers' perception of science as an objective discipline and their authority in teaching scientific knowledge (Camino and Calcagno 1995; Levinson 2006). Although science courses are not the only courses in which environmental issues can be introduced to students, they provide the greatest opportunity to discuss the relationship between humanity and nature. Since environmental educators advocate for a socially critical approach to fully understand these issues (Camino and Calcagno 1995; Fien 2000), they should pay more attention to the development of teaching modules and pedagogical models that enhance the learning process through engagement with environmental dilemmas. Oulton et al. (2004) made a pedagogical recommendation that teaching outcomes should focus on the *nature* of the controversy and also emphasize teachers' and students' *critical reflection* on their own opinions.

## 19.4 Issue-based Teaching Approach: Theoretical Foundation and Practices

This section presents an instructional model that is consistent with the perspective of action competent and critical theory for which environmental education community has been advocating. Subsequent to the literature review for establishing the theoretical foundation, I would like to present some case studies involved in my research projects.

The premise of environmental education is often defined as the idea that learners must develop integrated knowledge of environmental systems and processes in order to comprehend how everyday decisions affect the consumption of environmental resources. Yet, evidence has shown that an increase in knowledge does not necessarily lead to awareness or desirable action to further environmental protection (Kollmuss and Agyeman 2002). More than a decade ago, Wals and van der Leij (1997) asserted that environmental education should "seek to enable participants to construct, transform, critique, and emancipate" (p. 24) their relationships with others and the environment. That is, the aim of environmental education should be to organize a meaningful learning experience that will facilitate students' fuller participation in the environmental issues they are concerned about. Every student should be regarded as a driver of action rather than an information receiver (Wals 2010). Consequently, a new paradigm for teaching and learning has been proposed in order to achieve the goal of informed participation in environmental decision-making. It is called a "reflexive paradigm," and held that both teachers and students bring their knowledge to bear in defining the environmental problems being investigated in classrooms and in everyday life (Gauthier et al. 1997). Along the similar line, Zeidler and Sadler (2008) advocated the idea of "the formation of conscience through the exercise of reflexive judgment" (p. 203).

Based on social critical theory, reflexive action involves critically examining one's personal and theoretical dispositions and, at the same time, investigating how his or her own personal and theoretical commitments can transform patterns of social discourse or political decision-making on environmental issues (Voss et al. 2006). As such, reflexivity implies that these activities or actions require clear reasons and articulated decisions. In reflexively oriented learning, learners are involved in a dialectic of knowing and being (Hart and Nolan 1999), which is a process of "exploration of not only what we know but also more centrally, what we do not know (i.e., our unawareness) and why and how we have come to know or not to know" (Raven 2006, p. 560). This orientation is concerned with exploring the process of social dynamics through "critical and contextual review and action" (van Rensburg 1994, p. 14). The nature of environmental education is transformative in the sense that it asks people to think about how to change and actively deal with environmental issues (Hart 2002), as well as to examine the limitations of their own knowledge about the environment. What can be recognized as environmental issues or problems are often filtered through the process of social construction and depend on how human individuals and groups conceptualize living systems (Gauthier et al. 1997). In the discussion of environmental issues, people are allowed to debate the issues, and draw on their own conceptualization of environment, and take scientific, social, and cultural dimensions of information into account in their decision-making. In reflexive environmental learning, students are encouraged to participate in a problem-solving process with reference to their own practices and interests.

Given all of this, my study proposes an action-oriented instructional model, called the issue-tackling learning cycle (ITLC), which aims to help students better structure their thinking and evaluate various potential actions regarding environmental issues. The foundation of this learning model is the soft systems methodology

(SSM), which is described in the book by Checkland and Poulter (2006) and is "an organized, flexible process for dealing with situations which someone sees as problematical, and situations which call for action to be taken to improve" (p. 4). Given this definition, environmental issues are viewed as a "problematical situation" rather than "a scientific problem," because they are too complex, often lack of conclusive information, and involve different aspects of thoughts and multiagent perspectives with various associated values and beliefs. A problematic situation means that something needs to be done and involves people who are trying to act purposefully. The typical pattern of soft systems thinking activity includes four stages: "finding out," "model building," "discussing/debating," and "defining/taking action." Therefore, the ITLC, a modified form of the SSM, demands that students develop solutions to the environmental issues using the following processes: identifying the issues, proposing focused models of action, and using these models to examine real-life situations and then to verify the improvement of the status quo via the corresponding actions.

### 19.4.1 Case 1

In developing the ITLC model, we designed a series of teaching activities. One environmental issue we adopted was the BSE incident in 2005 and the associated question of whether our government should resume imports of American beef products. This issue not only involves abundant biomedical scientific knowledge but also implicates ethical, economic, and political aspects. The desired learning outcomes include a comprehensive understanding of the facts of the BSE incident. Equipped with the necessary scientific knowledge, students are then guided in constructing feasible concrete models to explore different perspectives of the BSE incident and in considering how to apply these models to other real-life scenarios. At the first stage, students are asked to identify and discuss issues regarding BSE incidents from the literature survey. They should be able to give the formal name of the disease, describe its symptoms, identify its pathogen and its cause, name other diseases caused by the BSE pathogen, and understand why BSE could provoke widespread panic. In the second stage, students propose their own responses to the BSE incidents after analyzing different points of view and scientific evidence relating to public concerns about BSE and policy regarding the import of beef products. In stage three, students discuss and debate the feasibility of different action models proposed previously. In the final stage, students reaffirm which solutions they would adopt and apply them to real-life settings. They should be able to apply the responses to BSE to other similar scenarios, such as the foot-and-mouth disease controversy that occurred elsewhere (Oulton et al. 2004) and the current rabies outbreak.

This teaching activity has been implemented with students in a joint college (Cheng and Liu 2011) that is also suitable for students in the 14- to 19-year-old age range (see Oulton et al. 2004; Wellington 1986). During the implementation, we gathered students' outputs including individual worksheets and diagrams, and group discussion. It was found that students were able to consider the elements that constituted the BSE incidents from multiple perspectives. The perspectives they analyzed included economic, diplomatic, political, scientific, and environmental dimensions. In the group discussion, students further recognized hidden dimensions of the incident, such as the effect of mass media. Some groups mentioned that the media's "like to make troubles" manner of reporting leads to the public's shallow knowledge of BSE and thus the misled public may not be able to make the right decisions. Notably, a group of students said that many technologies in the era of biotechnological advancement were fundamentally in violation of natural laws and that BSE is simply a small part of this larger trend. They offered that as human beings, we ought to think about how we can make choices between technology and the environment. This is a case in which this activity provided students the "opportunity to exercise the reflexive nature of conscience" (p. 204) suggested by Zeidler and Sadler (2008). In terms of the policy aspect, most of the students believed restricting imports was a feasible approach, while some of the students said CJD had to be extensively studied. Students also deemed the public understanding of BSE an important solution to the issue. We can conclude from this trial that the ITLC model allows students to autonomously comprehend the substantive knowledge related to the issue and elevate the level of their reflection through discussion with peers. Furthermore, students can reflect on their own knowledge and values to make a decision and take corresponding action. The next round of the learning process can be continued when students become aware of other environmental debates in the future.

### *19.4.2 Case 2*

Another teaching example was designed for upper elementary students. The environmental topic was exotic species. The specific term "exotic species" can be found in the science textbook for the sixth grade students. We found the need to clarify invasive exotic species from other introduced species. "Exotic" or non-native suggests that these organisms are foreign to a certain geographical area and are accused of as immodest and guilty, like the monster in *Frankenstein* (Chew and Laubichler 2003). Such a metaphor commonly appears in mass media and even in textbooks. However, we are also surrounded by exotic species in our daily lives; they include fruits and vegetables, garden plants, and pets. Invasive species are defined as those that threaten local biodiversity. Control of invasive species could also raise tensions between environmental ethics and scientific agendas (Andrew and Robottom 2001). Therefore, the first stage of teaching activity was designed to clarify the terminology and definition of exotic and invasive species and identify the problem of invasive species. The teacher would show many news reports regarding invasive species to elicit students' awareness and prior experiences. A case of native invader Chinese bulbul (*Pycnonotus sinensis*) was then presented to stimulate conceptual conflicts, setting the students up to discuss why "native" species can also cause the decline of other native species such as Taiwan bulbul (*Pycnonotus taivanus*). After having sufficient understanding of the issue, students were guided to carry out an investigation of invasive species dispersed in the campus and neighborhood community. Ben-Zvi Assaraf and Orion (2009) have suggested that outdoor learning provides real-world experience that fosters knowledge integration. During the investigation, students could easily find a common invasive plant *Mikania micrantha*, which has been discussed extensively in textbooks and the media (see Liu et al. 2011). After experiencing field observation, students could have a whole class debate about what should be done to deal with this invasive weed. Through this exercise, students would have the opportunity to evaluate the pros and cons of management decisions regarding invasive species and reflect on human responsibility for the origin of the problem. I have seen reflexive action taking place in this example. The teacher and his students conducted a further investigation project on another invasive species, Asiatic painted frog, on their campus, and decided to take action in monitoring and controlling the expansion of the species. This teaching activity was actually designed after the teacher completed his master's thesis regarding teacher understanding of exotic species and biodiversity (see Tang and Liu 2008). He continues to develop the innovative school-based curriculum of this environmental topic today.

## 19.5 Finding a Niche for Environmental Issues in Science Curricula

My intention to matching environmental education and science education together is obvious, although it may not be a concern in other countries. Research on using environmental issues as a context and a material in school curricula is worthy of more efforts for both academic communities. Since these two universities I have served are traditionally the institution for teacher education, my follow-up studies shall be directed to teacher capacity of teaching this subject matter. By doing so, the niche for issue-based environmental science education in school may be secured.

Given that environmental issues are increasingly recognized as a legitimate societal concern and a focus of educational activity, environmental education has emerged as an important part of school programs, particularly in the science curricula of some Western countries (e.g., Colucci-Gray et al. 2006; Gough and Robottom 1993; Hart 2003; Hodson 2003). A number of studies continue to call for curriculum and pedagogical efforts endorsing reflexivity in science and environmental education (Barrett and Pedretti 2006; Sauvé 2005; Zeidler and Sadler 2008). Teaching of controversial environmental issues is the best approach for cultivating reflexive inquiries and social transformation and for bridging the mutual relationships between science education and environmental education (Gough 2002). The rationale for this proposal is robust, but more efforts are still needed for finding effective ways to convince teachers to implement such instructional materials or thematic curricula. In addition to evidence-based research on instructional models, studies on teachers' perspectives on environmental issues and their practical considerations in teaching such topics are warranted.

There is no doubt that teachers' knowledge of, and values, regarding environmental issues may influence their teaching practices and how they view students' learning using environmental issues. Therefore, we echo Hart and Nolan's (1999) call for strategies that "make it possible for teachers and students to work with, and as inquirers, to confront their own notions and ideas about the way the world works, and about the meaning of teaching and learning as a process rather than mere knowledge acquisition" (p. 41). To search for these strategies, the first step should be to develop a transformative curriculum, referring to STSE and SSI education, in order to meet the goal of fostering scientifically and environmentally literate citizens. This puts the challenge in the hands of the teacher in implementing such a curriculum. The teacher needs to acknowledge himself or herself as a reflective practitioner and a learner so that he or she is able to "gear curriculum to students' needs and facilitate students' capacity for critique" (Barrett and Pedretti 2006, p. 244). However, teachers' values and beliefs are often unaffected by persuasion unless professional development courses engage them in meaningful intellectual encounters through which they are encouraged to critically examine their values and essentially experience reflexive thinking. We have seen a few studies regarding instruction on controversial issues in Taiwan that have taken teacher perspectives into account (Lin 2006; Lin and Chin 2012). Examples of teacher education program aiming to provide pre-service teachers experiences in exploring local environmental issues are still lacking; this will be an agenda for future research. Presumably, science teachers can benefit from an interdisciplinary training program that would better equip them to appreciate the complexity of environmental issues and encourage them to save space for involving environmental issues in classroom discourse.

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# Chapter 20
# Comments on Section 4: Thoughts on Science Curriculum Reform and Teacher Learning in Western Countries and Taiwan

**Onno De Jong**

> *Learning without thoughts is waste, thoughts without learning are dangerous*
>
> Confucius (in The Analects)

**Abstract** After reading the chapters of this section of the book, several similarities and differences between science (teacher) education in Taiwan and Western countries came to mind. In this contribution to the book, a brief elaboration of my emerging thoughts is given for the following three topics:

i. Influences on science curriculum reform,
ii. Professional development of teachers: specific learning styles,
iii. Contributions of teacher learning communities to science curriculum reform.

## 20.1 Introduction

After reading the chapters of this section of the book, several similarities and differences between science (teacher) education in Taiwan and Western countries came to mind. In this contribution to the book, a brief elaboration of my emerging thoughts is given for the following three topics:

i. Influences on science curriculum reform,
ii. Professional development of teachers: specific learning styles,
iii. Contributions of teacher learning communities to science curriculum reform.

Readers should be aware that the four preceding chapters are interesting but not aimed at providing a full overview of Taiwanese science curriculum reform and teacher learning. It is also good to know that the term 'Western countries' mainly re-

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fers to Western European countries and the USA. They are taken together although science education partly differs from country to country. However, in the field of curriculum reform and teacher education, they have so much in common that it is acceptable to combine them for the aim of clarifying my thoughts.

## 20.2 On the Influences on Science Curriculum Reform

The ongoing reform of many Western science curricula is the result of the interaction of a broad range of influential factors. In my opinion, three of the main factors are:

i. Demands from society: prepare students for a changing world,
ii. Interest in general views on teaching and learning, especially social constructivism,
iii. Requests from science research community: update curriculum content.

A concise elaboration of these factors is given below and outcomes are related to the Taiwanese situation as described in this section.

The first influencing factor is the growing demand from society to *prepare students for a changing world* in which they are able to actively participate in complex societal discussions and difficult societal decisions. As a consequence, a large number of innovative projects have been launched in Western countries. For instance, projects implementing context-based chemistry education in the USA (Schwartz 2006) and the UK (Bennett and Lubben 2006). Other projects introduce modules including controversial socio-scientific issues that students should discuss by using evidence-based argumentations. An example can be found at a German project where students discuss the public debate about the value of eating snacks and its impact on personal health (Marks et al. 2008).

