Mei-Hung Chiu *Editor*

Science Education Research and Practice in Asia

Challenges and Opportunities

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Chapter 1
Introduction

Science Education Research and Practice in Asia

Mei-Hung Chiu

Abstract The purpose of this book is to highlight the current status of Asian countries with regard to science research, teaching, and learning and the potential problems Asian countries face as they take their place as leaders in science education. As such, this introduction provides the background for the discussions that follow in this book. This book comprises 31 chapters separated into five sections: overview of science education in Asia, content analysis of science education research, assessment and curriculum, innovative technology in science education, and teacher professional development and informal science learning. Included in this work are six commentaries from internationally well-known science education scholars who provide in-depth analyses of the current issues facing science education research and practice.

1.1 Introduction

Asia has been experiencing spectacular economic growth over the past three decades, and important lessons can be drawn from this region (i.e., China, Hong Kong, Japan, Singapore, South Korea, and Taiwan; Lohani 2014). According to the World Bank's Knowledge Economy Index (KEI), countries that score higher on the KEI have higher levels of economic development and vice versa (World Bank 2007, as cited in Asian Development Bank 2014, p. 4). In other words, they found a positive correlation between KEI and GDP. However, as for the education and skills subindex score, Asia and the Pacific received an average score of 4.66, which is far below the average Organisation for Economic Cooperation and Development (OECD) score of 8.01 (Asian Development Bank 2014). Despite considerable progress in increasing access to education, many Asian economies still have education systems that lag behind those of more advanced nations (except Japan, Korea, and Taiwan, whose education scores were above average). A recent report

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from the Asian Development Bank claimed "Developing countries in Asia are uniquely positioned to use the knowledge-based economies (KBE) as a platform for sustainable growth and innovation in a way that may well change the global competitiveness landscape of the future" (p. 6). Therefore, KBE should be beneficial to all countries that intend to connect to, and make a difference in, the global world.

In addition, several reports on Asian economies indicated a high graduate unemployment rate (in one Asian country, over one-third of the graduating population is unemployed, and in another, research shows that over 10 % of the unemployed population are high school graduates), and 45 % of employers surveyed in Asia reported difficulty in filling positions due to a lack of suitable talent in their markets. This is compared to a global average of 34 % (e.g., Manpower Group 2012; Mourshed et al. 2012; Xinzhen 2009, as cited in Asian Development Bank 2014, p. 32). In 2015, the global average increased to 39 %, which underscores the need to identify and address the challenges teachers, researchers, and policymakers face in educating their local populations (Mourshed et al. 2012). It is not enough to prepare students for employment, but they must be prepared for "employability" (Asian Development Bank 2014, p. 32). Does science education prepare students by equipping them with the knowledge and skills required in the twenty-first-century marketplace? What are the implications of KBE for a nation's educational system?

The following sections present recent statistics showing what has already been accomplished and what challenges we may face in the future so that readers can draw their own conclusions from the chapters in this book.

First, according to the results from the Trend of International Mathematics and Science Study (TIMSS) and Programme of International Students Assessment (PISA), a number of Asian countries have outperformed on both the TIMSS and PISA over the past few decades. The TIMSS is designed to investigate science and mathematics performance by fourth (around 9–10 years old) and eighth (around 13–14 years old) graders across the world. The PISA examines scientific literacy of 15-year-old students. Although these two tests assess different competencies in science for different age groups, both attempt to compare educational outcomes in order to improve each participating country's educational achievements. As a result, for the past few decades, it is no surprise to many educational researchers, governmental agents, and policymakers that Asian countries have outperformed other nations. The major findings from these assessments include the following: (1) Asian countries outperform other countries on the TIMSS and PISA; (2) the leading Asian countries tend to have low interest in science; and (3) the leading Asian countries tend to have high-stakes entrance examinations.

The attributes of the high-stakes entrance examination system might partially explain why these countries experience high performance but low interest in science. However, countries without high-stakes entrance examinations also demonstrate top academic performance (such as Finland). As such, we cannot simply attribute the outcomes of these countries to their examination systems as there are likely other elements (e.g., teacher quality in Finland; Lavonen and Laaksonen 2009) that influence these outcomes. Additional longitudinal investigations are needed to better understand the impact of science curriculum and science education policies on science outcomes in countries with different economic and cultural characteristics.

Second, according to a report based on the data from the Survey of Adult Skills (a product of the OECD Programme for the International Assessment of Adult Competencies, PIAAC), there is a positive relationship between performance on the PISA and the corresponding age group's performance on the Survey of Adult Skills. This analysis was done specifically for mathematics and reading competence because scientific literacy was not tested until 2006. The report revealed that 15 year olds in Finland, Japan, Korea, and Sweden performed above average in 2000. Twelve years later, adults 26–28 years old in these same countries also performed above average on the Survey of Adult Skills. In other words, it is likely that countries whose 15-year-old students demonstrate high performance will be the same countries whose young adults (around 26–28 years of age) will also perform well (OECD 2013). Students near the end of their compulsory schooling who perform at high levels tend to maintain their lead after they transition from school into young adulthood. Therefore, according to the OECD (2013), "School systems need to ensure that their students perform at a high level by the time they complete compulsory schooling and that these skills are maintained and further developed thereafter" (p. 1). A related area that requires further study is the manner in which, and degree to which, individual countries are equipping their individuals with core skills *after* they leave school (OECD 2013, p. 4). Countries with compulsory education that goes beyond 15 years have more opportunities to prepare their citizens for the changing world.

Although PISA science has not been investigated by the PIAAC, we anticipate a similar result would be revealed. In recent years, it has become increasingly clear that basic reading, writing, and arithmetic are not enough. The importance of twenty-first century non-cognitive skills—broadly defined as abilities important for social interaction—is attracting growing attention and is increasingly recognized as influencing citizens' abilities to use their knowledge and skills to make a better life. So, what should we teach in and out of school during the K-12 years and even beyond so we can equip our students for the next era? How should students be assessed in order to measure their competence in school?

Finally, in addition to the international studies on student performance, the scholarly performance of science educators has also been investigated. Based upon a series of content analyses on research trends in science education from 1998–2007 (i.e., Chiu et al. 2015; Erduran and Mugaloglu 2015; Lee et al. 2009; Sozbilir et al. 2015; Tsai and Wen 2005), in addition to the English-speaking countries (such as Australia, Canada, UK, and USA), several Asian countries increasingly published in the internationally well-known journals, such as *International Journal of Science Education (IJSE)*, *Journal of Research in Science Teaching* (JRST), and *Science Education*. For instance, Taiwan was ranked 6th in 2003 and 2004 and then 5th in 2005 and 2007, and Israel was ranked 4th for 2003 and 2005, 5th in 2004 and 2006, and 7th in 2007. However, Turkey was not among the top 10 until 2006 and then was ranked 9th for the period between 2003 and 2007. Given that English is the dominant language for publishing professional research in international journals, this presents barriers and challenges for researchers whose mother tongue is not English (Bencze et al. 2012; Chiu and Duit 2011).

However, it remains a dilemma whether to publish research locally in one's native language or in English for worldwide readers. This is no doubt a situation that many non-native English speakers face when they consider publishing their research. On the one hand, the research is likely contextualized to reflect the needs of the society and educational system in which it was conducted. Therefore, the outcomes of the research should provide feedback for that specific context. On the other hand, lessons learned in one context often have implications for other contexts, both similar and divergent, and contribute to the new global knowledge base. Going forward, English is likely to remain the dominant language. As such, how do international scholars face the dilemma of where to publish throughout their professional careers? From my observations, when a junior faculty member needs to be promoted in academia, publishing articles in international journals becomes a "must do" action to take. For senior researchers, it is a channel to connect to the entire professional society. But, on the other hand, senior scholars have social and academic obligations for sharing the outcomes of their research with local science teachers, graduate students, and policymakers and also must act as mentors for younger scholars by sharing their academic products. This type of contribution of translating research outcomes into tangible benefits for the local society represents a model of sharing and mentoring with younger scholars in order to further the research agenda and improve the overall quality of research in the field.

Should the science researcher of today focus globally or locally? The answer is "glocally" (both globally and locally). In other words, one needs to be globally oriented and simultaneously contribute back to one's own society. How can Asian countries catch the global wave of science education reform and also go beyond what has been presented above? There is no simple answer for this dilemma, but paying more attention to the impact of publishing in international journals and encouraging researchers to find a balance between globalization and localization is the future of science. It is with this understanding that we have poised this book to help the reader discover new avenues for pursuing science education on a glocal scale.

1.2 Background of This Book

The Asian countries/regions presented in this book were chosen because of their geographic locations. The nations/regions included in this book are China, Hong Kong, India, Israel, Japan, South Korea, Lebanon, Macau, Malaysia, Mongolia, Oman, Russia, Singapore, Taiwan, Thailand, and Turkey.

1.3 Structure of This Book

This book includes five sections: overview of science education in Asia, content analysis of science education research, assessment and curriculum, innovative technology in science education, and teacher professional development and informal science learning. The wide range of topics covered in this book provides a thorough description of the state of science in Asia today. A short description about each chapter is presented below.

1.4 Section 1: Overview of Science Education in Asia

The first section includes two parts. The first part contains five chapters that describe the general development of science education in several Asian countries to present overviews of what have been accomplished in the field, and then one commentary chapter.

Chapter 2 concerns science education in China and was coauthored by Wang, Zhu, and her colleagues at Beijing Normal University. Their chapter touches on a wide range of topics (e.g., curriculum and textbooks, nature and history of science, students' alternative conceptions and reasoning ability, and teacher professional development) in chemistry, physics, and biology education. The authors highlight the emerging need to publish papers in international journals, discuss how science education research has rapidly grown over the past decade, and point out that science education researchers in China are actively participating at international conferences to contribute to the future of this research.

In Chap. 3, Boujaoude and El-Hage describe the history and structure of the science education system in Lebanon. They identify several challenges for science education in their country. For instance, the assessment of student achievement focuses mainly on pure academic knowledge rather than on the active use of knowledge in everyday contexts. Also, the language of instruction of science in Lebanon is a foreign language (mainly English or French rather than Arabic, which the majority of Lebanese students use), resulting in students having lower than desired knowledge and skills in science. This is not unique to the Lebanese educational system. Later, we will read Chap. 5 for Malaysia whose country share similar problems in terms of balancing dual languages (mother tongue and English) in science classrooms and daily life. More importantly, several higher order skills (e.g., information and communication skills and problem-solving skills) are not yet integrated into the science curriculum.

In Chap. 4, Wei describes science education in Macau and presents the results of an in-depth study that examined science education in the country using questionnaires, classroom observations, interviews, case studies, and document analyses. He found that the use of science textbooks was influenced by the neighboring regions, with Mainland China being the most influential. He also found that according to students, neither the regular classroom environment nor the laboratory environment was fully consistent with the tenets of constructivism. In particular, science teaching was not highly relevant, and learning was passive. Therefore, Wei comments that although student achievement in Macau is above average according to the OECD, it is not good enough, and the nation requires large-scale support in order to improve the professionalism of the country's science teachers.

In Chap. 5, Halim and Meerah depict how science and technology became a vehicle for improving the global competitiveness of Malaysia. In particular, they address the impact and usefulness of research outcomes in informing practice and science education reform. They also indicate that special emphasis was given to the acquisition of science knowledge, mastery of science and thinking skills, and acceptance of the moral obligation of being responsible for the planet. More importantly, the understanding that the country would require skilled workers in the science and technology field led to the initiation of programs related specifically to STEM education in Malaysia. However, in such a multicultural society, the students speak in their mother tongue at home but use English in learning science and mathematics, which creates a barrier to learning science knowledge in an effective way and results in unsatisfactory performance in international comparative studies (such as TIMSS).