The second influencing factor is the increasing interest in general views in teaching and learning. In many Western countries, the psychological learning theory of *social constructivism* is leading and is incorporated in science education. According to this theory, learning is a dynamic process in which learners actively construct meanings from their actual experiences in connection with their prior understanding and social setting. As a consequence, innovative projects have been launched that include teaching for promoting active student learning, for instance, a Dutch project involving inquiry-based learning (Van Rens et al. 2010). Other examples are projects using educational technologies for supporting active student learning, such as the use of information and communications technology (ICT) tools at a Finnish project on computer-based molecular modelling (Aksela and Lundell 2008).

The third influencing factors are the ongoing requests from the Western science research community to *update the curriculum content*. As a consequence, several innovative projects have been implemented that incorporate modern science topics, such as an Israeli project on teaching basic nanotechnology concepts (Blonder and Sakhini 2012). Other projects pay attention to the scientific issue of the nature of science (NOS), for instance, a USA project on the teaching of the nature and functions of models (Gobert et al. 2011).

What about Taiwan? The influence of the three factors is reflected in the curriculum innovations that are presented in this section. Some examples are given below.

Regarding the first factor, Chap. 19 reports about two projects on context-based science teaching and the use of (controversial) socio-scientific issues: the bovine spongiform encephalopathy (BSE) ('mad cow disease') incident in 2005 and the case of 'exotic species' in Taiwan.

Regarding the second factor, Chap. 18 presents a project about inquiry-based student learning. In this project, students have to compare the value of the traditional 'slash and burn agriculture' method with the value of modern working methods.

Regarding the third factor, reports of specific projects are lacking, but Chap. 17 indicates that the Ministry of Education emphasizes the importance of incorporating frontier science research topics in senior secondary education. More specifically, Chap. 16 refers to successful efforts to enhance students' interest in learning nanoscience topics.

In conclusion, this section clearly reports several Taiwanese curriculum innovations that correspond to a large extent with such innovations in Western countries. This similarity is not a real surprise because it is well-known that, since about half a century, the Taiwanese science curriculum is mainly influenced by views and practices from Western countries, especially from the USA. The present section shows that this influence is still ongoing. However, there is also another aspect. Taiwan is now a very high-tech developed country. For that reason, it is plausible that Taiwanese high-tech educational software and related technologies will be disseminated to Western countries. In that case, and maybe other cases, the traditional route of impact on science curriculum reform from West to East will be reversed.

## 20.3 On the Professional Development of Teachers: Specific Learning Styles

The implementation of curriculum innovations requires professional development courses that offer adequate support to teachers and provide guidance that also fits their specific styles (manners) of learning. In my opinion, teacher learning is influenced by three important factors that can be related to the following characteristics of inservice teachers as adult learners:

i. Teachers are culture-directed learners: self-directed (Western); others-directed (Taiwan),
ii. Teachers are practitioners: practice-oriented learners,
iii. Teachers are experts in their own teaching: learning by action and reflection.

A brief elaboration of these factors and specific learning styles for Western and Taiwanese inservice teachers is given below.

Firstly, teacher learning is influenced by the culture in which teachers live. Western countries are rooted in the Jewish-Christian cultural tradition which considers individual fulfillment as the major driving force for learning (Triandis 1995). For that reason, in general, Western teachers are interested in courses that offer a lot of possibilities for a *self-directed learning* style (Candy 1991). These courses provide space for teachers to become owners of their own learning. Nevertheless, they are also open to learning challenges offered by others such as their teacher educators.

Secondly, teachers are practitioners, and, in Western countries, they are often not very interested in formal theories and general rules. For that reason, in general, they are interested in courses that provide space for a *practice-oriented learning* style (Usher and Bryant 1989). These teachers are motivated to learn about informal theories and specific rules that emerge from and guide practice. In general, teachers like to know how to act in a particular situation and are eager to hear stories about 'practices that work'.

Thirdly, teachers are experts in their own teaching and they do not like superficial new learning. They prefer courses that contribute to develop a deeper understanding of their practice. For that reason, in general, Western teachers are interested in courses that fit an *action-reflection learning* style (Adams 2000). In the classroom, teachers have to make many decisions in a split second. They are able to do so because their actions are guided by 'split-second' thoughts that are often rather unconscious. Therefore, it is not easy for teachers to explain what they are doing or what they know. However, tacit knowledge can be made explicit through 'reflection-in-action' and, thereafter, 'reflection-on-action'. Courses can use both modes of reflection to help teachers to improve their understanding of their own practices.

What about Taiwan? For many centuries, the way of teaching and learning in this country had strong roots in Confucian culture. The influence of this heritage is still ongoing, although Western cultural influences are emerging. The Confucian heritage emphasizes the importance of harmony, maintaining a hierarchical distance, a rather low individualism, and learning that primarily contributes to societal development (Triandis 1995). Individuals are considered as important participants of a collectivist society. In a recent comparative study of Taiwanese and German preservice teachers, Laschke (2013) reported that the learning of the preservice teachers from Taiwan was less affected by individual characteristics than the learning of their German colleagues. This evidence-based difference will be stronger for inservice teachers because they spent a larger part of their life in a Confucian inspired environment. For that reason, it is plausible that, in general, Taiwanese teachers will be more interested in professional development courses that offer a lot of possibilities for an *others-directed learning* style (Hofstede et al. 2010). They will prefer courses that primarily enable them to acquire competences that are important from a collectivist point of view. Nevertheless, because of Western influences, they will also be open for a somewhat more individualistic learning style.

The present section does not provide information about Taiwanese teacher courses related to a particular culture-directed learning style. However, at several places, specific information is given about courses that give space to both other learning styles. For instance, Chap. 18 reports on a course that fits practice-oriented learning by asking teachers to design and use 'culturally responsive' teaching methods for their own practice. Chapter 17 describes a course which requires action-reflection learning by asking teachers to reflect on curriculum modules which they have taught in the classroom.

In conclusion, this section suggests similarities between Taiwanese and Western teachers regarding their involvement in courses that include practice-oriented learning and action-reflection learning. The main difference between both groups of teachers is their culture-directed learning style. Firstly, in general, Taiwanese teachers will have a stronger preference for courses that focus on the tradition of collectivism, that is, learning together in a group. Secondly, in general, they will also have a stronger preference for courses that pay attention to the traditional hierarchical order in the classroom in which the teacher is the superior owner and transmitter of knowledge. Thirdly, Taiwanese teachers will have a weaker preference for courses that include the teaching of controversial socio-scientific issues because of the Confucian cultural roots of emphasizing harmony and avoidance of conflicts in discussions.

The described differences can be considered as sources of ideas for changing some aspects of teacher learning in Taiwan and Western countries. In Taiwan, teacher courses can pay more attention to classroom teaching that offers opportunities for students to take responsibilities for their own learning process. In Western countries, teacher courses can focus more on classroom teaching that includes student learning in groups and stimulates students to create consensus when discussing controversial socio-scientific issues.

## 20.4 On the Contributions of Teacher Learning Communities to Science Curriculum Reform

Self/others-directed learning, practice-oriented learning, and action-reflection learning can be promoted by establishing courses that are designed as teacher learning communities (TLCs). The core group of a TLC consists of teachers but other groups, such as teacher educators, unit designers, and, in case of use of modern technologies, ICT specialists, are often involved. Teacher learning communities can be distinguished into various categories, for instance short-termed and long-termed TLCs, and online and offline TLCs (De Jong 2012). An interesting distinction can be made by looking at the kind of contribution TLCs make to curriculum reform. In my opinion, the following distinction can be made:

i. TLCs contributing to the acceptation of new modules and teaching,
ii. TLCs contributing to the adaptation of new modules and teaching for own practices,
iii. TLCs contributing to the development of modules and teaching for a new curriculum.

A concise elaboration of this distinction for some Western and Taiwanese science curriculum reform is given below.

TLCs that contribute to the *acceptation* of innovations aim to support teachers to understand and use the innovations. These TLCs are quite common among many Western science curriculum projects. The projects often produce teacher manuals and other materials that can be used for teacher discussions. It appears that interaction among teachers is essentially in facilitating teacher change processes (Roth et al. 2011). This contributes to reduce teachers' resistance to innovations and stimulates a growth of teachers' self-efficacy in new teaching (Adams 2000).

TLCs that contribute to the *adaptation* of innovations are aiming at helping teachers to create a good connection between the innovations and the demands of their specific teaching practice. Although these TLCs are not very common in Western science curriculum projects, interest in them is rising. An example of a Dutch project can be briefly described as follows (Stolk et al. 2011). In the first cycle of the project, six chemistry teachers from different schools came together with a teacher educator to discuss a draft of a particular module. This draft was related to a general curriculum innovation theme, viz. teaching chemistry in contexts. The teachers adapted the draft module for their own classroom practice and expressed their intended new teaching strategies. After implementation, they exchanged their experiences and reflected on the module, the underlying ideas, and related teaching strategies. The teacher educator coached the teachers when designing an outline of another new module based on the underlying ideas discussed before. Finally, the teachers discussed the enacted design, reflected on the results, and developed intentions for new teaching practices. The outcomes of this cycle were used to refine the project and to implement a second cycle in which seven other chemistry teachers were involved. These findings showed that teachers' professional development led to their successful empowerment for adapting and teaching context-based innovative modules, provided they had sufficient time and resources (Stolk et al. 2012).

TLCs that contribute to the *development* of modules and teaching strategies for a new curriculum aim to involve teachers as co-owners of the innovations. The curriculum innovation can be small-scale or large-scale. The use of TLCs in large-scale projects is quite new and hardly used in Western science curriculum projects. An example can be found in the Netherlands, where a national project on chemistry education reform was launched based on a bottom up approach (De Kleijn and Seller 2010). Small teams of teachers from about 150 secondary schools were the bearers of the project. In the first part of the project, about a quarter of the teams were coached by a teacher educator to design one or more innovative modules that focus on relating contexts to chemistry concepts. The new modules were used by nearly all teams for teaching in their classrooms. Their experiences were recently incorporated in the second part of the project. This time, teacher teams from about 20 schools, each supported by a coach, actively participated in a pilot focusing on the development and the enactment of a draft of a coherent context–concept curriculum. An evaluative investigation of the pilot project indicated that this curriculum was feasible, teachable, and testable (Ottevanger et al. 2011). The pilot outcomes will lead to the formulation of a new national chemistry curriculum and related examination program for secondary schools.

What about Taiwan? In the present section, several teacher learning communities are reported as can be seen in the examples below.

TLCs contributing to the acceptance of innovations are described in Chap. 16. For instance, an inservice course in which teacher educators and teachers discussed how to embed constructivist-related teaching into appropriate science topics. Teachers had to apply their learning in their own classrooms. Results showed that this TLC supported the teachers to transform traditional teaching into constructivist teaching to solve teaching problems they experienced.

A TLC mainly contributing to the adaptation of innovations is presented in Chap. 17. Science educators collaborated with six teams of teachers and provided them with workshops and lectures in order to update their knowledge about the curriculum reform. This stimulated four teams to adapt new teaching strategies in several ways, such as introducing appropriate socio-scientific issues and relating them to core concepts in the textbook. Findings indicated that the TLC enhanced understanding and appreciation of the curriculum reform among the teachers and increased their knowledge of adapting problem- or core concept- centred curriculum modules.

TLCs contributing to the development of new modules and teaching strategies are also reported. The scale of the projects in which the TLCs are embedded is not very clear, especially regarding the number of participating teachers/schools and the extent of the covering of the curriculum. The TLC described in Chap. 16 is part of a project in which science teacher educators and teachers cooperated in small groups to develop integrated modules to be used in teachers' own classrooms. The outcomes suggested that this TLC improved pedagogical knowledge and teaching skills among the teachers, and changed their beliefs. The TLC presented in Chap. 18 is part of a project on integrating indigenous ('Paiwan') cultural aspects into the science curriculum In this context, a group of science teacher educators and teachers, along with local stakeholders ('tribal elders'), collaborated in developing and enacting appropriate modules and teaching approaches. A report on changes in teachers' expertise and beliefs is lacking.

In conclusion, the given examples show that teacher learning communities play an important role in science curriculum reform. Many of them are embedded in research-based projects, which makes it possible to clarify the important contribution of TLCs to teachers' learning processes and outcomes. The use of TLCs embedded in projects for a bottom up and/or large-scale science curriculum reform should be promoted more, not only in Western countries but also in Taiwan. A final remark about TLCs: about 2500 years ago, Confucius had said (in The Analects): *When I walk along with two others, from at least one I will be able to learn.* I guess he also had teachers in mind.

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# Part V
# Reflections

The first part is Chap. 16, written by the science editors of the *International Journal of Science and Mathematics Education* (IJSME) to share their personal experiences working with local scholars in Taiwan. Yore et al.'s unique experiences and expertise in science education have initiated and shaped some of the country's research in science education. Although their viewpoints cannot represent all international scholars' positions on science educa tion in Taiwan, the lenses they used to infer how science education research developed over the past three decades can tell an inspiring story about the history of Taiwanese science education.

Along the same line, the second part includes comments and reflections from international scholars who have been to Taiwan for different purposes, such as delivering plenary speeches and workshops for conferences, or/and talks at universities. They share what they saw and what they felt to allow us to see for ourselves both from the outside as well as from the inside. The story of Taiwan's experience and achievement is continuously being developed to promote science education for future generations. Taiwan is not a big place and has little natural resources. What Taiwan has, however, are its people. The never-ending challenge of science education is the bridging of the gap between research and practice to develop and utilize this natural resource. We have solid research outcomes that form the basis for promoting science education research and should be ready to face the reality of school practice. All these will allow us to see the strengths we have and the challenges we face such that we can continue to strive toward high-quality science education for future generations (see chap. 23).