In Chap. 6, Nookoo elaborates on science education in Mongolia since 1911 and describes how the first integrated science curriculum for primary and secondary schools was developed in 1925 and then separated in 1938 into three subjects (physics, chemistry, and geography—unlike other countries that included biology as their third scientific subject). Although the political and economic situation has changed over the past few decades, Mongolia still struggles with a shortage of experienced science teachers and limited support for conducting science education research.

In Chap. 7, Treagust and Tsui provide their comments on the five chapters that provide comprehensive and developmental reviews of science education research in those 5 countries/regions. Also, they highlight the language issues in teaching science subjects as the main theme across some chapters. As for multiple languages countries/regions, it becomes a challenge for teachers and students to switch between two languages, and such switching often becomes a detrimental factor in students' science achievement.

The second part of this section includes five chapters and takes readers on a journey to Oman, Singapore, Taiwan, and Thailand.

In Chap. 8, Al-Balushi draws our attention to the limited science education research being conducted in Oman and the limited number of science education researchers in the country. There is an emerging need to recruit more graduate students for science education research, perhaps by providing them with scholarship opportunities.

In Chap. 9, Tan and Teo illustrate the impact of the use of information, communication, and technology (ICT) on science education in Singapore. A thematic approach (e.g., diversity, cycles, systems, energy, and interactions) has been adopted in the primary science grades to present an integrated perspective on scientific ideas. As for the lower secondary science curriculum, an inquiry-centric approach, including the exploration of big ideas and important concepts from overarching themes, is the key element in science teaching and learning. Until the upper secondary and preuniversity levels, science is an elective subject aimed at equipping students with the scientific knowledge, skills, and attitudes to become confident citizens in a technological world. To ensure that the general population is scientifically literate and able to thrive in the twenty-first century, the emphasis needs to be on rapid scientific and technological advances as well as teacher development policies and practices.

In Chap. 10, Guo and Chiu provide a comprehensive review of the development of science education research sponsored by the Ministry of Science and Technology (MOST) in Taiwan. Based on the book, *Science Education Research and Practice in Asia: Challenges and Opportunities*, they pinpoint how receiving financial support for conducting research in science education was a privilege that led to the country's increased prominence in the international science community. It turns out that even though English is a second language for Taiwanese researchers, they conquered this language barrier and made Taiwan a competitive country in the science education field.

In Chap. 11, Faikhamta and Ladachart explicitly describes the influence of Western science education in Thailand. The Thai science curriculum was initially developed in an effort to decentralize the education system and to utilize a standards-based curriculum. Each school needs to develop its own school-based curriculum according to the national science standards. However, even though there were attempts to reform science education in Thailand, student performance has not significantly improved since 2008. Therefore, the Faikhamta states that although ICT and STEM are priorities, the science teacher preparation programs both for preservice and inservice teachers need to improve teachers' pedagogical content knowledge in order to improve the quality of science instruction.

In the last chapter, Lavenon summarizes the key issues about each chapter in this second part of this chapter and then helps readers to draw conclusions relevant for their local and global contexts. Lavenon draws several points from the four previous chapters for readers to ponder, such as external funding for supporting research, new research methodologies, communication and evaluation of research outcomes, collaboration among international scholars, and recruitment of doctoral students for conducting research, which can all play central roles in improving science education across the region.

1.5 Section 2: Content Analysis of Science Education Research

Content analysis in science education shows the trends and themes that have been published in professional journals and sheds light on the future direction of science research (e.g., Lee et al. 2009; Tsai and Wen 2005). This section's five chapters examine and comment on the research topics and fields published by researchers in certain countries in Asia as revealed from the content analysis methodology.

In Chap. 13, Chiu, Lin, and Chou describe their review of 365 articles on conceptual change in selected international science education journals. Seventy-eight of the 365 articles were published with Asian science education researchers either as the first author or the correspondence person. They also found that the most cited article across the world, including Asia, was Posner et al. (1982). However, the order of the next 25 most impactful articles was different for Asia compared to the rest of the world. In addition, there was no single author from Asia who was among the top 25 most impactful authors internationally, but three researchers from Taiwan were included among the top 25 most impactful authors in Asia.

In Chap. 14, Choi and Choi first briefly introduce the history of science education research in Korea, identifying a growth period from 1992 to 2003 followed by a maturity period from 2004 to 2013. They further describe their investigation of science education research in the *Journal of Science Education* published by the Korea Association for Science Education during the maturity period. They found that 23.2 % of the articles emphasized teaching, and 20.3 % of the publications emphasized learning in context, while only 6.7 % of the articles examined students' conceptions. This result was inconsistent with the Lee et al. (2009) study and suggests that international differences exist in publishing trends.

In Chap. 15, Erduran and Mugaloglu describe their analysis of research trends in Turkey in the key journals International Journal of Science Education (IJSE), Journal of Research in Science Teaching (JRST), and Science Education for the period of 1998 to 2012. From their analysis of the articles by Turkish scholars, they found that Turkey's contribution to science education research has grown dramatically during the past decade and that most of the publications were empirical research rather than theoretical pieces. To maintain the momentum of publishing articles in well-known international journals and equipping researchers with the competence to conduct research, they advocate for the importance of forming teams of science educators who encourage collaboration among senior and junior researchers, teachers, and postgraduate students in an apprenticeship model to develop respective expertise for science education.

In Chap. 16, a similar research methodology to content analysis was applied by Sozbilir, Akilli, Yasar, and Dede in Turkey. The authors investigated 1338 research articles published in peer-reviewed journals and describe the growth in the number of Turkish publications in international journals. One of the factors contributing to this outcome is the requirement that researchers publish internationally in order to obtain academic advancement. These authors found that not only were Turkish authors publishing in international journals, but they were publishing *high-quality* research papers in *respected* international journals. They encourage policies that would help researchers address educational problems by making nationwide data accessible. However, they suggest taking action against the trend of publishing research in international journals and, instead, focusing on finding solutions for needed science education reforms.

In Chap. 17, Parchmann raises several crucial issues for readers to consider in terms of the future direction and purpose of science education research. She frames her chapter by asking three reflective questions: (1) How do research emphases develop, and how do we set standards without restricting the broadness of the research field in science education? (2) How well do research communities cooperate and take each other's perspectives and findings into consideration? (3) How can policies help to develop a field of research, and how can research support the development of policies for improvements of practice? Parchmann describes how education researchers often do not get credit for their work because their publications had not appeared in international journals; this can lead researchers to lose interest in supporting their local education systems, which in turn may lead to their research findings not being used to support the development of science practice.

1.6 Section 3: Assessment and Curriculum

This section's four chapters relate to assessment and curriculum. Each chapter discusses the alignment between curriculum, instruction, and assessment that curriculum developers should take into serious consideration when designing science activities. The authors also concur that the quality of instruction should be reflected in students' assessments.

In Chap. 18, Cheung describes his investigation into secondary school students' beliefs about school-based assessment (SBA) of chemistry in Hong Kong. From his research, Cheung found that the most powerful predictor of student beliefs about SBA was the formative functions of SBA in Hong Kong. The introduction of SBA can enhance the validity of external examinations and encourage teachers to provide their students with opportunities to carry out various types of practical work to improve learning. For instance, Cheung claims that students would benefit if their teachers implemented inquiry-based laboratory experiments within regular chemistry lessons.

In Chap. 19, Fortus takes another perspective and describes how TIMSS and PISA testing influence teacher practices in Israel. He comments that despite the country's refocusing on science and technology in order to maintain and improve the level of science education in Israel, the nation's assessment system has not received enough attention from policymakers. Teaching to high-stakes tests has become the dominant force in school teaching and student learning, resulting in students being over-tested and under-motivated in science. Fortus advocates for the need for policies that direct teacher instruction and student learning in science, instead of allowing teaching to the test.

In Chap. 20, Teleshov and Zhilin introduce the long history of didactics in chemistry education in Russia and criticize the slow development of, and lack of innovative ideas for promoting, chemistry education. They pinpoint not only the need to accumulate teaching methods but also the need to improve teaching practices with evidence-based tools. More importantly, empowering science teachers with creative thinking for instruction remains a central task of science education reform.

In Chap. 21, Lederman states that assessment is mainly for measuring learning, teaching, and curriculum, while evaluation is for seeing how well science education programs meet their goals and how effectively policy is improving science education. Lederman challenges readers to ponder whether assessment has moved science education forward (like in Russia) or backward (e.g., lowering students' motivation and interest in learning science and entering technological fields).

1.7 Section 4: Innovative Technology in Science Education

The five chapters in this section discuss possible channels for the use of technology in science education. Although each chapter emphasizes a different approach for promoting science teaching and learning, the strategies provided in these chapters make good use of modern technology and try to infuse innovative technology into the curriculum for better delivery to learners. While technology has been quietly immersed into our lives, the answer for "how can we take advantage of this device for school learning and teaching" might be found in the following chapters.

In Chap. 22, Fujii and Ogawa design a chemistry lesson for sustainable development that links science, technology, society, and environment (STSE) as a new approach for students in Japan and Korea. The approach they use provides opportunities for students to view science as an integral part of their everyday lives.

In Chap. 23, Agarkar introduces an open educational resource via a Web site in the regional language (Marathi) as a means for enabling students, teachers, and parents to meet the diverse needs of school systems in India. Agarkar argues that one has to be aware that merely uploading materials on a Web site does not guarantee improvement in science education.

In Chap. 24, Chang, Hsu, and Hung describe their investigation of how students and teachers used Web-based Inquiry Science Environment (WISE) as a vehicle to develop integrated understanding of science concepts and to formulate scientific explanations in Taiwan. The authors found that the positive impact from the use of WISE allowed students to engage in scientific activities rather than teacher-centered activities.

In Chap. 25, Wang and Yang suggest the use of technology to enhance science teaching and learning in various ways. However, they also point out that although technology has greatly advanced over the past few decades, the topic of how technology influences learning continues to be debated. There is no doubt that the development of ICT creates new opportunities for school science practice. The authors propose a model with three key elements for effective learning with technology (i.e., nature of ICT, transforming, and mediation model) that allow for reflection on how to design an appropriate technology curriculum for science education.

In Chap. 26, Liu comments that although the Education for Sustainable Development (ESD) agenda has been discussed and made progress in its theories and practices in environmental education in the past few decades, ESD has not been recognized as a core vision in science education curriculum reform. Therefore, he advocates not only to help citizens construct the knowledge of ESD but also to help them take action in order to enhance the capacity of citizens to deal with science- and technology-related situations in their everyday lives for ESD. Finally, he summarizes the three previous chapters by highlighting the four interrelated dimensions for successful scale-up: depth, spread, sustainability, and shift in ownership. Each is elaborated in depth in the chapter.

1.8 Section 5: Teacher Professional Development and Informal Science Learning in Science Education

This final section with five chapters examines teacher professional development and informal science learning and includes a final chapter on the importance of science education for all. Chapters 27 and 28 discuss teacher professional development and highlight the need for high-quality science education in order to catch up with the need for globalization. Chapters 29 and 30 extend the content from formal schooling to informal science learning and broaden our view about the value of science education through lifelong learning. Chapter 31 summarizes the current state of science education in various contexts, as well as what lies ahead for the field.

In Chap. 27, Mamlok-Naaman, Katchevich, and Hofstein describe the centralized approach for science education in Israel. To advance science education and improve teacher practices and student learning, Israel introduced four models of high school science teacher professional development (i.e., leadership workshops for teachers, action research, evidence-based professional development, and teachers as curriculum developers). The authors describe each model; in particular, they highlight the importance of sharing instruction-related knowledge between experienced teachers and novice teachers as well as treating teachers as equal partners in decision making about their own profession development.

In Chap. 28, Isozaki describes the Japanese approach to science teacher professional development and relates this to the issue of globalization. The author also discusses issues of cultural context in order to help non-Western countries reflect on their research and practice in science education.