# Chapter 21
# An International Perspective on the People and Events Shaping Science Education in Taiwan—Past, Present, and Future

**Larry D. Yore, James A. Shymansky, and David F. Treagust**

**Abstract** This reflection considers the array of women, men, and events that have contributed to the research and development of science education in Taiwan during the last 50 years. The chapter explores the documents, programs, institutions, and scholars that have influenced science education in Taiwan at the local, national, and international levels. In this chapter, the authors begin their study by discussing the successes, challenges, and promises of science education in Taiwan via e-mail and face-to-face meetings, to establish tentative trends and assertions based on their nearly 80 years of combined experience in Taiwan. They were among some of the early visiting science educators to Taiwan in the 1980–1990s and continue to consult and visit until the present time. They have served as founding senior and associate editors of the *International Journal of Science and Mathematics Education*, a research journal with roots in Taiwan. More than 50 years were partitioned into more manageable periods: pre-1980, 1980–2010, and post-2010. The authors then proceed to collect information from websites, science educators, and journals to verify and elaborate these trends and assertions. They informally interview international science educators who were involved in Taiwanese projects to map out some of the potential critical events and people. Next, they survey past (retired), present (active and established), and future (postdoctoral fellows and recently appointed faculty members) science educators in Taiwan using a simple e-mail questionnaire. Completed surveys are analyzed, seeking evidence to support or modify these trends and assertions. As a final step, the authors consider the content of research articles published in English-language journals to determine the research foci and trends during each period. They develop speculations about what occurred and what had been promised.

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## 21.1 Introduction

Science education in Taiwan has enjoyed an interesting and successful evolution over the last 50 years, moving from its status as a new nation with little educational research experience or activity to a position of international prominence in science education in the areas of student achievement, teacher education, curriculum development, research, and leadership. The commitment of the 1960s and 1970s to enhancing science instruction has been manifested in Taiwan's performance in Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA). The steady pattern of comparatively high student achievement in science, mathematics, and reading literacies has continued over the last decade, although some decreases have been detected in recent years, leading to concerns about students' attitude toward and identity with science. The evolution of normal, education, and private universities has met or exceeded the demands for science teachers, by innovative recruitment of scientists and engineers into teaching and by high-quality teacher education programs and graduate programs. Curriculum development has evolved by importing Western science curricula to developing original curricula and implementing these programs in the schools. Science education research has moved from implementation studies of curriculum, instruction, learning ideas, and evaluating teacher education programs, to contemporary investigations of cognitive science interpretations of science learning and teaching, increased use of complex statistical models and techniques for the primary and secondary analyses of large datasets, applications of neurosciences and eye tracking in documenting mental activities associated with science learning, infusion of information communication technologies in formal and informal environments, increased public awareness, and enhanced science literacy. Science educators from Taiwan have provided leadership regionally within East Asia and internationally within North America (the National Association for Research in Science Education (NARST)) and beyond (the International Union of Pure and Applied Chemistry (IUPAC) and the International Conference on Chemical Education (ICCE)). The future for science education in Taiwan appears to be promising as well as perplexing, as science education addresses changes in population demographics and ever-changing national priorities and helps address science literacy for all citizens and pipeline career science literacy for some.

## 21.2 Methods

This chapter provides an international perspective by three participant-observers and trusted critics of Taiwan's science education journey over the last five or more decades. The authors continue to be actively involved in science education in Taiwan as members of international science education communities, journal editors, graduate supervisors, and visitors and collaborators. To identify key events and people, outline tentative trends and assertions, and establish development and verification procedures for these speculations, they initially shared their experiences with one another and discussed their perceptions of the successes, challenges, and promises of science education in Taiwan via e-mail conversations and face-to-face meetings.

Next, they informally interviewed international and national science educators to map out more fully the potential critical events and people during the time period under investigation**.** They identified a nonrandom sample of past (retired), present (active and established), and future (new faculty, postdoctoral fellows, and recent graduates) science educators from Taiwan ($n=63$) with the help of their contacts. These science educators were surveyed using a simple e-mail questionnaire about their demographics, advanced degrees, publications, and beliefs about the successes and challenges during the three periods.

Informed volunteers completed surveys ($n=41$, response rate ~70%) that were individually summarized and grouped as respondents with particular insights in the past ($n=6$), present ($n=25$), and future ($n=10$). All responses were fully analyzed so as to elicit details and evidence to enrich, support, or modify the preliminary trends and assertions for each period of interest. The authors selected a small number of science educators in Taiwan, about whose work they were aware, from specific time periods to illustrate the types of contributions. The selected individuals represent numerous other individuals who made similar contributions over the 50+ years considered.

As a final step, the authors considered the content of research articles published in English-language journals identified from web-based searches and from the survey respondents to determine the research foci and trends in the early years, recent past, and future times (especially in-press articles). This consideration allowed them to speculate on delivered successes and challenges and the promises in progress, which provided details for the preliminary trends and assertions about science education—past, present, and future.

Consequently, this chapter is organized into arbitrary periods to provide a brief contextual overview of the past (pre-1980) and the people and events of that era, before describing the present (1980–2010), and speculating about the future (post-2010). A summary assertion is provided that encapsulates the trends and outcome of each period. A review of Taiwan's unique social, political, and cultural context, however, is critical for understanding these trends and claims. A contextual overview reveals similarities and differences between Taiwan and other countries entering similar journeys. It is hoped that the reader will gain a sense of the challenges and opportunities that have been unique to Taiwan as it has developed internal resources, recruited international academic advisors and collaborators, and enacted and supported the evolving science education agenda with national and international implications for science education associations like the NARST, the European Science Education Research Association (ESERA), the Australasian Science Education Research Association (ASERA), the National Science Teachers Association (NSTA), and others. These features of the experiences in Taiwan can offer speculations about the actions and contributions of science educators and science teachers in the future and in emerging countries (e.g., Turkey, Kingdom of Saudi Arabia, Republic of South Africa, and some Latin and South American countries such as

Brazil). Clearly, other countries new to science education research can benefit from Taiwan's successes and challenges.

## 21.3 Contextual Overview

Taiwan spent nearly 50 years under Japanese control, producing both positive and negative effects on the people of this "Precious Island" known then as Formosa. The people learned to be creative, disciplined, and focused, and they deepened their personal and spiritual beliefs (combinations of Buddhism, Confucianism, Taoism, and others) in the value of education and hard work (Huang and Yore 2003). The post-World War II period provided opportunities for this ingenuity to flourish, and the material rewards of creativity and hard work soon followed as the new nation advanced toward its economic goals. The long-term residents and post-1948 arrivals appeared to believe in their national goals and shared commitment to hard work to reach these goals. These industrious people developed a series of governments that focused on human resources and development, laying the foundation for the manufacturing industries of the 1960s and the technological power of the 1990s.

In 1945, compulsory education for all students in Taiwan was set at 6 years of elementary school so as to strengthen the quality of the nation's workforce. In 1968, the government extended compulsory education to 9 years (6 years of elementary school and 3 years of junior high school) and, in 2014, to 12 years (adding 3 years of high school). This progressive increase in the required years of education included a tradition of high-stakes examinations for entrance into the most prestigious junior and senior high schools. Although the high school entrance examination will end in 2014 (the entrance examination for junior high school ended in 1968), the high-stakes university entrance examination continues to produce stress for high school graduates and their families as well as schools and teachers. The results of these examinations are used to establish prioritized admission to specific postsecondary institutions each year. The expanded central objectives of education during these required attendance and curriculum changes were to arouse citizens' patriotism, thereby contributing to the nation's goals, enhancing their scientific knowledge, and producing an informed workforce.

The National Science Council (NSC) was formed in 1959 under the name the National Council on Science Development. Its head was a minister and trusted member of the government with a seat on the Executive Yuan (executive branch of the Republic of China) and served as a central organization for scientific and technological efforts, which later became an economic engine for the nation. The seat on the Executive Yuan provided a close linkage between science research, technological innovations, and government policy—an uncommon situation in many countries that have either independent or semi-independent research foundations or agencies with only indirect connections with politicians and bureaucrats. The Minister was assisted by Deputy Ministers heading the major parts of the NSC organization.

The Science Education Council was formed in 1967 and was renamed as the Science Education Division in 1969, undergoing a further name change in 1982 to the Department of Science Education (DSE). It was headed by an appointed director and formed one of the administrative units in the NSC. The director had direct reporting lines to the minister and deputy minister of the NSC and provided on-site advice to these decision-makers in meetings of the Executive Yuan. Able and committed permanent NSC staff and a variety of short-term, highly qualified, postdoctoral fellows supported these directors. Table 21.1 lists the directors from 1970 to 2014, their term of office, and their former academic affiliation. An inspection of the prior academic positions held by these directors reveals a heavy reliance on administrators and professors from government agencies, institutes, and national universities: the National Taiwan University (NTU), the National Central University (NCU), the National Taiwan Normal University (NTNU), the National Changhua University of Education (NCUE), and National Chaio Tung University (NCTU). After their term of office, many of the directors returned to academic leadership positions (presidents, directors, and central administrators) in their former and other institutions.

Over its history, the DSE was reorganized into disciplinary divisions (ranging from two to seven divisions) that evolved to address new goals and capture the research priorities of the NSC. An informant stated that "the current ongoing reorganization plans called the 'Organic Law of Executive Yuan' by the Executive

**Table 21.1** Directors (1970–2014) of the Science Education Division (1970–1982) and the Department of Science Education (1982–2014) at the National Science Council of Taiwan

| Name | Term | Prior academic affiliation (position, department, institution) |
|---|---|---|
| Chu, Hui-Sen | 1970.01–1974.05 | President, National Institute of Compilation and Translation (presently National Academy for Educational Research) |
| Huang, Chi-Jen | 1972.07–1977.09 (Deputy Director) 1977.09–1981.06 | Chief Secretary, Department of Education of Taiwan Province |
| Mao, Song-Ling | 1981.07–1985.06 | Professor, earth science, NTNU |
| Leu, Hsi-Muh | 1985.08–1987.07 | Professor, mathematics, NTNU |
| Yen, Chi-Lin | 1987.08–1991.07 | Professor, mathematics, NTNU |
| Shu, Rong-Fu | 1991.08–1995.07 | Professor, physics, NTNU |
| Guo, Chorng-Jee | 1995.08–1999.09 | Professor, Graduate Institute of Science Education, NCUE |
| Cheng, Yeong-Jing | 1999.12–2002.07 | Professor, biology, NTNU |
| Lin, Fou-Lai | 2002.08–2006.07 | Professor, mathematics, NTNU |
| Lin, Chen-Yung | 2006.08–2008.07 | Professor, life science, NTNU |
| Hue, Chih-Wei | 2008.08–2010.07 | Professor, Department of Psychology, NTU |
| Chen, Gwo-Dong | 2010.08–2013.08 | Professor, computer science and information engineering, NCU |
| Chou, Chien* | 2014.02– | Professor, Institute of Education, NCTU |

*Denotes that the Director, Department of Science Education, also supervised the Department of International Cooperation during the transition of the two separate departments into a single organization.

will have the NSC and the DSE integrated with other units and agencies to form the new Ministry of Science and Technology (MOST). The DSE will be merged with the International Cooperation Department to become a new Science Education and Development and International Cooperation Division within the Ministry of Science and Technology." The Executive Yuan and President of Taiwan (March 3, 2014) announced the official establishment of the Ministry of Science and Technology with Dr. San-Cheng Chang as minister; he is a current Minister without Portfolio, a highly successful businessperson, and a Professor in the Department of Civil Engineering, NTU. However, the Executive Yuan has not set the actual date for the consolidation of Science Education and International Cooperation as the Department of International Cooperation and Science Education, but the transition has started with the new Director of the DSE also supervising the Department of International Cooperation." These organizational changes will likely maintain the functional specifics of the DSE for the near future, while changing the lines of communication and power structure within the new department and the central government that science education has enjoyed since its formation within the NSC. Fortunately, the interim director/supervisor—Professor C. Chou—is an active member and established leader in science and technology education research community who will appreciate the unique needs of science education research while she supervises, learns, and handles the demands and travel and meeting schedules of the international cooperation portfolio during the transition of the independent agencies into a single department.

## 21.4 Pre-1980: The Formative Years

The majority of informants, and the authors' own assessment, indicated that the NSC and the DSE were instrumental in the development and success of science education in the pre-1980 and 1980–2010 periods and laid the foundation for future success. During its early years, the NSC focused on academic science and technology, research and development, and national economic goals with limited attention to educating future scientists, engineers, and technologists, and little attention to science teachers. Starting in the 1970s, the NSC funded graduate studies in the USA for potential scientists and engineers; it also funded some fellowships for mathematics study in the UK. Unfortunately, many of these highly qualified people did not return to Taiwan. However, some of these scientists who received the NSC fellowships did develop an interest in science education while studying academic sciences in the USA, and became critical advocates for and leaders of science education and science teacher education after their return to Taiwan.

The education of future science teachers during the early part of the pre-1980 period was left to the work of teachers colleges and normal universities. Teachers colleges provided generalist education for elementary school teachers, whereas normal universities provided discipline-specific specializations and required strong science content backgrounds from the academic science departments, approximating that of the national universities' B.Sc. degrees. The ensuing struggles to establish disciplinary identity and academic integrity for science education within Taiwan were partially achieved by academic scientists and leading science teachers advocating for the science curriculum, teacher education, and professional development. These efforts led to enhanced science teacher education, increased importance of science education in the schools, and recognition of the need for science education research.

Collectively, these academics, the NSC, and the Ministry of Education (MOE) established science education as an academic discipline, developed the infrastructure for science education (Science Education Advisory Committee), and enhanced science teaching and graduate studies (Science Education Center at NTNU) and later in 1987 the formation of graduate studies with a PhD program (Graduate Institute of Science Education at NTNU). One informant reported that the "Science Education Advisory Committee provided advice, guidelines, and consultation to the MOE for the development of new science education programs and reforms in general and science curriculum reforms in particular, in all grade levels at the national level. This greatly facilitated the speed of science education reforms, particularly the development of new science curricula in Taiwan."

Teacher education and science teaching were hampered by the quality of science teachers (non-science majors), the examination culture of society, and the test-driven science instruction in schools. One informant, describing the way in which instruction manifested itself, stated, "Students are trained to seek the right answers from the textbook." Some informants viewed the same event, such as new science textbooks or the 1960s National Science Foundation (USA) sponsored inquiry and discovery programs, as a success whereas others viewed it as a challenge. One informant believed that the Taiwan-published textbooks were evidence of success (National Curriculum Development Institute) because these resources were viewed as "made in Taiwan" products and thus an indication of the newly achieved nation status. Others believed that a single authorized textbook for specific courses constrained science learning to rote memorization of difficult content knowledge, cultivating science only for elite students who were focused on a science or technology career, and teaching as lectures and examinations. Alternatively, the importation of hands-on inquiry modules was viewed as a way of overcoming the traditional dependence on textbooks and reading about science. A former Director of the DSE at the NSC stated, "Although teachers expressed concern for the students' attitude, they continued to be imprisoned by the textbook, existing courses, [examinations], and traditional teaching methods… [and the] educational opportunities were limited for disadvantaged populations, including those living in the countryside, aboriginal areas, and students from poor families." Another informant suggested that science educators viewed traditional laboratory work to be conducting experiments using only prescribed procedures. Since only one version of the prescribed textbooks was used in class, students' scientific understanding was narrowed within the scope of what was presented. The increased emphasis on science in schools and science fairs was positive, but the examination-driven instruction inhibited teachers from spending time on laboratory work or developing students' scientific epistemology. Instead, the curriculum stressed content-knowledge achievement on the national examinations, which were highly valued by Taiwan's society. One informant pointed out that, like many countries worldwide and especially in Asia at this time, higher education was relatively unpopular prior to 1994. The majority of junior high school students opted for vocational schools or joined the workforce. Only about 40% of the students opted for general high school, and only about 30% of these students passed the university entrance examination (about 12% of the overall student population).