In Chap. 29, Tal discusses an avenue for science learning from schools to nature. She provides a comprehensive review on the history of out-of-school learning in Israel and comments on the shortage of students' hands-on learning experiences, which prevents students from appreciating the learning of science. To conquer this problem, the author offers a professional development program aimed at helping teachers to lead outdoor inquiry activities. The inclusion of outdoor activities can help shift the focus from teacher-centered to student-centered learning.

In Chap. 30, Dahsha and Pruekpramool explore how to make good use of community resources to promote science learning in Thailand. The authors describe how to identify and maximize one's own local cultural resources. They also describe the use of learning stations to share and discuss knowledge acquisition and completeness.

In Chap. 31, Calabrese Barton uses a story about Quentin's invisibility and marginal situation to elaborate on how to provide quality and equality in science education for disadvantaged children. This highlights the value of teacher professional development once more.

1.9 The Goals of This Book

The purpose of this book is not to provide rigid answers to the diverse questions introduced throughout. Instead, this book is intended to present the reader with the background necessary to understand the challenges that lie ahead for science education across the globe. The chapters presented here highlight science research and practice in different contexts. Furthermore, they present a variety of strategies and programs that can be adopted for different contexts and cultures in order to ensure the next generation is well equipped to be scientifically literate.

I hope this book provides explicit directions and profound reflections for readers who are interested in conducting science education research or promoting science education in practice. I also hope researchers, educators, and policymakers will take away from this book various channels for promoting scientific literacy to a variety of students in a variety of locations. Finally, I hope this book ignites people's interest in promoting science education not only locally and regionally, but also globally, and that this work contributes to making a better future for the generations to come.

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Part I
Overview of Science Education in Asia

Chapter 2
Science Education Research in Mainland China

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Abstract Since the eighth curriculum reform of basic education started in 2001 in Mainland China, many changes and innovations have occurred in science education practice and research. This chapter presented the status of science education research (SER) in Mainland China. In order to provide an overview of SER, four Chinese core journals that focused on physics education, chemistry education, biology education, and geography education, respectively, were selected to review and analysis the papers in 2011 and 2012; the results showed the affiliation of researchers and research topics. Moreover, this chapter introduces SER in Mainland China from research fields such as curriculum and textbook, science teaching, science learning, teachers' professional development, scientific inquiry, and learning progressions and students' domain-specific cognitive development. In the research fields, the representative studies in physics, chemistry, and biology education were reviewed, because the SER in Mainland China is closely integrated with separate science subjects.

2.1 Introduction

In 2001, the eighth curriculum reform of basic education commenced in Mainland China, and the Ministry of Education of the People's Republic of China issued an educational document entitled *Guideline of Curriculum Reform for Basic Education (trial)*. After that, a series of curriculum standards and policy documents which were published included integrated science curriculum standards for primary and middle schools, individual subject (physics, chemistry, biology, and geography) curriculum standards for middle and high schools, *Outline of the National Action Scheme of Scientific Literacy for All Chinese Citizens* (2006–2010–2020), *The National Mid- and Long-term Education Reform and Development Framework* (2010–2020), and

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so on. The main goals of the reform were to improve Chinese citizens' scientific literacy, build up human resources, enhance the country's capacity for independent innovation, and realize the great rejuvenation of the Chinese nation; the reform opened a new chapter of science education in Mainland China. Over the past 10 years, science education researchers in Mainland China have had fruitful achievements, paid much attention to the trend of the development of international science education, and actively participated in the conferences of international science education.

Science education of Mainland China has provided a large number of science and engineering talents for the development of China and the world. In 2011, the number of papers in the SCI database, written by researchers from Mainland China, has been ranked second in the world, next only to the USA (Research Group of China scientific and Technical Papers Statistics and Analysis 2013). In PISA 2009 and PISA 2012, students from Shanghai won the first place twice. As such, the world has been paying more attention to Chinese science education and many studies on science education by scholars from Mainland China (Wang et al. 2012d; Sun et al. 2014; Zheng et al. 2014) have been published in mainstream international journals of science education.

Currently, all of the core science education academic journals in Mainland China are single-subject journals. Consequently, the studies on science education are mainly published in journals aimed at physics education, chemistry education, biology education, or geography education, respectively. In order to provide an overview of SER in Mainland China, the study reported in this chapter selected four Chinese core journals, namely *Physics Teacher* (PT), *Chinese Journal of Chemical Education* (CJCE), *Bulletin of Biology* (BB), and *Teaching Reference of Middle School Geography* (TRMSG), based on *The Guide to Chinese Core Journals*, consulted the experts in physics, chemistry, biology, and geography education, and reviewed the papers in selected journals in 2011 and 2012 by statistical analyses and content analyses.

The data of the selected journal papers were from the *Chinese Journal Full-text Database*. It included the title, author, organization of the author, publication name, key words, abstract, and the year published. Non-research papers, such as conference notices, test questions of contest, journal bulletin, and news of science and technology, were excluded. Table 2.1 presents the number of papers published in the selected journals, indicating that about 40 physics education papers, 29 chemistry education papers, 23 biology education papers, and 26 geography education papers were published per month from 2011 to 2012.

Table 2.1 Number of papers in the selected journals in 2011 and 2012

Journal	Amount of papers		
	2011	2012	Total
PT (monthly)	490	460	950
CJCE (monthly)	359	338	697
BB (monthly)	288	263	551
TRMSG (monthly)	311	318	629

Table 2.2 Papers by different organizations in the selected journals in 2011 and 2012

Journal	Papers from different organizations			
	University/college *n* (%)	Secondary school *n* (%)	Teaching research office *n* (%)	University/college and secondary school *n* (%)
PT	128 (13.5)	689 (72.5)	47 (4.9)	44 (4.6)
CJCE	319 (45.8)	329 (47.2)	46 (6.6)	82 (11.8)
BB	262 (47.5)	241 (43.8)	33 (6.0)	65 (11.8)
TRMSG	130 (20.7)	436 (69.3)	63 (10.0)	40 (6.4)

The authors of the papers published in the selected journals in 2011 and 2012 were mainly from universities or colleges, secondary schools, and teaching research offices which are set in provincial and municipal Commissions of Education. Table 2.2 presents papers according to the authors' organizations, showing the number and percentage of papers whose authors' organizations were university/college, secondary school, teaching research office, or both university/college and secondary school. The table indicates that the number of papers from universities/colleges and secondary schools is almost equivalent in chemistry education and biology education; papers from secondary school far outnumber papers from universities/colleges in physics education and geography education; papers from teaching research offices are relatively few; cooperation between university/college and secondary school in SER should be strengthened.

The research topics are divided into eight categories based on content analyses of the 2011 and 2012 papers in the selected journals. The number and percentage of papers in each category is shown in Table 2.3: (1) *Instruction* includes instructional design, instructional theories, instructional mode, classroom instructional record, and instructional reflection; (2) *Subject Knowledge* includes subject frontier knowledge, special topic knowledge, subject knowledge in context; (3) *Test Questions* includes development, adaption, analysis, and question solutions of college entrance examinations, senior high school entrance examinations, and contest examinations and exercises; (4) *Experiment teaching* includes experiment improvement, experiment design, experiment teaching theories; (5) *Curriculum and*

Table 2.3 Research topics of papers in the selected journals in 2011 and 2012

Research topics	Journals				Rank
	PT *n* (%)	CJCE *n* (%)	BB *n* (%)	TRMSG *n* (%)	
Instruction	366 (38.5)	223 (32.0)	187 (33.9)	256 (40.1)	1
Subject knowledge	71 (7.5)	85 (12.2)	179 (32.5)	158 (25.1)	2
Test questions	296 (31.2)	24 (3.4)	27 (4.9)	126 (20.0)	3
Experiment teaching	164 (17.3)	166 (23.8)	127 (23.0)	9 (1.4)	4
Curriculum and teaching materials	21 (2.2)	61 (8.8)	11, (2.0)	34 (5.4)	5
Teacher education	16 (1.7)	52 (7.5)	4 (0.73)	32 (5.1)	6
Learning	12 (1.3)	62 (8.9)	2 (0.36)	4 (0.6)	7
Accomplishment evaluation	3 (0.32)	19 (2.7)	4 (0.73)	6 (0.95)	8

Teaching Materials includes curricula at home and abroad, curriculum resources, curriculum standards or programs, school-based courses, textbooks, and teaching materials; (6) *Teacher Education* includes professional development, training, and pedagogical content knowledge of preservice and in-service teachers; (7) *Learning* includes learning process, learning psychology, misconceptions or alternative conceptions, and learning ability of students; and (8) *Accomplishment Evaluation* includes development and application of evaluation scale and evaluation methods, and evaluation of students' accomplishment. Table 2.3 presents the number and percentage of papers published in the selected journals of 2011 and 2012 concerned in terms of the eight research topics, indicating that SER in Mainland China paid most attention to *Instruction*, followed by *Subject Knowledge*, *Test Questions*, *Experiment Teaching*, *Curriculum And Teaching Materials*, *Teacher Education*, *Learning,* and *Accomplishment Evaluation*.

In the following sections, SER in Mainland China is introduced in detail in six aspects—*curriculum and textbook*, *teaching*, *learning*, *teachers' professional development*, *scientific inquiry*, and *learning progression and students' domain-specific cognitive development*—with representative studies in physics (chemistry or biology) education, based on the review of literatures which are not limited to the journals mentioned above.

2.2 Curriculum and Textbook

Because of the eighth curriculum reform in basic education, *curriculum and textbook* became one of the hottest study fields in science education in Mainland China. The research topics included curriculum standard, curriculum philosophies and beliefs, analysis and comparison of textbooks, use of textbooks, evaluation of textbooks, and so on.

There were mainly two types of research on curriculum standards of science education: analytical and comparative, in which the main method was text analysis. The analytical studies aimed to give annotations for the contents in the curriculum standards of Mainland China and to provide references from other countries and regions to the curriculum reform in Mainland China. For example, Wang (2012b) elaborated overall exposition and concrete analysis of the basic thoughts and practical basis on the newly revised *Chemistry Curriculum Standard of Compulsory Education* which was issued by the Ministry of Education of the People's Republic of China in 2011. Curriculum standards from the following countries and regions were also analyzed: the USA, Malaysia, France, Australia, Canada, Britain, New Zealand, Singapore, Japan, Russia, Hong Kong, Macao, Taiwan, and so on.

The comparative studies on curriculum standards included the contrast between the 2011 version and the 2001 version of *Curriculum Standards of Compulsory Education*. For example, the characteristics of the new curriculum standards and inspirations for chemistry teaching in high schools were drawn (Wang and Wang 2012). Some researchers carried out a comparative study of Mainland China's and other countries'/regions' curriculum standards. This research selected nine high school chemistry curriculum standards from America, Canada, France, Finland, Japan, Britain, Korea, Australia, and Taiwan and compared them with Mainland China's high school chemistry curriculum standards. The following six key terms were extracted from the comparison: *curriculum structure*, *learning progressions of chemical key concepts*, *breadth and depth of chemistry knowledge*, *capacity requirements*, *performance standards*, and *curriculum evaluation*. And the research summarized the common and forward-looking characteristics of the international curriculum standards. Feasible suggestions to problems on issues such as the selectivity of the school chemistry curriculum, the organization of the curriculum content and the selection of specific content, and the set of learning levels in Chinese chemistry curriculum were given (Wang et al. 2013a).

Based on literature analysis, international science curriculum comparison, and the tradition of local K-12 biology education, the committee of biology curriculum teaching standards summarized the philosophies and beliefs for middle school biology curriculum: (1) biology for all students, (2) promoting biology literacy of students, and (3) to advocate inquiry-based and active learning in the classroom (Liu and Wang 2012). Apart from the three beliefs outlined above, there is an additional one for high school biology curriculum—learning biology in real-life context. All of these beliefs are the guiding principles for selecting curriculum content and developing biology learning activities.

In the studies on analysis and comparison of textbooks, researchers commonly focused on the construction of textbooks, the difficulty and coverage of textbooks, and some specific topics (e.g., experiments, theories of sciences, history of sciences, key concepts, exercises), and important ideas in science education, such as scientific literacy, STS (Science, Technology and Society), and scientific inquiry. For example, there was the overall analysis of the current high school chemistry textbooks, based on the viewpoint of cultivating students' scientific literacy (Hu and Wang 2009; Zhi and Wang 2009; Wang et al. 2010a). These studies described unique connotations and values of the textbooks in developing the students' scientific literacy and analyzed systematically the organization of the curriculum content, selection of the specific content, column setting, and teaching function. The analysis and comparison of textbooks from the following countries and regions were also conducted: the USA, Malaysia, France, Australia, Canada, Britain, New Zealand, Singapore, Japan, Russia, Hong Kong, Macao, Taiwan, and so on. For example, the analysis of the core concepts, topic contents, and charts in the textbook *Chemistry: Concepts and Applications* from the USA and its comparison with other textbooks from other countries/regions were studied. It was also compared with three versions of high school textbooks in Mainland China, which were published by People's Education Press, Shandong Science and Technology Press, and Jiangsu Education Press (Huang and Wang 2010; Yang and Wang 2010; Jiang and Li 2011). And there were also some studies on the textbook *Advanced Chemistry* from the perspectives of basic concepts, basic theories, organization of its contents, and layout characteristics (Xing et al. 2011).

On how teachers/students use textbooks, Bi and Wan (2013a) made the investigations of middle school and high school chemistry teachers with the *Questionnaire on How Teachers Use Textbooks* and the students with the *Questionnaire on How Students Use Textbooks*. The questions in both questionnaires were corresponding, so as to evaluate the consistency between the teachers and the students. At the same time, interviews and classroom observations were used to supplement the information collected about the use of the textbooks. In order to inquire about what kind of textbooks the schools need, the researchers used the methods based on the Grounded Theory to analyze the collected information. Then, a further study (Bi and Wan 2013b) found that teachers, textbooks, students, curriculum resources, and the teaching management system were the five core factors that influence how the chemistry teachers used textbooks.

There were some studies on the evaluation of textbooks. Yang and Hu (2011) used the model of the Quantitative Analysis on the Curriculum Difficulty Degree to analyze and evaluate the degree of difficulty of textbooks. Ji and Bi (2010) used fuzzy comprehensive evaluation method to evaluate the quality of chemistry textbooks. Yan and Li (2012) used evaluation systems based on nature of science (NOS) which include "explicit naive, implicit naive, mixed, implicit informed, and explicit informed levels" to analyze the presentation mode of NOS in the textbooks published by Shandong Scientific and Technology Press, and found that textbooks mainly reached the explicit level of the integration between the scientific content and NOS. The difficulty of some physics content knowledge in textbooks was analyzed, such as relativity theory (Yin et al. 2010) and quantum theory (Zhong and Guo 2010). Niu and Li (2013) evaluated the consistency of the coverage, difficulty, and distribution of content knowledge in different curriculum standards and textbooks of physics. Lu and Liu (2012a) explored the consistency between the standards-based high school biology textbooks and high school biology curriculum standards with Porter's alignment model. Yu and Zheng (2013) analyzed the structure of high school biology textbooks published by People's Education Press with interpretive structural model (ISM) and introduced a practical method for analyzing the logical structure of a textbook.

2.3 Teaching

Research on science teaching in Mainland China mainly included topics such as basic science ideas, NOS, history and philosophy of science, inquiry-based teaching, classroom teaching behavior, evaluation of teaching, experiment teaching, and various teaching strategies/models.

Bi and Lu (2011) thought that the basic chemical ideas (BCI) refer to the students' whole view of chemistry based on the deep understanding of the characteristics of chemistry, the BCI mainly include the ideas of chemical elements, particles, chemical change, chemistry experiment, classification and the values of chemistry, and so on, and BCI teaching can transform students' learning style, promote the level of understanding and application of chemical knowledge, and improve students' scientific literacy ultimately. Liang (2011a) thought that matter and its transformation are the basic questions of chemistry; therefore, the views on elements, energy, and NOS are the core chemical ideas. The effective teaching strategies of BCI included the following: teaching specific knowledge under the leadership of BCI; highlighting the thinking style of chemistry; mining the connotations of chemical knowledge; designing thought-provoking questions; and guiding students to explore, experience, and rethink (Bi and Cui 2011). Wang et al. (2008) constructed an instructional design model based on BCI and expounded how to conduct the instructional design based on BCI by using the case of "ionization balance."

The NOS-related studies included theoretical analysis and empirical investigation. For example, Zhou and Zheng (2010) discussed the basic situation of NOS education in Mainland China. Meng and Li (2011) explored the relationship between NOS and history of science (HOS) by taking the theory of ionization as an example and summarized the elements and principles of teaching with the use of chemistry history. The empirical investigations proved that the history and philosophy of science (HPS)-based teaching mode had an obvious influence in promoting the high school students' understanding of NOS (Yang et al. 2012). Yan (2009) used open-ended questionnaires, semi-structured interviews and group interviews, and structured text analysis to analyze the understanding levels and characteristics of high school students' views of NOS, and found both grade and gender had significant main effect on understanding NOS.

Inquiry-based teaching is advocated by the eighth curriculum reform in basic education in Mainland China, to change the traditional teacher-centered and lecture-based teaching approaches. As inquiry-based teaching/learning was new and challenging for most science teachers, it aroused researchers to study both theory and practice. For example, only in biology education, there were over 25,000 papers published between 2010 and 2013 when searching the key words "biology" and "inquiry" on the China National Knowledge Infrastructure (CNKI) Web site—the most influential Chinese academic database in Mainland China. All of these papers showed the research findings and practical reflections on inquiry-based teaching/learning of biology. Deng and Liu (2011) set up a school-based course *Refusing Alcohol* in a middle school in Beijing. This course was adopted from American BSCS supplementary courses and modified according to local situations. The whole course emphasized inquiry and was designed in accordance with the 5E instruction model. This empirical study indicated that the 5E model is an effective way to implement inquiry-based teaching/learning and showed a good example of applying the model. Fu and Liu (2013) developed a school-based course with resources from the network platform *Web-based Inquiry Science Environment* (WISE) established by the American organization *Technology Enhanced Learning in Science* (TELS). The entire course was also designed based on the 5E model and implemented in two middle schools in Beijing. After comparing the pretest and posttest scores of the experimental class, Fu and Liu found that students' understanding of biology concepts and ability to solve problems had improved significantly. Yang and Liu (2014) proposed a procedure of instructional design, *Starting*

Your Lesson Planning from Key Concepts Focused Questions, based on previous studies of inquiry-based learning, teaching for understanding, and "less but better." This procedure is a guide for teachers to design student-centered teaching activities based on key concepts, so as to give students the opportunities of independent thinking and help them to deeply understand concepts. Besides, argument-driven inquiry (ADI) recently becomes an emerging topic in SER in Mainland China (He and Liu 2012).

On classroom teaching behavior, since 2003, a research team led by Changlong Zheng in Northeast Normal University has begun to study the classroom structure in secondary chemistry lessons. Using classroom observation and textual analysis in more than 900 chemistry lessons, they argued that "teaching behavior" and "learning behavior" happened simultaneously in real lessons rather than being isolated from each other, and they always came out as an Instruction Behavior Pairs (IBP). Based on this standpoint, they proposed two key concepts: Instruction Behavior Pairs (IBP) and Instruction Behavior Chain (IBC) (Lou and Zheng 2010b). From a huge number of classroom observations and statistical analyses, they found there were mainly five common models of the smallest IBCs in chemistry lessons. According to the degree of students' classroom participation, the five models were defined as "Model of Teachers' Direct Lecture" (MTDL), "Model of Teachers' Self-Questioning (MTSQ)," "Model of Students' Direct Response (MSDR)," "Model of Students' Discussions and Exchange (MSDE)," and "Model of Students' Self-Directed Learning (MSSDL)" (Zheng 2013). Another notable classroom teaching behavior on which research was based was about the characteristics which can promote students' chemical domain-specific cognitive and reasoning mode development (Wang and Ren 2013). The research took into account the nature, characteristics, and requirements of the teaching which promotes students' cognitive and reasoning mode development and the current studies on the classroom behavior observations in national and international studies. It also proposed that classroom teaching behaviors were divided into seven categories: asking questions by teachers, making use of students' answers, explaining by teachers, modeling, making students' thinking explicit, answering by students, and students' activities and built a chemistry classroom teaching behavior model of promoting the development of students' epistemic mode. In the study, two typical categories of lesson cases were selected based, respectively, on "analyzing knowledge" and "promoting students' chemical domain-specific cognitive and reasoning mode development." Then, the researchers coded the videos of the selected lessons in terms of the model of the teaching which promotes students' cognitive and reasoning mode development and conducted quantitative analysis of the time and frequency of different teaching behaviors. The research showed that the most important teaching behaviors in the lessons in light of promoting students' epistemic mode development were modeling and making students' thinking explicit.

With respect to evaluation of teaching, there were two types of research. The first type was the construction of evaluation frameworks. Jiang (2013) developed an evaluation framework for the validity of inquiry-based teaching, reviewed existing study results, proposed the initial framework, then invited experts on physics education from faculties, teaching personnel from schools, senior in-service physics teachers as consultants, and revised the initial framework to be a content validity-based evaluation framework. At last, a survey was conducted on students and teachers, and the internal reliability and content validity were tested and analyzed. In the second type of research, researchers proposed performance evaluation, progression evaluation, formative evaluation, motivated evaluation, and multiple approaches to conduct these evaluations. The implementation approaches included guided worksheets, open-ended writing, progression files, concept maps, and so on. Li (2012) explored the usage of performance evaluation through analyzing physics teachers' responses to a questionnaire, designed the procedures of performance evaluation used in laboratory teaching, and took "how to measure velocity" section as an example to demonstrate how the procedures were used in specific knowledge teaching.

The studies on experiment teaching are an important part of SER in Mainland China. The focus mainly included the following: the status of experiment teaching in schools, experimental projects and contents, and the use of new experimental technologies. For example, according to the articles published in *CJCE* from 2011 to 2012, the researchers investigated the present status of chemistry experiment teaching in secondary schools (CETSS) in some particular provinces (e.g., Hubei, Tianjin) and special areas (e.g., the Western rural areas, the earthquake areas) of Mainland China with questionnaire survey and text analysis. Numerous studies showed that the present situation of CETSS does not look good, and there are a lot of problems. It is common that teachers "just explain experiments orally," "just draw experiments on the blackboard," "just show experiments on the screen," and "just ask students to recite experiments," without doing real experiment demonstrations or letting students do experiments by themselves. Studies on the experimental projects and contents are the largest part of experiment teaching study. Many experiments set in textbooks were improved or redesigned by teachers to match the needs of specific contents teaching, such as catalytic oxidation of ammonia, verify the properties of the carbon dioxide, the reaction of sodium and water, ethanol dehydration to ethylene, hydrogen combustion in chlorine gas, and so on. This type of studies reflected the teaching creativity of teachers in CETSS. On new experimental technologies used in experiments, some researchers applied handheld technology to explore conductivity changes in aluminum hydroxide preparation experiment (Li and Qian 2012), and some explored the acetic acid ionization balance with handheld technology (Cui et al. 2011). Moreover, digital information system combined with various sensors was used to present the results of experiments with brief graphs, allow visualization of the process of chemical change, and help students to understand related concepts and contents.