The critical component of these formative years lay in the strong efforts and commitments of many people: science teachers and professors, politicians, and bureaucrats. One such leader was Jong-Hsiang Yang, science teacher, director of the Experimental Center of Science Education at the Hsin-Chu High School, and later a professor at the NTNU after completing his doctoral degree. As a science teacher, Yang was invited in 1963 to participate in the Biological Sciences Curriculum Study (BSCS) summer institute held by the University of Northern Colorado. He returned to Taiwan and enacted a series of workshops to help biology teachers learn about and try out the new BSCS curricula. He also organized the visit of Bentley Glass, Director of BSCS, to observe the implementation of the BSCS yellow version biology program and organized the second Asian Association for Biology Education conference. "[Dr. Jong-Hsiang] Yang has led us through the important years of science education [in Taiwan]. This included the rebuilding of science education (1950–1960), implementing a new science [curricula in biology, chemistry, earth science, and physics] (1960–1970), gaining the academic status of science education," and later expanding the research approaches available in science education (Lin 2008, p. 11).

Other leaders and advocates for science education were scientists, such as Chorng-Jee Guo, a PhD (Brown University, 1974) with specialties in solid-state and low-temperature physics. He championed changes in science teacher education at the Taiwan Provincial College of Education (now NCUE) to meet the demands that emerged when compulsory education were increased from 6 to 9 years (1968), and the subsequent increase in demand for science teachers at the junior high school level. Professor Guo refocused his academic interests and efforts from physics to science teaching, science teacher education, and professional development. He stated, "Although not educated as a science educator, I realized that our missions [at the Taiwan Provincial College of Education] to prepare qualified science and mathematics teachers were both very important and demanding. I began to read journal articles in *Science Education* and the *Journal of Research in Science Teaching,* to invite well-known science educators to visit our campus, and to encourage my younger colleagues to pursue higher degrees in science education abroad. After I visited the Science Education Center at the University of Iowa in 1980, I had a better understanding as to what science education is all about and how to do research in science education. … While I kept teaching physics courses to the undergraduate students for the next 10 years or so, my research interests and efforts turned to science education." Dr. Guo continues to advocate for the underrepresented and underserved, such as the indigenous peoples of Taiwan.

Other informants believed that the expansion of the NSC funding support in the late 1970s, for advanced degrees in science education, for the faculty members at the national normal universities and teachers colleges was what provided the needed momentum to continue the efforts of the early leaders. The funding established recognized academic leadership for science education moving into the 1980–2010 period, developed homegrown talent in the recently developed PhD programs in the normal universities, and expanded science education research beyond curriculum development and implementation, to address other pressing learning and teaching issues.

The major challenges for science education in Taiwan during and after the pre-1980 period were the recognition and definition that science education is a professional research field under the umbrella of education, the cultivation of science education researchers, and the financial foundation for science education research. The NSC and the MOE played major roles in addressing these challenges. Like many other countries, however, at the end of this foundational period in 1979, relatively few women and indigenous people participated in science teacher education and science education research in Taiwan.

In summary, the pre-1980 period reveals two central themes. First, the MOE, NSC, universities, and science teachers cooperated to establish clear national priorities and patriotism. Second, the initial leadership, planned development, and evolution of the leadership laid the foundation for Taiwan's successes and the basis upon which to address the challenges of the 1980–2010 period. During these early years, it appears that grassroots leaders and many junior faculty members were recruited into the national normal universities and national teachers colleges. The most promising among them were encouraged to seek advanced degrees in the USA and, to a lesser extent, in the UK, with the support of the NSC fellowships. Unlike the early scientists and engineers, many of these highly qualified people returned to Taiwan and became department chairs, deans, presidents, directors at NSC, and internationally recognized science educators. Their scholarship and professional efforts went into teaching, graduate supervision, program or curriculum development, implementation of 1960–1970s reforms, professional development, and administration. Some who were located in academic science departments published their research in academic science journals. One informant stated, "A survey of published articles revealed that before 1980 few people in the educational field focused on science education research specifically. There were only two articles published in the [recognized English-language] international [science education] journals, and in fact, none of the graduate institutes of science education were founded before 1980. Science education researchers belonged to different academic science departments, such as physics, chemistry, or biology departments." The pending supply of newly minted PhD's, with active agendas in science education research, influenced the reorganization and repurposing of normal universities and teachers colleges.

## 21.5 1980–2010: The Decades of Outreach and Expansion

The 1980s, 1990s, and 2000s were three critical decades for science education in Taiwan that built on the formative years (pre-1980). These decades were marked by continued effective leadership of established leaders and their contemporary replacements, and strong contributions by the NSC and MOE to curriculum reform, international visitors, conferences, and education research. In addition, the investments in human resources produced dividends in increased scholarship, a new generation of leaders, and a major shift in the directions of scholarship, research, and professional contributions. Most normal universities and teachers colleges evolved their status, goals, and structure toward research-oriented graduate institutions. The academic expectations reflected ever-rising standards in research and publication, that, as the years progressed, transitioned away from practical, mission-driven, classroom applications toward curiosity-driven endeavors. Science education benefitted from a series of forward-thinking directors of the DSE over its history (Table 21.1). During the period 1981–2008, however, the DSE was directed by people who were science and mathematics educators (Song-Ling Mao, His-Muh Leu, Chi-Lin Yen, Rong-Fu Shu, Chorng-Jee Guo, Yeong-Jing Cheng, Fou-Lai Lin, Chen-Yung Lin). Their leadership defined the critical period in Taiwan's science education that refocused the goals and intentions of NSC funding to stimulate scholarship, research, professional contributions, and larger multi-institutional research agendas that brought science, mathematics, and education into a common, unified focus. The current director of the DSE, its first female director, has the daunting task of leading science education during the reorganization of the NSC as the new Ministry of Science and Technology and the resulting consolidation of Science Education and International Cooperation into a single department.

The science education graduates in this period appeared to benefit from the strong foundation, support, and expectations that pre-1980 events and people had established. Early leaders continued to be involved, whereas others formalized their graduate credentials and scholarship and solidified science education as a university discipline in Taiwan (Yeong-Jing Cheng, PhD, 1985, Iowa; Jong-Hsiang Yang, PhD, 1986, Nebraska; and the first of many women, Tai-Chu Huang, PhD, 1987, Indiana, and Tien-Ying Lee, PhD, 1987, Ohio State University). Many of these leading science educators were beneficiaries of the NSC foreign scholarship programs allowing international graduate studies at some of the most prestigious science education universities in the USA. Some mathematics educators attended prestigious universities in the UK. Later, fellowships in 1990–2010 were used to study science and mathematics education in Australia, Canada, France, Japan, and Germany. These scholars returned to their university positions or became postdoctoral fellows who increased the ranks of science education researchers. They influenced policy, funding, research, and university-supported reforms to improve the quality of science education. The leaders of the 1980–2010 period can be identified as recently retired professors who studied in the USA in the 1970s and early 1980s (Brown, Indiana, Iowa, Nebraska, Ohio State), current leaders who studied in the USA in the late 1980s and 1990s (Columbia, Harvard, Iowa, Iowa State, Georgia, Michigan, Minnesota, Missouri, Northern Colorado, Oregon State, Pittsburgh, Texas, and others), more recent graduates who studied in many other countries than the USA, and homegrown leaders who studied in the newly formed PhD programs at universities in Taiwan. During the early years of this period, very few of these productive scholars graduated from universities in Taiwan, but during the later years more scholars were products of these maturing universities.

Many leaders and advocates for science education during the 1980–2010 period were “leaders by design”: talented early- to mid-career faculty members in the normal universities’ academic science departments, and in the education universities’ departments of education and teaching, who were awarded the NSC graduate fellowships to study abroad. One such leader was Yeong-Jing Cheng, a PhD (University of Iowa, 1985; he also studied at Ohio State for a year prior to his doctoral studies) with specialties in science education and biology. Professor Cheng earned his bachelor’s and master’s degrees from the NTNU, assuming teaching assistantships and instructor appointments in the department of biology. He taught biology and secondary biology method courses and published academic biology research. After returning from his PhD studies, he assumed several administrative positions at the NTNU and served the MOE and the NSC in several capacities on major committees and taskforces. He was appointed director of the DSE at the NSC in 1999 and served until 2002. Dr. Cheng was instrumental in developing new research funding and large multi-university interface projects, and expanded the research focus to cognitive sciences and e-learning. His most enduring achievement was the *International Journal of Science and Mathematics Education*, which he established in 2002. It was recognized in 2011 with the Social Science Citation Index ranking under founding editor-in-chief Dr. Fou-Lai Lin and the current editor-in-chief Dr. Huann-shyang Lin. Dr. Cheng retired in 2008 but continues to be active in science education issues at the NSC.

Under the leadership and advocacy of these science educators, the MOE, NSC, and universities funded and delivered numerous science education events—international conferences, special issues of journals, books, multi-university projects, and international collaborations—that increased the research proficiency and activities of professors and graduate students across Taiwan. During the 1980–2010 period, the NSC, the DSE, and several advisory committees strategically increased funding for internal resources and promoted the growth and improvement of many projects. These research agendas have the potential to inform current policy and future research efforts.

Funding and infrastructure to support scholarship resulted in increased professional development opportunities for a large number of professors and graduate students who undertook collaborative research with international science educators from Australia, Canada, Germany, UK, and USA and participated in invited workshops, symposia, and conferences. Conference attendees acquired international exposure and publicized and shared research activities and findings. These workshop and conference agendas (a) reflected the perceived needs of Taiwan, and the development and interests of the attendees and (b) stimulated changes in research approach and focus, views of learning and teaching, curriculum, assessment, and professional development. They also promoted international and inter-university research projects. These activities attempted to break down the research and development silos, by developing national collaborative networks of faculty members and graduate students across the normal, education, and private universities. They also moved research approaches and topics toward complex problems and mixed-method designs.

The DSE's infrastructure at the NSC evolved from a traditional content focus to a more contemporary organization that could address persistent challenges and opportunities. The 1983 structure consisted of four traditional discipline-specific divisions focusing on education at the secondary-school level: mathematics, physics, biology, and chemistry education. Between 1993 and 2008, the department was reorganized to capture new priorities and the divisions were given different names and foci. As of 2014, there were seven divisions within the department: science education (comprising science curriculum, learning, assessment, science teaching, and science teacher education), mathematics education, information education, applied science education, medical education, multi-population science education, and education and communication of science and technology literacy citizens. This organizational structure reflected the change in focus from secondary-school curriculum to broader contemporary research and development.

Likewise, the NSC funding encouraged applicants to develop interdisciplinary networks and research teams that could address longer-term and larger inquiries concerning internationally pressing issues. Two former directors of the DSE pointed out that this funding attracted numerous scientists and science educators to participate in science education research, resulting in dramatic increases in research outcomes (e.g., published papers, international conference presentations, and national conferences). Innovative funding initiatives during this period moved science education research projects toward the involvement of multiple institutions, international collaborations, large interface projects, and the upgrading and refocusing of graduate programs. The formation of an English-language research journal (*International Journal of Science and Mathematics Education*) was likely central in making research results from Asian countries more readily available to international readers. There appears to be a move away from curriculum development and implementation projects toward more curiosity-driven investigations. A preliminary inspection of 86 articles published in English-language journals by one or more authors from Taiwan revealed ten popular research themes (popularity indicated by order): inquiry, culture, learning and e-learning, students' perceptions, teachers' perceptions, curriculum, assessment, science literacy, research trends and approaches, and concept/conflict mapping.

Although research was enjoying increased funding and recognition, considerable attention continued to be paid to curriculum and instruction. The focus was switching, however, from the importation of curriculum, teaching, and assessment ideas from other countries to a "made in Taiwan" approach. This transition is clearly illustrated in the *White Paper on Science Education* (MOE 2003), a product of the First National Science Education Conference (December 21–22, 2002). The

*White Paper* refocused science education onto the goal of motivating all citizens to understand the uses and applications of science, enjoy the wonderment of science, and appreciate its beauty. This aspirational (blue skies) document's purposes were to influence future economic growth, education policy and funding, curriculum development, and science education research. The short-term goals included communication between government and related agencies, constant monitoring of goals, connections between goals and activities, and evaluation of implementation efforts. The longer-term goals included clear and consistent regulations, research-informed policy, policy research, and administration. The document also set policy goals, which included evaluation standards, disciplinary R&D centers, consideration of special-needs learners, budget for popular/informal science activities, cross-department research projects, research centers to promote effective research, and a national evaluation committee for teacher education. The *White Paper* provided visions, guidelines, concrete expectations, plans, and approaches for achieving these goals; standards for teacher education (knowledge, internships, and professional practice); and described ways to engage indigenous peoples, enhance the climate for school science, enact popular science and informal environments, and encourage life-long learning. The MOE overview stated:

> Science education is an essential component of education. Its main concept is to educate every single citizen through cultivating his/her scientific literacy. The goal of science education is to improve the scientific literacy of the public and to help people develop the ability to innovate, create and develop attitudes of care and concern for others. (http://english.moe.gov.tw/public/Attachment/2122416571071.pdf, retrieved June 5, 2013).

The responses to the survey of science educators also revealed that notable successes of this period included the emphasis on learning science in informal environments and in relation to socioscientific issues, policy changes regarding teacher education and professional practice, and science literacy as a central curriculum focus. Several respondents realized that the *White Paper* expressed a futuristic agenda to be accomplished over the next two or three decades.