Various teaching models, methods, and strategies were developed because of the eighth curriculum reform in basic education in Mainland China. For example, using "physics and teaching model/method/strategy" as key words, academic publications were searched in CSSCI, graduate students' dissertation data base and *Physics Teacher Journal*. The analysis on these publications showed that the number of publications was continually increasing from 2001 to 2013. Dozens of publications on teaching models, methods, and strategies were found, such as the 5E model, modeling instruction, interactive teaching, peers' collaboration teaching, POE (Prediction, Observation, Explanation) teaching strategy, cognitive conflict-based teaching model, and scaffolding teaching model. These models/methods/strategies were developed based on the following four foundations: specific content knowledge, the orientations (e.g., problem solving, concept understanding, and experimental training) of different lessons, epistemological ideas of teaching, and different cognitive levels of students. Li and Wang (2013) used the 5E teaching model to develop teaching activities for "lever" concept in Grade 9, and the teaching procedure included five stages: inspiring students' interests, exploring, explaining, transferring, and evaluation. Constructivism and inquiry-based teaching ideas were employed mostly to develop teaching strategies/models.

2.4 Learning

This section focuses on science learning research in Mainland China, such as alternative conceptions, conceptual change, and academic achievements.

Qian and Li (2011) found that high school students had alternative conceptions in learning electrolyte solution which were attributed to: (1) students' limitations of thinking about quality; (2) interferences from related concepts; (3) influence of the factors, such as students' cognition, emotion, and motivation; and (4) the presentation of teachers' teaching and teaching materials. With the implications of the study above, two strategies for conceptual change teaching were put forward: One was to reinforce the practice and to increase students' perceptual knowledge and another was to encourage students to construct complete cognitive structure by independent inquiry. Zhang and Wang (2012) conducted a study to investigate middle school students' conceptions of acids/bases in different grades in Beijing and compared the results with those in Taiwan, so as to explore how curricula and instruction affected the conceptual development of students. Eleven secondary schools were selected in the study. The results indicated that students' conceptions of acids/bases in Beijing were different from those in Taiwan, and there were also differences in different schools in Beijing under the influence of core concept learning and the curricula. The conceptions and conceptual evolution were explained in light of students' epistemic development. Deng et al. (2011) found middle school students' different degrees of conceptual change when teachers used POE (Prediction, Observation, and Explanation) strategy and PDEODE (Prediction, Discussion, Explanation, Observation, Discussion, and Explanation) strategy in teaching "solution," compared the effects of the two strategies, and provided suggestions for teaching of conceptual changes.

Teaching beliefs, instructional materials, and teaching approaches have changed greatly in the K-12 education reform in Mainland China, which triggers corresponding reforms in the assessment of student learning achievements. So, many questions about student assessment were raised and followed up by corresponding studies, such as "whether the standardized test is aligned with national curriculum standards," "what the status of students' conceptual understanding is," and "how to develop and implement diversified ways of assessment." Lu and Liu (2012b) conducted quantitative analysis of the alignments between the national high school biology curriculum standards and the standards-based high school exit examination (HSEE) of 2009 in four provinces with Porter's alignment model. As a result, it was found that none of the four HSEEs of 2009 were significantly aligned with the national biology standards. The low alignment indexes are mainly because the four HSEEs generally require lower levels of cognitive skills than that of the standards. These results deserve universal attention of both policymakers and test developers in Mainland China. Liu and Liu (2012) investigated Grades 10–11 students' understanding of photosynthesis by designing and using a two-tier test fitting for the Rasch Model. This study showed that it was easier for students to understand factual knowledge than the conceptual knowledge. Ren and Li (2011) analyzed the consistency of item difficulty with multidimensional analysis system (MAS) and cognitive task analysis (CTA). The absolute difficulties of 30 typical test questions of ion reaction were calculated with MAS and CTA, respectively. The relationships between these two results were analyzed in detail in three aspects: the transformation dimensions, coding numbers, and MAS absolute difficulties. This study suggested that the results of the two methods were of high coherence. Chi and Wang (2010) studied the composition and characteristics of chemistry examination papers of the college entrance examinations in Mainland China, discussed the problems in compiling examination paper, and provided suggestions for reforming chemistry examinations and chemistry teaching.

Students' competence in disciplines (e.g., chemistry, physics, and biology) as a core component of academic achievements has got attention of the researchers in Mainland China. For example, Yang and Wang (2012) conducted a study on CDC, which is defined as a kind of special ability "the competence that students acquired in the learning activities of chemistry curriculum." They thought the core components of CDC as "competence in representation of symbols," "competence in experiments," "competence of model-based thinking," and "competence of quantitative thinking." This study analyzed the learning progressions of the CDC components and defined the performance and content knowledge of different levels of CDC. In light of the Rasch Model, this study designed a set of assessment instruments which could be applied in testing students' CDC on a large scale. And the results showed that there were significant differences between grades, genders, and schools in CDC.

2.5 Teachers' Professional Development

As the basic education reform is sweeping across Mainland China, teachers are facing challenges of having to constantly enhance their professional literacy to do a good job. Under these circumstances, the teachers' professional development comes into researchers' sight.

Liang (2011b) analyzed the value of pedagogical content knowledge (PCK) based on international studies. He thought that PCK has ideational and practical characteristics, affects teachers' teaching ideas and behaviors, and serves as a bridge between the two.Then, he studied the structure and construction of chemistry teachers' PCK and pointed out that chemistry teachers' PCK included chemistry knowledge based on teachers' understanding of chemistry, knowledge about students' understanding of chemistry, knowledge about the chemistry course, teaching strategies, and representation of specific chemistry themes. Zhang and Wang (2013) analyzed the conception and structure of PCK based on previous international studies of science teachers' PCK. Furthermore, they discussed two factors—teaching experiences and teacher training—that impacted on the development of teachers' PCK and provided references for effective science teacher training.

Wang et al. (2012c) investigated chemistry teacher's PCK based on specific themes of chemistry knowledge with questionnaire and found that chemistry teachers in high schools did not do well in understanding the new content of the "chemical reaction principle," whereas some older teachers did even worse and that teachers with higher education background had better PCK. They suggested that the teacher training agencies should pay more attention to explain the new knowledge in the new chemistry curriculum to help teachers acquire it as soon as possible.

Hu and Wang (2010) conducted some intervention studies on chemistry teachers' PCK. They carried out remote training with training video and online discussion for teachers based on problems of teaching elements and compounds in compulsory courses (ECCC). They also investigated teachers' understanding of content systems, teaching characteristics, teaching methods, and ideas on ECCC by a questionnaire. They found that after training, teachers' understanding of ECCC became better; however, their teaching practice on ECCC needs to be strengthened.

Some researchers investigated the differences between expert and novice chemistry teachers from several aspects, such as teaching strategies (Lou and Wang 2010a), selection and use of teaching methods (Zhang and Yang 2011), and experiment teaching behaviors (Gai et al. 2012). The methods of classroom observation, video analysis, case analysis, and interviews with teachers were adopted. These studies found a lot of differences between expert and novice chemistry teachers which were useful for novice teachers' reflection on their teaching and training of preservice teachers.

In recent years, investigations on the situation of teachers' professional development have become abundant and covered both general and specific aspects such as curriculum beliefs (Xu and Li 2011; Yang and Yang 2011). Besides, with the rapid development of the Internet, online learning has already become a new approach for teachers' professional development in Mainland China (Liu et al. 2008).

2.6 Scientific Inquiry

Scientific inquiry is emphasized in science curriculum standards in Mainland China, not only as a learning objective and content, but also as a learning style. So, scientific inquiry is a very hot topic in SER.

Studies on scientific inquiry-based teaching focused on four categories. The first category is research on the model and strategy of scientific inquiry-based teaching. The subject is experience from teaching practice summarized by school teachers in scientific inquiry-based teaching, such as four-step teaching method, collaboration and exploring learning model, and student-centered scientific inquiry teaching strategies. And some graduate students also proposed some scientific inquiry-based teaching models and strategies and conducted empirical investigations, such as a scientific inquiry-based teaching model to facilitate students' cognitive change, a worksheet-based scientific inquiry teaching strategy, and a network-based physics scientific inquiry teaching model in middle and high schools (Wang et al. 2013b). The second category is about studies on designing scientific inquiry-based teaching plans. The subject is teaching samples developed for specific curriculum content by school teachers. The third category is about studies on the function of scientific inquiry-based teaching, such as Wang's (2012a) "scientific inquiry, retrospection, and implication" teaching model to improve students' understanding of NOS. This study selected Grade 11 students in Nanjing as samples, and the results illustrated that students taught via scientific inquiry-based method understood better on "the relativity of scientific theory," but the understanding of their whole knowledge of NOS was not improved significantly. The fourth category is studies on the status quo of scientific inquiry-based teaching, which were conducted by university/college faculties and graduate students via questionnaire-based investigations and interviews, focusing on teachers' beliefs on inquiry-based teaching, teachers' teaching practice, and teaching effect and influence factors.

Studies on students' inquiry ability and evaluation are mainly conducted by university/college faculties and graduate students. Researchers investigated students' performance on different subskills used in scientific inquiry process, such as asking physics questions, analyzing data, and argumentation. As for asking physics questions, the results illustrated that there were seven factors correlated with this skill, which are as follows: students' interests in physics, contexts created by teachers, students' knowledge foundation, new knowledge, students' sense of self-respect, the atmosphere of asking questions, and the influence of authority (Bao 2006). As for the validity study of worksheets used as an evaluation tool for students' inquiry performance, the results illustrated that the raters' reliability of observation-based scale was relatively high and acceptable, while the reliabilities of the open-ended worksheets, structured worksheets, and guiding worksheets were lower than observation. As the openness degree of the worksheets decreased, the raters' reliability went up, because the requirements on worksheet were more and more explicit and consistent with students' performance, and it was easier for raters to rate (Luo 2007).

Studies on teachers' beliefs and performance on scientific inquiry are mainly conducted with questionnaire-based investigations. For example, researchers compared teaching in the USA and Mainland China by using Likert items, open-ended items, and teaching videos. The findings illustrated that teachers working in Mainland China considered scientific inquiry as using unchanged procedures to understand content knowledge, whereas American teachers paid more attention to how to create context to facilitate students' engagement in learning activities and also focused more on the process of the development of students' cognition. Meanwhile, the expected performance evaluation criteria on "how to do inquiry" in Mainland China is lower than that in the USA, whereas some expectations—such as operating with laboratory equipment, using scientific terms, and information and communications technology (ICT)—were higher than those in the USA. Teachers in Mainland China considered how to guide students to do inquiry in class and also thought that teachers should guide students to collect and analyze data, interpret phenomena, and do communications. In comparison, the US teachers focused on the development of students' asking questions, collaboration and communication, argumentation, and critical thinking, and they also paid more attention to students' problem-solving ability in exploratory processes and guiding them to give explanations. Lastly, teachers in Mainland China focused more on the safety issues of inquiry activities than did US teachers (Wang and Guo 2011). Another researcher employed qualitative and quantitative methods in a study analyzing the text of 67 teaching plans in order to gain knowledge on teachers' understandings of: (1) what inquiry-based teaching is; (2) why inquiry-based teaching is needed; and (3) how to practice inquiry-based teaching in language expression and teaching practice. The results illustrated that teachers took inquiry-based teaching as an ideal teaching model, but teachers' understanding of the overall scientific inquiry and elements involved in it was very superficial (Lu 2013). In addition, this study also found that there were nine factors mainly accounting for the development of teachers' beliefs in inquiry-based teaching, which are as follows: cases of inquiry teaching, the environment of teachers' work and living (such as job training opportunities provided for in-service teachers), teachers' study on pedagogical theory, experience of individual progression, the practice of inquiry-based teaching, the practice of inquiry, the consideration on inquiry and inquiry teaching, the consideration on students' thinking for problem-analyzing processes, and the understanding of NOS.

2.7 Learning Progressions and Students' Domain-Specific Cognitive Development

Learning progressions (LPs) , as a hot topic in international SER, also attract the interest of researchers in Mainland China.

Some researchers selected key biology concepts and constructed the concept progression map for elementary, middle school, and high school students (Zhang and Liu 2010; Li and Liu 2010). The results and conclusions of these studies were adopted by Grade 7–9 National Biology Curriculum Standards (2011 edition) with clear statements of students' understanding of each key concepts in different biology topics (Liu et al. 2012).

Tan (2010) developed an inventory, which was named "energy and life," to describe students' understanding of progressions on energy from Grades 8–12, and anchor items were designed and set in assessments for students of different grades.

Li and Liu (2012) studied LPs of scientific inquiry in K-12 science curriculum. Based on Lawson's theory of scientific reasoning patterns, researchers measured students' development of scientific reasoning ability via the instrument Classroom Test of Scientific Reasoning (CTSR) developed by Lawson for elementary school students to undergraduate students (Guo et al. 2011). The results implicated that students' progressions for scientific reasoning could be significantly observed across Grades 5–10 and were consistent with Piaget's developmental theory (Wei et al. 2011). However, for undergraduates, the progressions of scientific reasoning were not significant across the years. The underlying reason now is still vague although the researchers have discussed the potential influencing factors based on the current teaching method and content, whereas the mechanism in cognition development is also not reached, and the ceiling effect of the test was eliminated for the low mean scores of overall students' responses (Guo et al. 2011).

In 2004, Lei Wang at Beijing Normal University and her team members proposed a new notion named "chemical cognitive and reasoning mode (style) (CCRM)" for the first time. They thought that there was an interior factor which influences specific concept learning and student's cognition on specific topic and content domain. The factor is a kind of thinking mode or perspective of cognition which is used in conceptual understanding, reasoning, and problem solving. What is the cognitive and reasoning mode of a specific domain? They defined it as "the mode of cognition and reasoning which is used by students when analyzing phenomena, solving problems, and understanding ideas in a specific domain."

At present, the theoretical and practical research on CCRM has achieved certain results. They recognized that there were three components of the cognitive and reasoning mode; in other words, cognitive and reasoning mode can be illustrated by the following three cognitive variables: (1) *perspective of cognition*, that is, the special lens or viewpoints which are used by students to understand ideas, analyze phenomena, and solve problems. The perspectives of cognition are differently based on different cognitive objects and domains or different students; (2) *path of reasoning,* that is, the path and process of reasoning which are usually supported and influenced by the combination of the perspectives of cognition; (3) *patterns of cognition and reasoning* which are generally classified into macroscopic/microscopic, qualitative/quantitative, isolated/systematic, and static/dynamic categories (Wang and Xiao 2004; Wang and Yang 2006).

Wang and her research group's studies indicated that CCRM did exist in chemistry learning and had many kinds of categories and levels. It is stable, educable, and invisible (Wang and Xiao 2004). The cognitive and reasoning mode relied on a specific domain named as the cognitive domain. The cognitive domain reflects the knowledge content attribute of the cognitive and reasoning mode, for example, water solution, inorganic substance, organic substance, and chemical reaction. The level of a student's cognitive and reasoning mode is related with what kind of cognitive and reasoning tasks the student is capable of doing and what level his/her performance is. There are several categories of the cognitive and reasoning tasks and performances, such as describing, illustrating, explaining, predicting, designing, and controlling. Understanding the concept of "cognitive and reasoning mode of the specific domain" can help us to characterize the differences between students and the development in their learning. The differences among students are reflected by the amount and the level of *perspective of cognition* and *pattern of cognition and reasoning,* as well as what kind of cognitive tasks they can deal with (Wang and Yang 2006).

Lei Wang and her research group have been pushing forward the development of the theoretical framework of cognitive and reasoning mode. They thought that the learning progressions of the specific domain or topic could be described by the development of domain-specific cognitive and reasoning mode of students. And the latter could be described from the changes that took place from five aspects: (1) the perspectives of cognition, (2) the relations and combinations of different perspectives of cognition, (3) the path of reasoning, (4) the category of patterns of cognition and reasoning, and (5) the level of cognitive and reasoning performances. The development of domain-specific cognitive and reasoning mode of students was related to grade, curriculum, and content knowledge, but it is not absolute. It was decided mostly by the transformation from knowledge to cognitive and reasoning mode (Wang and Zhi 2011).

Later on, researchers conducted a series of studies of instructional design and teaching strategies which can promote students' epistemic development as well as students' cognitive and reasoning mode of core chemical knowledge. By January 2014, more than 200 lessons based on promoting students' chemical domain-specified cognitive and reasoning mode development had been conducted in 37 secondary schools under the project of "Design Based Lesson Study by University-School-Collaboration (DBLSUSC)." The case content covered most of the contents of elementary school and middle school (Wang et al. 2010b; Zhi et al. 2012; Wang et al. 2012a; Jiang et al. 2012). All of the studies achieved good teaching results.

The basic procedure of the above studies involved: (1) forming a research group, including chemistry education experts, graduate students, and high school teachers; (2) diagnosing the problems of original teaching design and classroom teaching by classroom observation, video analysis, and interviews with teachers and students; (3) discussing the problems found, reaching a consensus and redesigning teaching based on promoting students' epistemic development and designing pretest and posttest to detect the teaching effect; (4) putting the new teaching design into classroom teaching, carrying out pretest and posttest to test the teaching effect by classroom observation, video analysis, teachers' interviews, and interviews with students; (5) summarizing the effective teaching strategies and discussing the problems needed to solve in the future; and (6) studying the problems in the studies. This is an all-win process of the action research, and it solved the problem that SER is hard to be applied to teaching practice. In above process, the science education theories can be tested and developed in practice; an effective path of putting the science education theories into practice is found and will promote the secondary school teachers' understanding of the theories and improve their teaching research ability, reflection ability, and classroom control ability; and finally, these theories promote the secondary school teachers' professional development.

2.8 Concluding Remarks

Encouraged by the K-12 science education reform in Mainland China, SER has generated a large number of publications over the past 10 years, which is considered to be a golden age for the researchers. Because SER in Mainland China is closely integrated with separate science subjects, the reviews above were presented by studies in physics, chemistry, or biology education due to the length limitation of this chapter. In fact, physics, chemistry, and biology education all have had fruitful achievements in all the six aspects above. But, the internationalization of SER in Mainland China is not enough, especially in publishing studies in international journals. How to bring the native studies to overseas and how to get recognition of international peers are important tasks for the researchers in Mainland China.

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Chapter 3
Science Education Research and Practice in Lebanon: Current Status, Challenges, and Future Prospects

Saouma BouJaoude and Fadi El-Hage

Abstract Lebanon is a country that lies on the eastern shore of the Mediterranean Sea. Its location rendered it a crossroad for many civilizations—a fact that is reflected in its constitution and consequently in its educational system. The Lebanese constitution guarantees the freedom of education according to public law and regulations, which resulted in a pre-college private school education system that is diverse, energetic, and competitive and that serves almost 60 % of K–12 students in Lebanon. It is diverse in terms of the languages taught in schools, which include Arabic as the first language and English and French as the second and third languages. In addition to private schooling, Lebanon has a well-established public education system. Even though science has attracted increasing attention in the most recent educational reform, science education is still facing a variety of challenges regarding science teacher preparation, science curriculum, integration of science and technology, results of international comparisons, and the role of research in improving practice. This chapter describes and analyzes the current situation related to the aforementioned challenges and discusses future prospects in light of the Lebanese National Education Strategy 2010–2015 (http://www.opentech.me/~laes/upload/editor_upload/file/Vision%20Document%20%20English.pdf) for improving the quality of education in general and science education more specifically.

3.1 Introduction

Lebanon is a country that lies on the eastern shore of the Mediterranean Sea. Its location at the intersecting point of three continents rendered it a crossroad for many civilizations. Lebanon is about 225 km long and 50 km wide with a total area of

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around 10,452 km^2. Syria borders the country from the north and east, while Palestine is to the south. The population of Lebanon is, according to the CIA Fact Book, around 4 million.

Lebanon was in a war situation between 1975 and 1989. The Taif Accord (1989)[1] ended this war and established the principles that Lebanon is a unified and sovereign country with an Arabic identity that follows a democratic and decentralized form of governance, respects the freedom of belief and expression of its citizens, and does not discriminate among them on the basis of religion or regional origin. These ideas were codified in a new constitution, which emphasized the need for balanced and comprehensive economic and social reforms that would put the country on the path of development and prosperity. In the educational domain, the Taif Accord specified the following objectives: (1) provision of free compulsory education at least at the primary level, (2) emphasis on the freedom of education according to public law and regulations, (3) protection of private schooling and strengthening educational supervision, (4) reforming of public and vocational education, (5) strengthening of the national university, and (6) revision of curricula in order to strengthen national unity, as well as the promotion of cultural openness and uniformity of the books of history and civics.

When the war ended, Lebanon faced the challenge of building its educational system. Consequently, the country embarked on an educational reform in order to address a myriad of problems aggravated and/or caused by the war, which included national discord, outdated curricula, and a surplus of unqualified and demoralized teachers and administrators[2] (BouJaoude and Ghaith 2006). There were urgent needs to accommodate an increasing number of school age children, renovate old and destroyed school buildings and build new ones, establish a balance between formal education and vocational education, and achieve better coordination between pre-college and college education on the one hand and the job market on the other. In terms of science education, there was a need to update the curricula, teaching methods, and school laboratories among others. In the following pages, we start by describing the major components of the education system in Lebanon including the educational ladder, types of schools, teacher education, examination system, general objectives of science education, and structure of the science education program. We then identify and discuss major challenges that the science education system in Lebanon is facing, review and discuss the science education research that has taken place in the past two decades in light of the challenges, and finally discuss future prospects for science education.

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[1]http://www.al-bab.com/arab/docs/lebanon/taif.htm.

[2]http://www.mehe.gov.lb/uploads/file/ESDP%20modified%20march%202010/ESDP%20English%20FINAL%20-p%201.pdf.

3.2 Components of the Lebanese Educational System

3.2.1 Educational Ladder

Formal pre-college education in Lebanon starts from the preschool (Kindergarten) stage (ages 4–6). The basic education stage (ages 6–15) consists of the elementary stage and the intermediate stage. The elementary stage consists of two three-year cycles, whereas the intermediate stage and the secondary stage (Ages 15–18) span three years each (see Fig. 3.1). Additionally, many Lebanese schools are also equipped with nursery schools that cater to the needs of students who are younger than 4 years (BouJaoude 2002, Center for Educational Research and Development (CERD) 1994, 1995).

The Lebanese curriculum provides the common content for all students until Grade 10 (Fig. 3.1). In Grade 11, students may choose to follow the humanities stream or the science stream. Those who choose the humanities stream may either continue with the humanities and literature stream or follow the social sciences and economics stream in Grade 12. Students who choose the science stream in Grade 11 may choose the General Sciences Stream or the Life Sciences Stream in Grade 12. Each stream consists of a fixed number of courses that all students who chose the stream are required to complete. There are no elective courses within the stream. All students following the Lebanese curriculum are required to take the same science courses until Grade 10. However, the number of periods per week and the content of the course in Grades 11 and 12 vary depending on the stream in which the students enroll.