Several research projects focused on modifying and adapting science education ideas, rather than adopting these ideas without evaluation and customization. The combination of contemporary curriculum and instruction and the high priority that society in Taiwan ascribes to education was demonstrated in students' science learning and performance. Science achievement in the schools enjoyed recognized growth, as demonstrated in the TIMSS and PISA international surveys in which Taiwan ranked highly among participating countries. Several informants believed, however, that classroom instruction still focused too much on memorizing facts and concepts and that society still placed too much emphasis on test scores. They also suggested that students lacked creativity and critical thinking skills and that curriculum reforms were too rapidly forced on schools without adequate preparation. For these reasons, some science education innovations are not widely accepted by teachers in junior and senior high school. One informant stated: How to cultivate abilities with scientific application and argument are challenging in authentic teaching practice. Besides, the Grade 1–9 Curriculum stressed competence but ignored the importance of science knowledge. How to raise students' interest in science is challenging in science education. How to link science concepts and everyday-life science is also an important issue in science education. Students should have scientific argument ability but it is not included in formal education.

The challenges of the 1980–2010 period included population demographics (lower birth rates, foreign wives, indigenous populations); reorganization of the normal universities and education universities; the need, quality, and priority of teacher education; and the quality of curriculum and instruction of science education. The survey responses revealed details about these challenges.

Taiwan is a developed country with maturing demographics. Taiwan's decreasing birthrate and school-age population has reduced the need for teachers, but highly qualified science teachers are still needed in elementary and middle schools. The *White Paper on Science Education*, the restructuring of the normal and education universities, and the Teachers Education Law have had unpredicted negative effects on science teacher education; some teachers of science are not undertaking science education graduate degrees, and several undergraduate programs do not require a strong science background for teachers. These trends, combined with the increased number of postsecondary institutions offering teacher education, have reduced the priority of teacher education in the normal and education universities. One informant stated, "Because of the fierce competition, fewer and fewer students [who] majored in science, mathematics, and technology are preparing and receiving elementary teaching licenses." Respondents identified the following events as contributing to this challenge:

a. The changing government policy dealing with teacher education is illustrated by the fact that the Normal School Law was replaced by the Normal Education Law in 1979, that was in turn replaced by the Teachers Education Law in 1994. The Teachers Education Law opened multiple channels for teacher preparation and allowed all public and private universities to prepare teachers.
b. The 2003 *White Paper on Science Education* identified scientific literacy as the main goal of science education without fully defining what it was.
c. The Teacher Professionalism Index and Professional Performance Index (implemented in 2010) have articulated profession standards and performance for all educational levels.

These factors have been exacerbated by the increased number of postsecondary institutions involved in teacher education, which adds to the competition within a decreased demand environment. The reduction in teacher demand has reduced the number of faculty positions in the science teacher education programs, with several positions of retired professors standing vacant, also in turn reducing the number of science education research positions. Some universities have addressed the reductions in teacher education by shifting their efforts to other endeavors less directly related to K-12 education. This in turn has decreased these institutions' perceived relevance, judged by traditional criteria of schools as the only source of learning and instruction.

Nevertheless, as in Western countries, science education scholars continue to struggle for academic identity in the university hierarchy, where there is pressure to fill vacant science education positions with pure scientists or professors in the pure education area who do not support discipline-specific preparation and research. This struggle involving the dual membership of science education in science and in education continues worldwide, and the increased graduate credentials of science educators with PhD's have only partially addressed the identity concerns. Science educators in Taiwan face increased pressure to publish high-quality research in indexed English-language journals. The formation of the *International Journal of Science and Mathematics Education*, which is now listed in the Social Science Citation Index, has increased the publication of research findings from Taiwan. However, this is not necessarily seen as a good outcome. A respondent stated, "An increasing number of research articles published in the international English-language journals may decrease priority of classroom applications to close the local theory-practice gap." Another respondent stated, "… only a few scholars in Taiwan contribute most of these articles. We need more scholars to contribute their findings to the international community. In addition, we also need to create research questions and methodologies that address important issues and produce influential articles."

Many of the graduate institutes of science education were established during the 1980–2010 period to provide professional advancement for practicing science teachers and to promote applied science education research. A respondent stated, "Science teachers at elementary, middle, or secondary school levels had more chances to pursue their master's degree in science education area to improve their professional [and leadership] abilities. Science education scholarship and professional practice has focused on integrating science education theory in science curriculum, science teaching, and science learning. Lately, digital learning has integrated science with information communication technologies and has led science education to more modern changes in the research and teaching practices. More recently, the cognitive science tools such as eye tracker and electroencephalogram (EEG) also have started to involve the research to facilitate how students learn science and promoting public understanding of science." Some of the graduate institutes that offer PhD programs encourage their students to be an integral part of funded research projects as paid research assistants, as well as being independent doctoral researchers. These authentic research internships under the guidance of highly qualified science educators have made major differences in the research proficiencies of the graduates.

Increases in science achievement have been documented over the last two decades with international surveys such as TIMSS and PISA, but decreased attitudes toward and interest in science have also been documented. A respondent stated, "However, there is an indication of the weak abilities on proposing scientific issues and making argumentations of Taiwan students. Thus, there is a critical challenge on helping students realizing the meaning of science and promoting their interest of science." Another respondent stated, "Although the gaps still exist, the idea of insufficient understandings of human cognition was acknowledged by teachers of different levels. When it comes to the assessment evaluation like PISA, the gap existed between student good performance and poor attitude toward science, caused anxieties of education experts." The *White Paper on Science Education* has stressed making science literacy part of the curriculum for all students, giving young learners an appreciation for the importance of science in daily life and boosting their desire to learn more about the subject.

The deregulation of schools, which allows more local decisions and flexibility, has not only enabled informal education environments but also produced unknown costs and side effects. Such changes in policy and procedure have encountered mixed reactions across the science education communities. Some science educators have viewed the removal of the junior high and senior high entrance examinations as a positive change, whereas others have questioned the loss of the quality controls. Clearly, change and adjustment to policy amendments take time to influence the school and education cultures. One respondent stated, "Taiwan's science education reform has been carried out for many years, but the biggest problem is still the entrance examination pressure for university. This school reform puts emphasis on decentralization and de-emphasizing top-down authority. Therefore, it encouraged schools to select textbooks on their own, teacher use of student-centered instruction, school-based curriculum, and use of multiple assessments. It is hard to say if it has been successful or not, but this reform really brought compulsory education in Taiwan to a new milestone, including science education." In the words of another respondent, "Classroom instruction still focuses too much on memorizing facts and concepts. Society still places too much emphasis on the assessment results (e.g., international assessments and college entrance examinations). Students lack creativity and critical thinking skills." Another respondent expressed this view as, "The school education, even the whole society, does not provide students enough opportunities to think. Teachers and students are too busy doing nothing of extreme value."

Research findings have not yet made a difference in the classroom experience of teaching and learning science. Research still remains in academic silos, isolated from real teachers, students, and classrooms, with little cross-disciplinary interaction of science and socioscientific issues with mathematics, social science, language, linguistics, philosophy, and other disciplines. A respondent stated, "The theory-practice gap is widening. The survey results of published articles have shown that after 1990 science education research was very productive in terms of the amount of completed dissertations and international journal publications. However, it is unclear how fruitful these research findings were connected to practical educational settings, such as how these research findings were actually applied in everyday science classrooms or how educational reform was based on these research findings. In other words, as in many educational jurisdictions, one of the challenges for science education research might be how to improve communications between researchers, government policymakers, and teachers. In addition, the survey results of international publications indicated that there were fewer studies looking at the issues of professional development. In fact, none of the publications in the four indexed international journals was categorized in this theme. However, it is worth noting that action research is one of the most popular research types among master's theses and doctoral dissertations." Fortunately, in-service teachers in Taiwan are being encouraged to further study and improve their educational knowledge and teaching practice.

Many teachers take advantage of their own classrooms for implementing new teaching strategies or investigating their students' learning.

The use of new technologies has not enjoyed the same growth in classrooms and in evidence-based instruction as it has in the broader society. A respondent stated, "Teachers are encouraged to implement their science instruction with technology, to develop students' scientific and technology literacy. But, little has changed in technology-enriched classrooms. Students are still expected to ingest complex and abstract concepts." Another respondent stated, "Teaching in an information age and the World Wide Web to 'Net Gens' will need to influence *entrance examination oriented* teaching and learning (much remains to be done). The *Net Generation* student has grown up with information technology. The aptitudes, attitudes, expectations, and learning styles of Net Gen students reflect the environment in which they were raised—one that is decidedly different from that which existed when teachers and administrators were growing up." Still another respondent stated "Taiwan is the capitol of technology but science teacher education faces difficulties to nurture teachers' competence about properly using educational technologies in science classrooms."

## 21.6 Post-2010: Second Decade of the Twenty-First Century and Beyond

Initially, this section was informed by the authors' tentative predictions and verified by a group of new professors and PhD's ($n=10$), who identified promises and challenges as they represent the future of science education in Taiwan. Next, the preliminary trends were verified against the other respondents' comments about future promises and challenges. This process identified several promising opportunities with embedded Tai-Chi challenges—the Ying and Yang of Asian life. In summary, the respondents identified future promises and challenges as: (1) people and leadership; (2) teacher education that includes demographic changes, teacher demand, university reorganization, and professional practice; (3) NSC, MOE, and policy changes; and (4) educational goals, curriculum, and instruction.

1. As in the past and present, the future of Taiwan's science education depends on its people and leadership.

Taiwan has a group of young-generation science educators who have great enthusiasm and potential for research that can solve the science education problems currently facing the country. A respondent stated, "Thanks for the past 20–30 years of preparing science educators, we do have enough researchers who are doing valuable science education research. …The number of high quality research papers has increased significantly in recent years, and more researchers have started to organize international conferences and assume leadership roles in international research organizations. Taiwan's government has encouraged academics and international experts to network and to enhance our academic status and promote the importance of science education research." Respondents recognized that visibility of and opportunities for international cooperation in science education have increased and the market has become bigger because of the rise of Mainland China. A multivoice science education system is becoming possible.

Current leadership in science education in Taiwan is healthy, with a number of mid-career men and women holding leadership roles as university vice presidents, deans, department chairs, and directors, and executive members of international associations. One female role model is Ying-Shao Hsu, PhD (Iowa State University, 1985), whose specializations are curriculum and instructional technology. Her BS and MA degrees from the NTU were in earth and atmospheric sciences. Dr. Hsu is Research Chair Professor, Chair of the Graduate Institute for Science Education, and the NSC Outstanding Researcher (2013). Her research interests include metacognition, self-regulated learning, technology-infused learning, scientific inquiry, assessment, and teacher education. She actively participates in local, national, and international research associations and publishes in international journals devoted to educational psychology, general research, and science education.

However, many, if not most, of the current and recognized leaders are within 15–20 years of retirement. It is unclear which of the younger science educators are willing to assume future leadership roles. Therefore, it is necessary for the current leaders to identify and nurture potential future leaders by ensuring that they are given internship or apprenticeship opportunities to co-chair committees, serve on personnel appointment, reappointment, tenure and promotion committees, and receive leadership experience like attending university management courses/workshops that are provided by international university and academic associations. These efforts and opportunities involve financial and energy investments, but they are predicted to pay off in the same way as has the international graduate fellowships from NSC.

The leadership role of the DSE for the science education research community may change as a result of the upcoming formation and restructuring of the departments of International Cooperation and Science Education to take place soon (likely Fall 2014). The reorganization of the NSC into the Ministry of Science and Technology (March 3, 2014) may jeopardize the financial resources and intergovernmental communications for science education, because the DSE will be merged with the Department of International Cooperation as one division containing both agencies. Some of these concerns have been abated by the appointment of the current director of Science Education, who also serves as interim supervisor of International Cooperation.

2. Teacher education, demographic change, teacher demand, university reorganization, and professional practice

Taiwan has a history of establishing effective science teacher education programs and adjusting teacher supply to meet the demand. This was accomplished by recruiting scientists and engineers to become science teachers and by expanding program intakes to increase the number of certified science teachers when needed. The future brings a different phase to teacher education, due to the decrease in school-age population and the increase in the number of teacher education programs at national comprehensive and private universities.

Furthermore, the MOE's change in retirement provision is causing teachers to work longer. In the 1990s, elementary and junior high school teachers were able to retire at the age of 50. Now the government uses a combination of age and years of teaching experience to meet a target number of 85. A teacher with 30 years of teaching experience can retire at age 55, for example, as can a teacher who has 25 years of experience and reaches age 60.

This change in the retirement provision, along with the decrease in school-age children, has reduced the openings for new teachers in the K-12 school system. These factors have influenced the downward trend in teacher demand within an environment of increased production. A respondent stated, "There are fewer chances provided for qualified science teachers to enter into elementary or secondary schools. It is because too many reserved teachers (jobless qualified teachers) exist in our society, and fewer students want to be a (science) teacher. Plus, most in-service science teachers have gotten their master's or PhD degrees, so many graduate institutes of science education have the problem of recruiting new students. Some of these institutes may be closed in the near future resulting in the reduction of faculty positions and research in science education."

Taiwan's science education thus needs to reduce the number of teachers it produces as well as increase the quality of these teachers in areas of continuing demand: the elementary and middle schools, and some areas of high school programs—general science, physics, chemistry, technology, and mathematics. A respondent pointed out, "In Taiwan, many teachers of science in elementary schools did not graduate with science-related majors. This may reduce the quality of elementary school science education." Another respondent stated, "Improvement in the selection and preparation of qualified science teachers at the elementary school level is desirable." Still another respondent stated that the downsizing of the teacher education programs might lead to "the closing down of many science education departments in the university." From these comments, one direction forward may be to ensure that all elementary teachers who teach science have appropriate science background or hold a science degree.

The reorganization of universities, science education departments, and their priorities have led to science teacher education programs that are in some cases more theoretical and in other cases more traditional; in both cases, these science teacher education programs have not fully considered contemporary schools and diverse classrooms and education, learning and teaching beyond the traditional "brick and mortar buildings" called schools. Several respondents mentioned that teacher education programs needed to reestablish the anchoring foundations in clinical practice, where faculty members collaborate with classroom teachers to provide evidence-based practice and supervision in science teaching. Science education departments and programs need to expand their horizons to consider the public awareness of science, informal learning environments, ecotourism, and indigenous and rural communities. Such expansionary programs will allow the expertise now in science education to be repurposed and retained, thereby maintaining the critical mass of faculty members needed to have a vibrant research community and graduate studies environment. Parallel efforts should be given to establish national supply and demand studies for science teachers and evidence-based professional standards for science teacher education and practice.