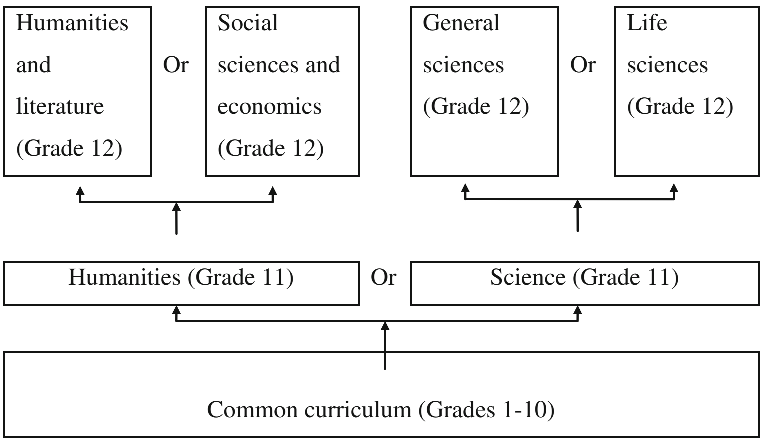

Fig. 3.1 Structure of the Lebanese educational ladder

3.2.2 Types of Schools

The fact that the constitution emphasized the freedom of education resulted in a pre-college private school education system that is vibrant and competitive and that serves almost 60 % of K–12 students in Lebanon. In addition to private schooling, there is a well-established public education system. The Lebanese education system is diverse in terms of the languages taught in schools which include Arabic as the first language and English and French as the second and third languages. Thus, we find schools that teach Arabic as the first language, French as the second language, which is the language of instruction of science and mathematics, and English as a third language and other schools that teach Arabic as the first language, English as the second language, which is also the language of instruction of science and mathematics, and French as a third Language. Presently, the Ministry of Education and Higher Education (MEHE) is the only ministry that deals with education in Lebanon and is in charge of higher education, general education, and technical and professional education.

3.2.3 Teacher Education

Private colleges and universities in Lebanon are affiliated with international and national religious, independent non-profit, and independent for-profit organizations and in the variety of languages they use. Presently, there are 40 private universities, colleges, and institutes in Lebanon (CERD 2012), 11 of which offer teacher preparation programs at either the undergraduate level leading to a bachelor's degree or to a "License" and post-bachelor's level in the form of teaching diploma programs. Likewise, the Lebanese government is involved in teacher preparation at the tertiary level through the Lebanese University, the only public university in Lebanon with branches in different parts of the country. However, it is important to note that the Lebanese government is involved in teacher preparation of public school teachers through CERD and the Ministry of Technical and Vocational Education. By law, CERD is responsible for preparing elementary and intermediate school teachers, whereas the College of Education of the Lebanese University is responsible for preparing secondary school teachers.

3.2.4 Examination System

External examinations in Lebanon occur in Grades 9 and 12. The Grade 9 examinations lead to the award of the Middle School Certificate (MSC). All candidates must sit for nine subjects: Arabic, mathematics, English or French as a foreign language, biology, chemistry, physics, geography, history, and civics. Attaining the MSC is a prerequisite to transiting to upper secondary schooling. The Grade 12 examinations lead to the award of the General Secondary Certificate (GSC). GSC candidates sit for 9–11 examinations depending on their stream. All public schools and most private schools offer the Lebanese curricula and examinations, whereas some private schools offer alternatives such as the French Baccalaureate, the International Baccalaureate, or American high school diploma programs.

3.2.5 General Objectives of Science Education[3]

According to CERD (1994),[4] science plays an important role in everyday life. It manifests itself in all aspects of human activity. Consequently, it is important that students become lifelong learners of science, starting with science at school but extending science learning beyond school years. To achieve the above, science teaching aims to realize the following general objectives: (1) develop the learners' intellectual and practical scientific skills, (2) deepen the learner's awareness in the ability of humans to understand, invent, and create, (3) understand the nature of science and technology, their development across history, and their impact on human thought, (4) insure that learners have acquired the facts, concepts, and principles necessary to understand natural phenomena, (5) motivate students to apply basic scientific principles in all sciences, (6) explain the scientific concepts and principles behind commonly used machines and devices, (7) acquire knowledge about health, environment, and safety practices and behave accordingly, (8) realize that some natural resources can be depleted and make the learner aware of the role of science in sustaining these resources, (9) encourage learners to use scientific knowledge and skills in novel situations especially in everyday life, (10) emphasize the role of scientists in the advancement of humankind, (11) encourage learners to be open to the ideas of scientists from different cultures and to their contributions in the advancement of science, (12) encourage learners to abide by such scientific values as honesty and objectivity, (13) develop the learners' scientific curiosity and orientation toward scientific research, (14) encourage learners to work independently and cooperatively in solving scientific problems, and (15) make the learners aware of career possibilities in different science-related areas.

3.2.6 Structure of the Science Education System

Science has received significant attention in the 1994 Lebanese Educational Reform Plan. For example, the number of hours apportioned to science teaching was

[3]All information about the Lebanese science curriculum was retrieved from http://www.crdp.org/CRDP/all%20curriculum/Sciences/Sciences_english/science_english.pdf.

[4]CERD (Centre for Educational Research and Development) (1994). National Educational Plan (Beirut, Lebanon: Centre for Educational Research and Development).

increased, biology was introduced at the intermediate and secondary levels, and an issues-oriented science curriculum was proposed for non-science majors. Moreover, emphasis was placed on encouraging teachers to use hands-on and minds-on science. Table 3.1 presents the number of periods per week of science at each grade level and in each stream, and Table 3.2 presents the number of periods per year of science at each grade level and in each stream.

3.2.7 Challenges Faced by the Science Education System

As mentioned earlier, when the civil war ended in 1990, Lebanon faced the challenge of building its educational system. A number of steps have been taken, and others are being taken in that direction. In the mid-1990s, the country embarked on an educational reform in order to address some of the problems such as adopting a

Table 3.1 Number of periods per week of general science, biology, chemistry, physics, and science literacy taught at each grade level of the Lebanese educational system

Subject	Grade															
	1	2	3	4	5	6	7	8	9	10	11		12			
											S	H	GS	L	SS	H
General Sc.	2	2	3	4	4	5										
Biology							3	2	2	2	2			6		
Chemistry							1.5	2	2	2	3		4	5		
Physics							1.5	2	2	3	5		7	5		
Sc. Literacy												3			4	3
Total	2	2	3	4	4	5	6	6	6	7	10	3	11	16	4	3

L Life sciences, *H* Humanities, *S* Science, *GS* General sciences, *SS* Social sciences and economics

Table 3.2 Total of periods per year of general science, biology, chemistry, physics, and science literacy taught at each grade level of the Lebanese educational system

Subject	Grade															
	1	2	3	4	5	6	7	8	9	10	11		12			
											S	H	GS	L	SS	H
General Sc.	60	60	90	120	120	150										
Biology							90	60	60	60	60			180		
Chemistry							45	60	60	60	90		120	150		
Physics							45	60	60	90	150		210	150		
Sc. Literacy												90			120	90
Total	60	60	90	120	120	150	180	180	180	210	300	90	330	480	120	90

L Life sciences, *H* Humanities, *S* Science, *GS* General sciences, *SS* Social sciences and economics
Major challenges to the science education system

new curriculum, publishing new textbooks, and training teachers among other activities. Moreover, there are presently a number of projects that aim to revise the curriculum, establish a professional development system, equip science laboratories, equip schools with information and communications technology (ICT), develop training materials, establish a training of trainers' model, and train science teachers. However, four of the major challenges were improving student achievement in science, equipping schools with the necessary material, laboratory, and ICT equipment to provide students with the opportunity to participate in minds-on and hands-on inquiry science, organizing professional development of teachers, and reforming the examination system to align it with new trends in science education. It is worth noting that many private schools in Lebanon are very well equipped and have the necessary infrastructure and do not suffer from problems with student achievement. However, the focus in this chapter is on general trends that might influence the majority of K–12 students in the country including both public and private schools. Below we discuss the major challenges faced by the science education system in Lebanon, specifically about low student achievement, school infrastructure needed to teach science, teacher training, and the examination system.

3.2.8 Student Achievement

The literacy rate of people in Lebanon is relatively high as a result of almost universal access to education. For example, the average literacy rate of adults is approximately 90 %, whereas that of youth is approximately 99 %. However, one of the problems facing science education in Lebanon is student achievement. In the absence of local standardized examinations that gauge student standards, international comparisons such as the Trends in Math and Science Study (TIMSS) can provide a benchmark that can be used to evaluate the quality of science education. In this respect, results of Lebanon on TIMSS at the Grade 8 level, the only test in which Lebanon participates, show that Lebanese students in general score below the international average in science as shown in Table 3.3. These results are attributed to a variety of factors such as the outdated teaching methods that focus on rote memorization and the weak language skills of students especially that the language of instruction of science in Lebanon is English or French, while the mother tongue is Arabic.

Following the war, the Lebanese government represented by the MEHE attempted to improve the quality of education to address the issue of low student achievement. In this respect, a National Education Strategy with six strategic

Table 3.3 Results of Lebanon in science on TIMSS between 2003 and 2011

Year	2003	2007	2011
TIMSS scale average	489	500	500
Lebanon	393	414	406

priorities was developed and is being implemented. These priorities include the following: education available on the basis of equal opportunity (e.g., improving student retention and achievement and development of infrastructure); quality education that contributes to building a knowledge society (e.g., professional development of the teaching workforce and modernization of school management) and education that contributes to economic development (e.g., ICT in Education), and education that contributes to social integration.[5] The results of implementing the strategy have not yet been published.

3.2.9 School Infrastructure Needed to Teach Science

There is an important link between improving student learning outcomes and a positive and safe learning environment. As indicated above, Lebanon's recent history and long civil strife took its toll on school infrastructure including buildings, playgrounds, and more importantly science laboratories in those schools that had such laboratories. Moreover, the lack of budgets during the long war years left schools with almost no ICT capabilities. Again here, the government represented by MEHE is presently attempting to remedy this situation by allocating its own funds as well as funds from grants and loans from the World Bank and support from United Nations agencies to rehabilitate existing schools and build new schools, equip schools laboratories, and equip schools with the latest technologies.[6]

3.2.10 Training Teachers

Teachers and the quality of their teaching have always been considered important issues in education and are likely to keep their significance in the future. Studies highlight the fact that student performance improves if the quality of teaching is improved (Seferoglu 2010). Specifically, science educators suggest that to be able to teach science effectively, that is, in a way that enhances student understanding and ability, science teachers need a thorough understanding of the ways their students learn science content and skills, the difficulties students may encounter, and the reasons why they face such difficulties. Furthermore, it is crucial that science teachers understand what and how science can be interesting or challenging for their students. Consequently, science teachers need to develop a large repertoire

[5] http://www.opentech.me/~laes/upload/editor_upload/file/Vision%20Document%20%20English.pdf and http://www.mehe.gov.lb/uploads/file/Reports/2013/ESDP_QuarterlyProgressReport_April262013_RevisedMay92013.pdf.

[6] http://deved.org/blog/education-development-in-lebanon/.

of instructional strategies and representations of science content which they can use in classrooms in a flexible way to meet different student needs.

Currently, there are approximately 40,000[7] Lebanese public school teachers, approximately 25 % of whom are science teachers, who need continuous professional development. The majority of in-service professional development is the responsibility of CERD. CERD's continuing training program (CTP) offers face-to-face trainings for teachers, led by a cadre of trainers who are mainly trained high school teachers. While CERD provides educators with out-of-school training, the Department of Guidance and Counseling (DGC) of MEHE is tasked with providing subject-specific support and supervision (including in-class follow-up, coaching, modeling, and mentoring) to teachers as they practice in Lebanese public school classrooms. The Faculty of Education at the Lebanese University is charged with the in-service development of principals, who must serve as instructional leaders as well as managers and community liaisons in their schools.