3. The NSC, MOE, and pending changes: Influences on teacher education and research

The NSC and the MOE are considering policy and procedures to facilitate moves toward more-articulated science education research and teacher education programs. The goal is to promote the aspirations/blue skies visions outlined in the *White Paper on Science Education*. One former director of the DSE stated, "The NSC is trying to establish a mechanism to transform research into practice, with a hope that research could say something to the improvement of classroom practice (science learning)." Several respondents reported that university authorities are more demanding of faculty members' academic performance. High academic engagement and publication in indexed international journals about topics that are not directly applicable to classrooms have reduced the emphasis placed on teacher education and professional development. These respondents believe that the emphasis of the university tenure and reward system is on quantity, rather than quality and on theory building rather than practical applications. A respondent stated, "Collaborative interdisciplinary research about cognitive mechanisms with neuroscience methods and techniques were needed to reveal insights into how people learn science." A promising young scholar believed that "there is interest in and willingness of classroom teachers to participate in collaborative research, but the pressure to publish is discouraging long-term classroom-based research." Another respondent cautioned, "Many researchers of science education make efforts to produce wonderful articles, but few of them go into the real science classrooms or schools to understand the realistic difficulties and help teachers to co-improve science teaching." The cooperation of scientists and science educators has produced some exciting projects, such as, "Nanotechnology into K-12 Curriculum." Interdisciplinary studies, collaboration between scientists and science educators, between researchers and schoolteachers, and international collaborations in research and curriculum developments were all viewed as promising efforts to address knowledge building and classroom applications.

Several respondents pointed out that "the science education policymakers of Taiwan seem to know we are leading in science education, both research and practice, with both local and international perspectives. However, many government members and staff officers are ill equipped as science education policymakers. Research and development outcomes from science education could help decision-makers in policy amendments or build up new laws for education." Science education researchers must start conducting policy research and reporting their research results in a writing style and distribution mode favorable to politicians and bureaucrats—Executive summaries, blogs, websites, etc. Such a concern about knowledge transfer and utilization is not unique to Taiwan but has been raised a critical issue in the continued growth of science education in many western countries (Fensham 2009).

4. Science education goals, curriculum, and instruction

The *White Paper for Science Education* represented a change in top-down government policy practice and identified science education and science literacy as national priorities. This document envisioned an agenda for the future (2023–2033), but the details, which remain undefined, will need further consideration before implementing the ideas contained. One respondent pointed out the tension between a vision statement and a reform roadmap, “There is a vital and active network of science educators, researchers, and teachers, [but] the goals and prospects of science education in [the *White Paper* for] Taiwan may be vague to some extent.” Another respondent believed that “there is no actual evidence that this new system [outlined in the *White Paper*] will be better than the previous one. Until now, many details remain unclear. How does the new system promote student’s learning interest? How will it measure student’s performance? We still are looking for the government to reveal a more detailed plan.” “Still others ...” is the start of a new paragraph because it introduces a new grouping of topics that are discussed. The 2nd sentence should NOT also start with “still other” -- the original text (provided in next Comment) should be inserted for this section.

Still others suggested that the *White Paper* needs to be translated into curriculum standards, teaching materials, classroom and assessment practices and the people need to determine if they are willing to change and trust the change agents—teachers. One respondent stated, “People [in Taiwan] lack self-esteem and trust. The parents do not trust teachers. The government does not trust teachers, either. This keeps teachers away from improving, staying where they are comfortable and safe.” Another stated, “Teachers need approval from parents to try innovations and parents are usually reluctant to let teachers use new materials and teaching methods unless they improve their children’s performances on assessments. New policies in education are politically oriented and not research based. The formulation of policies does not consider important cultural and social factors in Taiwan.”

It is difficult to keep the balance between examination-driven learning and student motivation in Asian countries. Like in many other countries such as Australia, Malaysia, Singapore, and South Korea with external examinations, teachers struggle with what to teach during the limited class time, and they normally choose to spend time on the concepts that are frequently covered in the entrance or final examinations. One respondent pointed out that, “Since compulsory education is going to be extended to 12 years in very near future [and high school entrance examinations are eliminated], it is probably a good time for science educators to examine and adjust the science curriculum, for making it more coherent, not only within one subject content but also among [all sciences and other disciplines].” However, such a goal will have implications for the kind of science teacher education programs that are offered.

A respondent stated the 2006 and 2015 PISA results that emphasized science literacy should be used to inform new science curricula that will “cultivate students’ inquiry competency, problem solving ability, and science creativity and [new curricula] should focus on relevant life issues and values, attitudes not just content, and that implementation of teaching and assessment practices that will be compatible with these new goals." Science education in Taiwan needs to provide current and future citizens with the fundamental science literacy and knowledge to critically engage in the public debate about pressing science, technology, society, and environment issues and solve these issues collaboratively. They should have the critical ability to judge, argue or select from among the information sources and various modalities.

Modern science teaching de-emphasizes the memorization of content knowledge and uses the instructional time and effort to promote students' positive identity, values and attitudes, critical thinking, creativity, and learn how to build interpersonal relationships and respect for others. The results from some international assessments have indicated that students from Taiwan demonstrated high knowledge but less positive attitudes, identities, and inquiry abilities, which might reflect the focus of national and local assessments on knowledge outcomes. Therefore, effort must be exerted to align examinations with the new goals and teaching emphases. Furthermore, advances in e-learning, technology-enhanced classrooms, and web-based learning environments have received attention in the last decade. One respondent stated, "The blind pursuit of educational technologies in classrooms without in-depth discussions of the educational effects of these technologies and effective uses has not served teachers and students well." The digitalized classroom has great potential in addressing the public understanding of science and technology, which is a goal of the *White Paper for Science Education*. Another respondent pointed out that this will require "(1) Understanding *net generation* students' learning behavior, (2) knowing how to facilitate *hypermedia* learning, (3) being able to apply *digital devices* for more interactive learning, and (4) understanding *social networking, screen language*, *net safety,* and *net etiquette*".

Although still in the beginning, the culture, language, and local context in Taiwan are being paid closer attention. There have been some attempts to explore and implement multicultural science education with special funding from the NSC for research and development projects involving indigenous people and their knowledge about nature and naturally occurring events. Unfortunately, only a few researchers have been working in culturally responsive instruction and border-crossing between traditional indigenous knowledge and western modern science areas; to date, there is only a limited amount of indigenous science education research (see for example, Chang et al. 2010; Guo et al. 2008; Kao 2007; Lee et al. 2012).

## 21.7 Closing Remarks

Science education in Taiwan has enjoyed and will likely continue to enjoy successes and face new and interesting challenges over the foreseeable future. Science education researchers have made huge gains in the field in the last 20 years—making many contributions through publications in the most highly ranked journals, hosting conferences, and participating in international organizations. Science education researchers around the world may be interested in this history of one nation's development of its research culture. With the historical context this book provides, international readers can gain a deeper understanding of the challenges that educators have faced and what may be in store for them in the future. Most importantly, the details of the experience in Taiwan can provide insights for emerging countries as they seek to build a productive science education community in their own setting. Taiwan's success has not occurred by chance. It is the result of determined participants, much effort, financial investment, and effective leadership.

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# Chapter 22
# Reflections from International Scholars

**Derek Cheung, Norm Lederman, Marcia C. Linn, Vincent N. Lunetta, Masakata Ogawa, Onno De Jong, Jari Lavonen, Stella Vosniadou, Lei Wang, Robert E. Yager and Dana L. Zeidler**

**Abstract** This chapter is to present some reflections from international scholars who have been visiting Taiwan for the past few years. These scholars would like to share their insightful feedback of their interactions with scholars, teachers, and students during their stay in Taiwan.

## 22.1 Scholars Note 1

Derek Cheung

I feel very lucky to have visited Taiwan many times when attending conferences. I have been to lovely places such as Taipei, Kaohsiung, Pingtung, and Changhua. The number of science education researchers in Taiwan is much more than that in Hong Kong. They have impressed me as motivated, diligent, and friendly professionals who have a genuine desire to improve science education, particularly the teaching and learning of different science disciplines in schools. Like Hong Kong, Taiwan is facing

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a lot of challenges in the field of science, and Taiwanese researchers are always happy to share their valuable experiences. Because many science education researchers in Taiwan pursued their doctoral degrees in overseas countries such as the USA and the UK, they are very good at providing an international perspective when analyzing different issues surrounding science education. I am hoping that I would have more opportunities to conduct collaborative research projects with Taiwanese researchers in the near future.

## 22.2 Scholars Note 2

Norm Lederman

My first visit to Taiwan was in 1993. I lived there for 6 months while doing a sabbatical sponsored by my former PhD student, and eventually a distinguished University President, Huey-Por Chang. Since 1993, I have visited Taiwan over 50 times. I have worked closely with faculty from various universities on research projects and professional development activities. In addition, I have worked extensively with elementary, middle, and high school teachers as well as middle and high school students. During my sabbatical at National Changhua University of Education, I had a very rewarding experience working with Huey-Por Chang (resulting in two publications),

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Chorng-Jee Guo, Kuo-Hua Wang, Hsiao-Lin Tuan, and Ching-Kuch Chang. I mention these individuals by name because they welcomed me as a colleague and played a significant role in my development as a science educator. Chinag-Yang Chou and Hou-Lin Chiu from National Kaohsuing Normal University were also important colleagues and I have continued to work with all of these individuals, in one way or another, for the past 20 years. I have always been very impressed by my Taiwan colleagues' knowledge of science education, pursuit of new knowledge, and their never ending thirst to improve the quality of science teaching and learning. The science teachers in Taiwan are equally dedicated. It is not at all unusual to have 100 or more teachers participate in professional development activities offered on Saturdays and Sundays. I am not being critical of the teachers I have worked with in the US, but it would be quite unusual to experience such participation in my home country. This is simply a testament to the dedication of Taiwanese science teachers and the value they place on education. Finally, over the years, I have been privileged to teach science to middle and high school students from Yuan-Lin Middle School and Mingdao High School (among other schools) during cultural exchanges in the US and Taiwan. It is not unusual for Taiwanese students to attend school on Saturday and spend each evening in review classes. However, I will never forget the day I was teaching 40 high school students at Changhua High School. It was about 40 °C and the classroom was not air-conditioned. The students were totally engaged for a total of 8 h, and this was not because I am such a great teacher. Rather, these students were so interested in learning that they did not want to miss any opportunity to learn.

My experiences with Taiwanese students, teachers, and university faculty members have changed my life significantly; both professionally and personally. My appreciation of the concerns and challenges facing science educators globally has been enhanced in ways that words can not describe. Of course, my time in Taiwan has not been all work, but space does not permit any discussion of the wonderful Taiwanese food.

## 22.3 Scholars Note 3

Marcia C. Linn

During my visit to Taiwan, I had the opportunity to meet with Taiwanese scholars from National Taiwan Normal University, the Graduate Institute of Network Learning Technology at National Central University, National Chiao Tung University, and National Kaohsiung Normal University. I learned about numerous exciting research and design projects. First, I was thrilled to see that Taiwan has established an instance of the Web-based Inquiry Science Environment (WISE) and added features to make it effective in local schools. Research exploring the nature of inquiry instruction in Taiwanese schools that adopt WISE is starting to reveal promising outcomes. Scholars in Taiwan are leading the way in the region by conducting research on student learning in regular classrooms.

Second, I enjoyed hearing about advances in technology. One project that shows great promise uses the built-in sensors in a tablet computer to create challenges and games for physical science.

Third, I was impressed with efforts to study social networking solutions and varied input mechanisms including multi-touch technologies. These studies are being disseminated at local, national, and international meetings.

Finally, I enjoyed initiating connections with the vibrant and stimulating groups in Taiwan. The hospitality of my hosts was exceptional. My visit to Mukumugi Gorge and Taroko National Park were fabulous. I expect this visit will lead to many fruitful interactions in the future.

## 22.4 Scholars Note 4

Vincent N. Lunetta

Intermittently from 1981 to 2004 I visited several primary and secondary schools and universities in Taiwan and worked with students, educators, and policy makers on scholarship and teaching projects relevant to Science, Technology, Engineering, and Mathematics (STEM) education. In the process, I observed many competent and energetic STEM teachers and scholars in Taiwan who were highly dedicated to improving the quality and productivity of STEM education as well as their own understanding of goals and strategies for promoting more successful learning in Taiwan.

The past 50 years have been characterized by rapidly advancing scientific knowledge, technologies, communication networks, and globalization. Globalization has had a powerful influence on politics, on the lives of people, and on the goals and nature of education in Taiwan and in many other nations throughout the world. New social science research methodologies and technologies have supported growth in our understanding of learners' cognition in science and mathematics. These new methodologies offer new opportunities to study the nature of teaching and learning experiences that can enhance STEM understanding and the goals we set for STEM learning. These developments have led to reform efforts in STEM education in Taiwan as well as in many other countries during the past 50 years. Taiwan has properly embarked on its own efforts to enhance STEM education relevant to its unique needs, opportunities, resources, and cultural contexts. One of the visible products of these efforts has been the participation and excellent performance of Taiwanese students in international STEM comparative studies, for example, the International Mathematics and Science Study (TIMSS). Other visible products include the development of contemporary goals for STEM learning in Taiwan and the concurrent development of STEM curricula and resources for Taiwanese learners and their teachers. The growing number of Taiwanese educators who have now received advanced academic preparation in STEM education scholarship, and the large number of Taiwanese STEM educators who now publish in international journals, participate actively in international meetings, and collaborate with international colleagues on STEM projects represent impressive accomplishments. National Science Council (NSC) support for the *International Journal of Science and Mathematics Education* and its associated editorial support for authors has been one of the several actions contributing to expanded, meaningful international engagements. Although evidence of progress is visible, it is important to gather objective data to examine the nature of what has occurred and what is underway. This data is part of the information needed to inform decision-making associated with how best to achieve important goals for STEM learners and their teachers in the months and years ahead. What are the most important foci for improving excellence in STEM learning in Taiwan today? What steps and actions are needed next?

## 22.5 Scholars Note 5

Masakata Ogawa

From the viewpoint of a Japanese science educator with experiences of more than 30 years' collaboration with Taiwanese science educators, one of the most impressive environments surrounding science education research is the existence of the Ministry of Science and Technology (formally known as National Science Council), in general, and its Department of Science Education, in particular, as a powerful funding agency. Especially, the Department of Science Education is set as an independent department, parallel with four other departments (Departments of Natural Sciences, Engineering and Applied Sciences, Life Sciences, and Humanities and Social Sciences). Furthermore, it has been directed and managed by science education researchers themselves. Recent great achievements of Taiwanese science education research in various aspects are, without any doubt, the fruit of rich funding programs of the NSC. In Japan, on the other hand, funding schemes for science education research have not been given such significance. They are allocated under the umbrella of Humanity and Social Sciences or Interdisciplinary Areas, not that of Sciences and/or R&D. It is this powerful funding scheme that may be one of the reasons why such huge differences between Taiwan and Japan, in terms of academic performance in international standards, may be visible. Honestly speaking, I have been envying Taiwanese science education researchers this funding scheme. The national government's decision on intensive investment to science education research about 30 years ago is now rewarded, indeed.

## 22.6 Scholars Note 6

Onno De Jong

My impressions are mainly based on several interesting visits to Taiwan. It was a real pleasure to have inspiring meetings with researchers, teacher educators, and (student-) teachers, and to visit secondary schools for observing science lessons. I was often impressed by the real interest and the eagerness to learn that I encountered.

Regarding the practice of science education, I observed that Taiwanese teachers, in general, are professionals and prepared for their job. Nevertheless, it seems to me that the relation between Taiwanese teachers and their students is quite hierarchical and the oral communication between them is not very intensive. For that reason, I wonder whether this situation stimulates teachers, in general, to listen to students' authentic reasoning and to support students to become co-owners of their learning.

Regarding research in science education, it is my impression that there is a growing interest in relating design research approaches, especially qualitative studies, to curriculum innovation projects and inservice teacher courses. In my opinion, this is a promising development. I hope that Taiwanese science education leaders will pay more attention to curriculum reform that is based on a bottom up approach for involving science teachers as co-owners of important innovations.

## 22.7 Scholars Note 7

Jari Lavonen

I have been honoured to collaborate and engage in research in science and teacher education with science education researchers from Taiwan. My first contact with Taiwanese researchers was the Finnish—Taiwan workshop on science education research in Helsinki in September 2007. During the workshop, Finnish and Taiwanese researchers presented their research projects. The Taiwanese delegation was directed by Professor Mei-Hung Chiu from National Taiwan Normal University. In addition to her presentation, we became familiar with the research projects of Professor Chin-Cheng Chou from Hungkuang University, Tzu-Hua Wang from the National Hsinchu University of Education, Huei Lee from National Hualien University of Education, and Shu-Nu Chang from Aletheia University. Thereafter, we organized workshops, for example, related to ESERA conferences and with the other visits, like the visit of Professor Mei-Hung Chiu and Professor Jing-Wen Lin to Turku, Finland in August 2008. I have been able to visit Taiwan Normal University at Taipei twice, in 2009 and in 2013, and National Taichung University at Taichung in 2011, and have given science education research related talks in the conferences. The first conference in 2009 was organized by Professor Mei-Hung Chiu and focused on science education research in Europe. This conference and other activities that I have participated in with Taiwanese researchers have demonstrated to me that they are willing to orient to European science education research and research collaboration, in addition to their partnerships in Asia, Australia, and North America. I am sure this geographically broad orientation offers possibilities to become familiar with current top research in all continents and thereby support the establishment of novel research and ask high quality research questions. Another observation I have made is the organization of research and PhD education in well-organized research groups. This makes it possible to create long term and high quality research projects like Taiwanese research projects in conceptual change research. Moreover, an important outcome of well organized research projects are the research papers in high quality international journals. My third observation in Taiwanese research is the creative use of technology in research and education, and versatile research on the use of technology in education. For example, Taiwanese researchers have developed research tools for textbook analysis and data collection and the use of mobile phones as clickers. I am very happy that the Taiwan researchers are summarizing their research projects and outcomes in the scholar book, *Science Education Research and Practices in Taiwan: Challenges and Opportunities*, in order to allow researchers around the world to become familiar with the high quality science education research in Taiwan. I wish fruitful research for Taiwanese colleagues in the future.

## 22.8 Scholars Note 8

Stella Vosniadou

In June 2001, I was invited by Professor Mei-Hung Chiu, who was then director of the Graduate Institute of Science Education at the National Taiwan Normal University, to give a series of lectures at the International Symposium on Cognitive Science and Science Education. I still have vivid memories from that visit which impressed me both for its intellectual climate and for its friendly and hospitable social atmosphere. It was a meeting devoted to the study of how people think, how thinking develops, how it can be cultivated, and of course about learning science. The students were intelligent, knowledgeable, and extremely motivated to learn. The questions followed one after the other without stopping, and it was a challenge to keep up! Professor Mei-Hung Chiu should be congratulated for nurturing such enthusiastic students, for her indefatigable efforts to promote science learning in Taiwan, for her research record, and now for her new book "Science Education in Taiwan: Challenges and Opportunities".

## 22.9 Scholars Note 9

Lei Wang

I came across Professor Chiu's work on personal conception when I first entered the field of educational psychology in science education in the late 1980s. It was also through Prof. Chiu's work that I came into contact with Chi's personal conception theory. In fact, Prof. Chiu's works interested me so much that I started to research Chinese middle and high school students' personal conception, personal conceptual change, and the later theories and practices of core concepts instigated student epistemological development in the field of the learning of chemical conceptions. In recent years, Prof. Chiu and her team have made great strides and revealed exceptional findings in regional investigations of personal conceptions, systematic theories of personal conceptions, mental models, models and modeling, and assessments. These findings have had a great impact on the world, especially in the Chinese mainland. As such, over the years, Prof. Chiu has been invited to give lectures in the Chinese mainland in universities such as Beijing Normal University, Guangxi Normal University, and East China Normal University and has been very well-received by both Chinese science education researchers and secondary school teachers. Furthermore, Prof. Chiu has also made great contributions in the promotion of international research in chemistry education.

The field of science education in Taiwan district has attained remarkable achievements that were noted globally after almost 20 years of persistence and hard work. A large number of dedicated science education researchers in Taiwan district, such as Professor Mei-Hung Chiu herself, and Doctors H. L. Tuan, C. C. Chin, C. J. Lien, and J. F. Hung, also emerged. Their works on areas such as pedagogical content knowledge, scientific inquiry, problem solving, scientific reasoning, and scientific argumentation were all important contributions in their respective fields. Consequently, there is much that we can borrow and learn from our Taiwanese counterparts: First is to have an effective science educational research management and assessment mechanism; second, to pay special attention to experimental research paradigms and methods; and lastly, to continuously and actively participate in international exchanges and cooperation.

In conclusion, we sincerely wish that our colleagues of Taiwan district will make even bigger and greater discoveries in science education research in the future and hope cross-strait exchanges in science education will continue and prosper.

## 22.10 Scholars Note 10

Robert E. Yager

Too often science is defined as information included in textbooks. Many teachers now offer great alternatives that add student choices of information to use for improving the curriculum. These indicate that their successes are not merely information given to students to remember! Many new science teachers (in Taiwan and around the world!) have started science study with problems. In so doing, they have become leaders in advocating tests and learner experiences that illustrate the actual “Doing” of science. This means the study of science must start with questions and attempts to answer/solve them. Many teachers continue to study reforms and then share their ideas with each other. This is a major goal of this book!

The science education reforms were conceived as Science-Technology-Society (STS). Many science educators in Taiwan were glad to endorse the changes that were included as STS sought to eliminate physics, chemistry, biology, and earth science as separate disciplines. A major change was a focus on the human-made world (technology). Many were quick to add engineering, but it was particularly hard to include “society” and its worldview focus. Societal problems were not endorsed by many as important reform efforts. Taiwan teachers have continued to lead the *New* reform effort called Science, Technology, Engineering, and Mathematics (STEM).

Scientists are generally portrayed as exploring the world around them and being encouraged to explain the objects and events encountered while exploring. Teachers embrace such ideas that also focus on collaborations with others which are based on personal experiences of students. Such science teachers are anxious to share their successes and failures with science classes. This means that students can realize personally the power of collaboration with others (teachers *and* students)!

Taiwanese teachers have organized workshops for other teachers—some have been designed to illustrate their teaching performances and their willingness to have it shared with others. All of these actions indicate a consideration of the nature of science that is more than merely remembering important science concepts and use of science "Standards". The reforms emphasize the application of concepts and process skills in new situations. Taiwanese science teachers with whom I have worked often continued as learners and provided examples of "Doing" science. Many continue to illustrate the power of colleagues as they continue to grow and experience the power of change while also providing examples for students! Some have continued their learning with me (for which I am grateful)!

## 22.11 Scholars Note 11

Dana L. Zeidler

In my international travels, I was fortunate to receive invitations to give keynote addresses and symposiums in 2007 and 2008 in Taiwan. Other than training for karate in Okinawa, I had never been to an Asian country and these two visits marked my first academic experience in Asian culture. I was honored to speak at National Taichung University, Taiwan Normal University, and National Chiayi University during these visits. The topics of these presentations included socioscientific issues (SSI) and moral reasoning, the connection between SSI and scientific literacy, and the state of the art of SSI in science education research. I was most impressed with how well-received these and related topics of sociocultural aspects of science education were embraced by the audiences, and how the scholars in Taiwan balanced their desire for new ideas with carrying on very focused research programs in their universities. I was also struck by how gracious all my hosts were—scholarship was always tempered with fostering friendships and immersing me in a plethora of cultural experiences to share the rich heritage and beauty Taiwan has to offer. It was particularly refreshing to see how engaging certain university scholars were with children and teachers in the public schools. I have seen how research from many individuals I met has found its way into top-tier journals and books in science education. My Taiwanese friends have certainly enriched our field! I look forward to sharing future experiences with scholars from Taiwan.

# Chapter 23
# Epilogue: Science Education Research and Practice in Taiwan—Opportunities and Challenges

**Mei-Hung Chiu**

**Abstract** The purpose of this final chapter is to reflect on the previous chapters and offer a comprehensive summary of the challenges and opportunities awaiting science education in Taiwan and globally. It also instructs the reader on how to connect research findings (as evidence) with school practice. Recommendations for implementation of the practices outlined in this work are provided so readers can make substantive changes in their home countries.

"Philosophy of science without history of science is empty and history of science without philosophy of science is blind" (Lakatos 1978, p. 102). Building on this proverb, I would say that *theory without practice is empty and practice without theory is blind* when it comes to science education. Putting theory into practice to improve the quality of school science education and to positively influence teaching and learning in school settings are great challenges for science education researchers. However, without engaging these challenges to make a difference for students, teachers, and society, little justification for the expenditures of money and human effort can be asserted. While publishing research results has become more and more important to researchers worldwide, we also have to ask whether published research is having any impact on practice in the real world.

According to online database Web of Science, 89 % (2808 out of 3168) of the social science articles in journals, tracked by the Institute for Scientific Information in 2014, were published in English. It is well accepted by researchers across the world that English is the lingua franca for scholarly publication and for sharing professional knowledge and experience (Chiu and Duit 2011; Bencze et al. 2013). Native English-speaking colleagues have dominated in globally oriented science education organizations and in leading science education journals (Martin and Siry 2011) leaving non-English-speaking and reading science educators and the majority of the world's population disconnected from these important scholarly and evidence-based information sources. Taking Kachru's (1992, cited in Martin and Siry 2011) concentric circle model of world Englishes as an example, Taiwan is posited in the

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expanding circle that considers English a foreign language since English is not used as an official/native language or as a second language. The preponderance of English in scholarly publications and other formal outlets greatly limits participation for non-English-speaking individuals (Martin and Siry 2011). There are numerous challenges and difficulties experienced by those who do not speak English as a first language when it comes to the dissemination of research via publishing in high impact journals and presenting at international conferences. Chiu and Duit (2011) addressed the challenges faced by international scholars in terms of publishing papers in English to share their findings and track the impact of their work. They acknowledged the emerging need for science educators to collaborate with each other across the world and to consider and respect each other's cultural and societal contexts. In line with this argument, Martin and Siry (2011) claimed that developing equitable partnerships among international scholars and learning from one another in an attempt to find value in research conducted in different contexts should be advocated. The multiple lenses that emerged from various cultural approaches can frame globalization of science education and contribute to the sharing and respecting of local contexts. Furthermore, Fensham (2011) highlighted that as a global citizen one has to be informed of, and actively involved in, social scientific issues (such as energy, climate change). Although science education has been widened internationally and has generated many healthy exchanges, cultural styles of education other than Western ones are still insufficiently recognized. I could not agree more with Fensham's point about science education representing a strong cultural phenomenon and its ability to serve as a constructive and robust buffer for the more negative effects of globalization. Here is where the Taiwan stories captured in the chapters of this book may be helpful to non-English-speaking emerging countries in Africa, Asia, Europe, and South America.

Scholars are facing increasing pressure to publish in English for either career promotion or grant applications because English-medium publications are often held at a higher status than publications in other languages (Lillis 2006). Taiwan is not an exception to this trend and has shown exponential growth in terms of publishing in international English-language journals. Science education research from scholars in Taiwan has attained high visibility in the world over the past decade. A series of content analysis articles (e.g., Chang et al. 2010; Chiu et al. 2015; Lee et al. 2009; Tsai and Wen 2005; Yen and Yang 2015) revealed that publications from Taiwan significantly contributed to the areas of conceptual change, teachers' professional development, e-learning, and eye tracking, as well as other science education-related areas. Also, Taiwan ranked as one of the top ten countries in terms of publishing in several well-known international science education journals since as early as 1999 and was even ranked the third, after the USA and the UK, in 2005 and 2007. Chang et al. (2010) investigated 3039 articles from 4 of the major science education research journals (i.e., IJSE, JRST, RISE, and SE) from 1990 to 2007. They found that among the 83 countries making contributions in science education research, Taiwan was among the top ten for six out of the selected nine topics. This was compared to the USA who ranked in the top ten for nine topics and England and Australia who were in the top ten for eight topics each. Taiwan was also identified as being in the top three for publications on the topics of nature of science and socio-scientific issues. It was not easy to accomplish these achievements, especially given the language barrier faced by Taiwanese researchers.

Since science education scholars in Taiwan feel pressured to publish in English, it has become a challenge for the local *Chinese Journal of Science Education* (an official journal of the Chinese Association for Science Education in Taiwan) to attract experienced and internationally well-known local researchers to contribute to its publication and be accessible to local Chinese-speaking and reading science teachers, educators, and policy makers (also see Chiu et al. 2015). Due to the heavy teaching responsibilities and other contributions (many professors in normal and education universities have 1.5–2 times the teaching and administration loads as international research-oriented universities), limited time and energy of each researcher, it is a challenge for researchers to prepare both local and international manuscripts for publication. As a result, senior or academically productive researchers tend to publish high-quality research articles in international journals. Relatively few researchers are able to find a balance and publish both locally as well as internationally (Chiu et al. 2015;). This phenomenon in science education research may not contribute to the enhancement of schools and implementation of evidence-based practices. However, it is the intentions of this edited book (chapters and commentaries) to document the lessons learned that may be helpful in maintaining Taiwan's future science education and guide emerging countries' science education research and publications.

## 23.1 Challenges and Opportunities

The processes of educational development have been contributing to the successful achievement of economic and cultural globalization . Alternatively, stable economic and political status can facilitate educational development. Taiwan has experienced democratic processes that have allowed various scholars to influence science education, such as Physical Science Study Committee (PSSC) and Chemical Education Material Study (CHEM Study) in the United States and Nuffield in United Kingdom in 1960–70's, Science-Technology-Society (STS) in the 1970–1980's, constructivism and science for all in the late of twentieth century, and Science, Technology, Engineering, and Mathematics (STEM) in recent years. The different traditions around the world should not be primarily seen as barriers but as chances to view science education in a new light by appreciating the uniqueness of cultural differences (Fensham 2011). Good educational solutions often capitalize on local problems and constraints, turning what looks like a problem into an opportunity (Ogborn 2005). Ushering in this new century with increased diversity in theories, instruction, races, curriculum, and learning in science education has provided many challenges and continued opportunities to apply the historical knowledge attained in the twentieth century and new perspectives from other disciplines for designing research and implementing school curriculum that prepares the next generation based on mutual interests across countries.

Taiwan's high international visibility through publications and outstanding performance on TIMSS and Programme for International Student Assessment (PISA) provide a platform on which to venture suggestions for the future and the other emerging countries. An inspection of the contributions in this book illustrates that science education researchers in Taiwan have appropriately adopted and modified Western research paradigms and pedagogical and learning theories in school teaching and learning. But, most important, Taiwan developed its uniqueness and innovative research topics and methods that have impacts on some areas of science education in practice. However, what can countries learn from other cultures and what can science education researchers contribute to their society? And more importantly, what can this transformation tell about keeping the uniqueness of cultural elements and societal concerns regarding science education? I present some opportunities and challenges of science education research and practice to conclude this part of the epilogue of the book and to raise points for readers to ponder.

### *23.1.1 Challenge 1: Building Network for International Cooperation on Research*

Taiwan has demonstrated a wide range of research interests and efforts through publications in various fields of science education. Such efforts have been undertaken in order to overcome the language barrier that many non-English countries experience. Although there are increasing numbers of publications in international journals from Taiwanese scholars, limited articles represent collaborations with international scholars. Among the limited international collaborations, two cases are highlighted here to demonstrate the potential for successful experiences in collaboration with international scholars. First, a collaborative research on classroom environments was conducted in Taiwan and Australia. The outcomes of this project included development of surveys related to the learning environment, students' perceptions of teachers' knowledge, and students' perceptions of teacher–student interactions in the two countries (e.g., Aldridge et al. 1999; Tuan et al. 1997; Tuan et al. 2000). The second study involved Taiwanese scholars who developed two-tier test items to identify and diagnose students' conceptions about physics, chemistry, and biology across grades. While the international scholars served as external facilitators for the project. The outcomes of this work appeared in a special issue of the *International Journal of Science Education* (2007) in which the methodology and findings of the integrated projects involving more than 100 researchers and school teachers over 4 years of data collection were reported (e.g., Chiu 2007; Chiu et al. 2007; Kao 2007; Lee 2007). Both cases shed light on the potential for collaboration with international scholars and how such collaboration can extend the research interests and enrich the research methodology of the collaborating partners. In addition, to enrich the larger research domain, such collaboration can enhance our understanding about the nature of science education and help refine our local theories and cultural understandings of learning and teaching in science education.

### 23.1.2 Challenge 2: Assessment for Learning and Understanding

Knowledge transfer and knowledge utilization currently play a central role in science education. Asian countries share similar cultures in assessments and social expectations of academic performance—assessment of learning. What, and how, can we learn from each country in Asia? What can our experiences in science education contribute to the field of assessment of, for, and as science learning in other countries? The PISA results show that some leading Asian countries (such as Japan, Korea, and Taiwan) experienced a paradoxical phenomenon of high academic achievement but low interest and self-concept in science learning (OECD 2007b). The average across-country score on teachers praising students was also below the international average for Japan, Korea, Singapore, and Taiwan (see the Chap. 8). This is consistent with finding in Trend of International Mathematics and Science Study (TIMSS) studies. Lu and Lien (in this book) described Taiwan's relatively low performance in the domain of practicing thinking skills, in particular on the explanation activity in the TIMSS 2011 survey. Due to the richness of the databases of these large-scale studies, they provide relevant information for curriculum reform in science education. However, these studies were considered more political than pedagogical—Who placed first in the performance rankings? It is a challenge for policymakers to decide how to make good use of existing data to draft and implement policies and practices that can improve school science climate rather than rankings in the studies. There is an emerging call for quality evaluation in assessment research and evaluation of the contribution of research to educational policy and move assessment practices toward assessment for and as science learning rather than simply assessment of science learning (accountability function).

Important findings on students' conceptual change in science have been discovered in recent years, but it remains a challenge to design alternative formats for assessing and investigating patterns of understanding in science (e.g., Chiu et al. 2015; Chiu et al. 2015). In addition, the best way to translate research findings into pragmatic instructional methods has remained elusive.

### 23.1.3 Challenge 3: Evidence-Based Practices in Science Education

The current gap between theory and practice is not a new issue in science education. Taiwan is no exception. First, international studies show that our students have high academic scores but low interest in science. In addition, total between-school variance in student performance (45.8 %) is larger than the OECD average (33.0 %)

(OECD 2007a, b). How can we find the balance among academic performance, learning attitude and motivation, and instruction?

Jagger and Yore (2012) argued that many instructional strategies reported in teacher education journals did not provide evidence of their effectiveness before being recommended to teachers. Alternatively, instructional strategies based on empirical studies were not well implemented in school systems and not carefully introduced to school teachers through professional education of science teachers, professional development programs, or teacher education programs. A series of questions flow from this contextual area:

- How can we convince policymakers and school teachers to integrate findings from science education research into school practice?
- How can we develop local learning and teaching theories that are grounded in current research outcomes?
- How can we balance the contribution of science education in research and practice?

Needless to say, if the twenty-first century needs different learners and citizens, then we have to change our assessment, instruction, and curriculum standards, as well as the expectations from teachers and parents in order to provide opportunities for engagement and cultivation of creativity, curiosity, and critical thinking. Little is known about the "Next Generation" other than it is unlikely that a passive lecture and textbook environment will work.

If teacher-centered instruction has to be changed to student-centered instruction and if teaching/learning for assessment has to be changed to teaching/learning for understanding, not only do we need to enhance teachers' competence in teaching, designing, and assessing but we also need to change students' attitude from passive assessment-driven learning to active learning and learning for citizenship and career literacy. Input from research can shed light on the implementation of creative and critical curriculum in school science classes.

### *23.1.4 Challenge 4: Maintaining or Even Advancing the Momentum of Research Outcomes and Impacts*

Thomas L. Friedman of *The New York Times* (2012) commented that Taiwan has no natural resources to live off—it even has to import sand and gravel from China for construction. However, Taiwan has mined its 23 million people for their talent, energy, and intelligence—men and women. The Ministry of Education (MOE 2013) in Taiwan announced the white paper for human capacity building. Among the main points in the blueprint was enhancing students' international competition competence.

Much of the international competitiveness in the 1970–1990 likely occurred because a sizeable number of students from Taiwan studied aboard. However, according to the annual report from the MOE, the number of students going abroad to study in the USA peaked in 2006 and 2007 at around 29,000. Only 22,000 students studied in the USA in 2012 and 2013.

How do we encourage (a) undergraduate and graduate students to pursue studies on science education oversees, (b) doctoral students to go abroad to study and gain more experience and expertise on science education, and (c) postdoctoral students to open their eyes to the world but also attract them to come back to Taiwan to serve the country. Moreover, the existing research outcomes from Taiwan has been well recognized, how we can keep this momentum in publications across the world and make significant contribution to science education becomes a serious question for us to ponder.

## 23.2 Opportunities

Based upon the challenges discussed above, four opportunities can be considered.

### *23.2.1 Opportunity 1: Building Network and Initiatives for International Cooperation on Research*

Taiwan has an opportunity to bring key research initiatives together with international and multidisciplinary teams of experts to carry out research that seeks solutions/strategies for promoting science education. However, very few articles published by Taiwanese researchers involved collaborations with international scholars to extend the impact of science education across countries. Building national and international learning communities of science education to collaborate, share, and stimulate inspiring initiatives should be the direction for researchers to pursue. In a globalized world, many countries face similar problems, such as climate change, global sustainability, ecosystem change, natural disaster risk, energy, and providing quality learning experiences to prepare students for future problems (Fensham 2011). Therefore, collaboration on conducting research and implementing research outcomes might open new avenues for science educators.

We should build upon our similar cultural backgrounds and beliefs about academic performance and respect for teachers. Conversely, we should take advantage of our differences and share strategies for solving problems through different channels with specific perspectives from other countries. Specifically, various networking communities can be established for senior and junior scholars, postdoctorate, and graduate students. Due to similar educational contexts (such as high-stakes entrance examinations), finding types of not only ideal but also practical conditions for science teaching and assessment can be a research topic of mutual interest that can be used to understand the relationship between assessment and teaching.

Visiting neighboring countries to gain more experiences and to collaborate should be the focus of future work. Due to the similar educational problems we face, there are many things that we can share and conquer together.

The topics discussed in this book lend themselves to collaborative research. Raising awareness and motivation via the use of innovative technology and diverse science activities might change the school climate and move students from rote memorization to deeper exploration of natural phenomenon. Taiwan has the potential to use innovative technology to reallocate students' motivation and attention to learn science material with a more positive attitude.

### *23.2.2 Opportunity 2: Alternative Assessment to Eliminate Students' Tendency to Memorize Instead of Adopt Knowledge in Context*

As reported earlier, alternative assessment provides a new avenue to examine students' performance, such as two-tier test items format for diagnosing students' conceptions of sciences, or items in PISA to assess students' scientific competence rather than assess for memorization of factual knowledge. With these alternative formats of assessment, it can help test designers to think about how to redesign appropriate items to really assess students' scientific literacy and how two-tier test items could be used in nationwide tests to understand the underlying framework of scientific knowledge. MOE is trying to amend the educational policy/structure to create a constructive environment for alternative assessment and to move beyond accountability by promoting assessment for and as learning. This is being attempted by using items from PISA administrations to educate school teachers on developing alternative formats of assessment for expanding students' mental sets. However, the impact of this effort has not been assessed because it focuses only on teacher's education and professional development and not on application in school practice.

All these should be taken into account when we consider how to change the format of assessment. Research findings from the field can help educational practitioners to rethink the alternative possibilities for teaching and learning. Meanwhile, we also need to align the assessment, instruction (maybe with innovative technology), and standards to fulfill the educational goals in school science.

### *23.2.3 Opportunity 3: Providing Evidence-based Instructional Strategies to Enhance Teachers' Competence in Science Teaching*

While there is a considerable amount of research documenting outcomes in science teaching as well as sources of students' performance on international studies, but making the good use of these existing sources for teacher's professional development on teaching and learning seems to be a complicated issue. The economics and traditional school policies and practices appear to counter the implementation of evidence-based approaches for countries that have emerging needs for science education reform. To extend this call, evidence for developing science education policy and school practice can strengthen and support professional education of science teachers and to ensure the implementation and transformation classroom practices and empower practitioners to be able to take actions and make decisions about professional practice. Likewise, teacher's professional knowledge and experiences can also play retrospective roles in guiding science education research goals and methods to warrant particular influences of research.

### *23.2.4 Opportunity 4: Enhancing the Transitional State for Different Generations*

During the past 30 years, researchers in science education in Taiwan could be categorized into three generations. Among them, the majority of scholars received their PhD from the USA and chose to come back to Taiwan to work as scholars. In the past 20 years, they became the major research force in science education and played important roles in shaping the direction of research in science education. How do we maintain, and even increase, this level of research talent so that Taiwanese researchers can continue to contribute both nationally as well as internationally?

First, several strategies might be developed to link and expand our country's human resources in science education. First, for senior scholars, they can set up mentor systems to assist young scholars develop collaborative research and share experiences and expertise on research and publications. Second, the building of learning networks that bring in international scholars to form international projects should be encouraged because it could integrate different research theories and methodologies from different cultures. Third, identifying universal problems, clarifying emerging issues and problems, exchanging views among researchers, and putting more human-oriented elements into research should be carefully considered. Fourth, providing more channels for young scholars, such as junior professors and post-doctorate fellows, to go abroad and gain international work and research experience so they are best equipped to return to Taiwan with an understanding of the global science stage. Also, job markets in Taiwan should be available for them when they decide to return to make contribution to science education. Although there were many factors influencing science education development in Taiwan, human power has always been the main source of research effectively utilize available funding.

Finally, research in the areas of media in science education and innovative technology as research methodological tools has been under-developed. Given the current technological advancement milieu, it could be said that such research would hold much promise for the future of science education.

## 23.3 Closing Comments

Ultimately, I hope this book has opened your eyes to the impact science education research has on a local, national, and international levels. Although it was the intention to underscore the significant role Taiwan has played on the global stage, it is by no means a slight toward research from other countries. On the contrary, the lessons learned in Taiwan may serve as a template for emerging countries in science education as well as for countries who are interested in promoting science education both locally and globally. It is my hope that some of you, regardless of where you are from, will be inspired enough to follow in the footsteps of those who had pioneered into the unknown decades ago and carry on their legacy with your insights and future exploration. At last but not the least, I appreciate very much to the authors for contributing their research and reflections to make this book appealing and inspiring.

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