The variety of professional development providers and the absence of a formal coordination system, as well as the lack of resources to conduct in-depth and long-term professional development, have resulted in many science teachers needing training in a variety of areas such as teaching methodologies, integration of ICT in the teaching learning process, and subject matter knowledge. More importantly, many of these teachers lack foreign language skills that influence the quality of their teaching because the language of science instruction is English or French. Again here, there are plans that are being implemented to address many of these problems. These plans include developing teacher and trainer standards and observation tools to gauge teacher classroom performance, preparing trainers, establishing teacher professional communities, and institutionalizing cooperation mechanisms for all entities that work with teachers.[8]

3.2.11 The Examination System

According to Jurdak and BouJaoude (2009), one of the major issues with the external examinations in Lebanon is the lack of alignment of these examinations with the curriculum—an issue that was a result of the lack of the coordination among committees charged with writing the curriculum and those in charge of examinations. Another issue is the fact that there are inadequate test specifications in terms of content and cognitive level for the individual subject tests. Consequently, much of the selection of test items is left to the discretion of examination committees, which prepare examination papers. This state of affairs

[7]http://www.crdp.org/CRDP/Arabic/ar-statistics/STAT_AR/2011_2012/PDF11_12/Text_12/GeneralEdu_12/Teachers_12.pdf.

[8]http://www.mehe.gov.lb/uploads/file/Reports/2013/ESDP_QuarterlyProgressReport_April262013_RevisedMay92013.pdf.

raises questions regarding the content validity and the reliability of the examinations (Jurdak and BouJaoude 2009). Yet another issue associated with the external examinations is that of their cost because they are very labor-intensive and costly especially in light of the fact that they are used merely as filters for promotion to higher grades in the case of the MSC and as a requirement for admission to universities.

3.2.12 Science Education Research in Lebanon

There were two studies that reviewed science education research in Lebanon. The first, by BouJaoude and Abd-El-Khalick (2004), reviewed research between 1992 and 2002. The second, by BouJaoude et al. (2009), reviewed research conducted between 2003 and 2008. The 2004 article reviewed 62 empirical science education studies that were conducted in Lebanon between the years 1992 and 2002. The overwhelming majority of these studies (50; 80.6 %) were master's theses. Of these, 44 were unpublished and 6 were published in refereed journals. The remaining studies, based on research conducted by one or more university faculty members, were published as refereed journal articles (8; 13.0 %), and conference proceedings, ERIC documents, pamphlets, and book chapters (4; 6.4 %). Finally, these studies were grouped into 11 categories: learner conceptions, curriculum and textbook analyses, problem solving in the content areas, nature of science, environmental education, teacher education, visual organizers, science process skills, attitudes toward science, analogies, and technology-aided instruction. The above review identified three trends in the science education research between 1992 and 2002: scope of the research, research methodologies, and theoretical frameworks.

The review showed that research was limited in scope in that the number of empirical studies conducted was small, the body of research was poorly disseminated, the focus of research was exclusively on secondary (middle and high school) students, and studies had limited numbers of participants and were mostly descriptive in nature. Furthermore, there was a lack of large-scale national studies and studies that focused on documenting and investigating classroom practices. Moreover, the majority of the reviewed research studies were quantitative in orientation but did not satisfy the standards of rigor required by this type of research. Finally, most studies drew on a simplified "constructivist" theoretical framework that did not necessarily guide the development of specific research activities and data interpretation.

The study conducted in 2009 reviewed 54 empirical science education studies that were conducted between the years 2003 and 2008 (3 doctoral dissertations, 24 master's theses, 3 master's projects, 21 papers in refereed journals or edited books, and 3 papers in conference proceedings). Of these studies, 30 (55.5 %) were unpublished and 24 (44.5 %) were published in refereed journals or chapters in books (21; 87.5 %) and conference proceedings (3; 12.5 %). Fifty percent of these studies (27; 50 %) were master's theses or projects. Analysis of the studies resulted in

12 categories: (1) learner conceptions; (2) curriculum and textbook analysis; (3) problem solving in the content areas; (4) nature of science (NOS); (5) environmental education; (6) visual organizers; (7) analogies; (8) technology-aided instruction; (9) classroom practices; (10) inductive/deductive teaching; (11) equity, values, and access to science education; and (12) miscellaneous studies (complexity paradigm, context of schooling, differentiated instruction, informal science education, language of instruction, the theory of multiple intelligences, and research reviews).

Four major trends emerged from the analysis of the studies conducted between 2003 and 2008: a shift toward qualitative and mixed methods research, an increase in the number of published studies, an increase in the number of studies conducted and published in French, and the emergence of research on classroom practices. Moreover, like the studies in the 2004 paper, the overwhelming majority of studies drew on a simplified "constructivist" theoretical framework with some of them not articulating clearly how the constructivist framework guided the research questions and interpretation of the results. One development, however, was the appearance of theoretical frameworks that are extensively used in France but not prevalent in American/Anglo-Saxon science education research, such as the complexity paradigm (Jörg et al. 2007), and new approaches to the interaction between scientific knowledge and systems of values. These emerging theoretical frameworks have the potential to enrich science education research in Lebanon and possibly introduce the international science education community to a unique opportunity to witness the American/Anglo-Saxon research traditions interacting with the French science education research traditions.

Yet another study was conducted in 2014 that aimed to summarize the body of science education research that was conducted in Lebanon between 2009 and 2014. This study is not yet published. Following the approach used by BouJaoude and Abd-El-Khalick and El-Hage (2009), all science education empirical studies conducted in Lebanon (K–16) between 2009 and 2014 by students and researchers situated both inside and outside Lebanon were included in the review. It included published research in English and French professional journals and theses and dissertations in Lebanese universities that offer master's and Ph.D. programs. Criteria for including a study for review included having a clearly delineated research focus and question(s), theoretical framework, methodology, empirical base, results, and discussion sections. The study conducted in 2014 reviewed 68 empirical science education studies that were conducted between 2009 and 2013 (25 master's thesis, 20 journal articles, 13 chapters in edited books, 8 conference proceedings, and 2 Ph.D. dissertation). Of these studies, 41 (60.3 %) were published: 20 (29.4 %) in refereed journals, 13 (19.1 %) in edited books, and 8 (11.8 %) in conference proceedings.

The framework developed by BouJaoude and Abd-El-Khalick (2004), which used a "research focus" to organize the studies completed between 2003 and 2008, was used initially to categorize the research conducted between 2009 and 2014. Analysis of the studies resulted in 10 categories, 5 of which appeared in BouJaoude, Abd-El-Khalick and El-Hage (2009), whereas 5 were new. The categories common between this review and BouJaoude and Abd-El-Khalick included curriculum and textbook analysis, nature of science (NOS), technology-aided instruction, classroom practices, equity, values, and access to science education, and miscellaneous studies (complexity theory and college science teaching). Furthermore, based on the review of the studies conducted between 2009 and 2014, five new categories were added to the initial framework. These were as follows: science education in the Arab states, impact of teaching interventions on learner conceptions, achievement and attitudes, teacher's knowledge, health and sex education, and assessment. It is worth noting that there were no studies in five of the categories that appeared in BouJaoude et al. (2009). These were inductive/deductive teaching, analogies, visual organizers, environmental education, and problem solving in the content area.

Analysis of the science education research conducted between 2009 and 2014 shows that the majority of the studies still subscribe to a simplified "constructivist" theoretical framework, like the studies conducted between 2003 and 2008, but with some attempts to articulate the relationship between this framework and the research questions and interpretations of the results. Another trend involved studies that aimed to understand the status of science education in Arab states as demonstrated by an edited book and an article on the topic (BouJaoude and Dagher 2009; Dagher and BouJaoude 2011) and a chapter in an edited book that investigated the status of science in Egypt, Lebanon, and Saudi Arabia (BouJaoude and Gholam 2014). Additionally, there were a number of studies that addressed health and sex education issues and e-learning. Finally, some of the trends identified in the research conducted between 2003 and 2008 continued, especially the increased use of qualitative and mixed methods and an increase in the number of published articles.

3.3 Conclusions and Discussion

In addition to the challenges that Lebanon faced as a result of its civil war that raged until the late 1980s and is still facing because of political and security instability, there are challenges that are inherent to the educational system that need careful consideration if the system is to succeed in providing Lebanese youth with the opportunity to live and succeed in the twenty-first century. The four major challenges inherent to the system are as follows: language of instruction of science, preparing students for the twenty-first century, reforming the examination system, and science education research and its relationship to practice.

As indicated in the first part of this paper, the language of instruction of science in Lebanon is a foreign language (mainly English or French), even though the mother tongue of the majority of Lebanese students is Arabic. This situation has the potential to influence student achievement in science (Amin 2009) and result in students with lower than desired knowledge and skills in science. There is an apparent possible dilemma facing decision makers regarding this issue. One of the arguments of using a foreign language of instruction is the possibility of making students competitive in the global economy; on the other hand, there is research that indicates that learning is more efficient when students' mother tongue is used as the language of instruction (Amin 2009; Wagner 1993). Despite its centrality to teaching and learning science, this challenge has not attracted the attention it deserves from researchers in science education in the past two decades, as can be clearly demonstrated from the reviews of science education research presented above.

Another challenge that Lebanon is facing is preparing students to live and work successfully in the twenty-first century especially because that this century requires that students be scientifically and technologically literate and proficient. The last time the Lebanese science curriculum was changed was in the mid- to late 1990s, that is, around 15 years ago. Since then, only minor changes have been implemented—changes that did not improve the science curriculum in ways that align it with the needs of the twenty-first century. In this respect, the partnership for twenty-first century skills[9] recommended putting emphasis on understanding core academic content at high levels, information and communication skills, thinking and problem-solving skills, and interpersonal and self-directional skills. Moreover, the partnership proposes that teaching and learning be implemented in a twenty-first century context, which necessitates learning academic content through real-world examples, applications, and experiences, and using appropriate tools and approaches to measure students' performance on twenty-first century content and skills. Unfortunately, many of these ideas are not integrated in the Lebanese science curriculum.

The third major challenge that the Lebanese educational system is facing is reforming the examination system. As indicated earlier, the examination system is already facing problems of limited alignment with the existing curriculum. It is also facing the added problem of focusing on pure academic knowledge rather than on the active use of knowledge in everyday contexts as recommended by the partnership for twenty-first century skills.

The final challenge is that of the purpose of science education research. As can be grasped from the review of science education research being conducted in Lebanon, it is limited in scope in that the number of studies is small. It is also focused on intermediate and secondary school students only and involves studies that included relatively small numbers of participants, thus limiting the generalizability of research findings. More importantly, results of these research studies are not disseminated in the science education community of K–12 teachers and university faculty members because of a lack of venues to share in the form of journals or conferences. As a result, the purpose of these research studies seems to be satisfying the requirements of master's or Ph.D. degrees for students and promotion for university faculty members.

The four challenges discussed above represent a few of the major challenges facing education in Lebanon in general and science education more specifically. It is hoped that the National Education Strategy, which is being implemented

[9] http://www.p21.org/.

currently, will energize all those concerned to marshal the resources and the effort needed to move the country and its children safely into the future because what the strategy proposes is a coordinated plan that aims at systemic change to move the educational system into the twenty-first century.

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Chapter 4
School Science Teaching and Learning in Macau: Problems and Challenges

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Abstract Science teaching is an important part of schooling in Macau, yet it has long been neglected by international education researchers. This chapter attempts to analyze the following issues concerning science teaching and learning in this special administrative region of the People's Republic of China: school-based science curriculum, science textbooks and their uses, science teaching methods, science learning environments, and students' attitudes to science and school science. The data used in this chapter were drawn from an evaluation project of science education in primary and secondary schools in Macau. In the last part of this chapter, the features of science teaching and learning in this region are identified and discussions conducted on whether these features are beneficial for the purpose of achieving scientific literacy.

4.1 Introduction

School science has long been an inseparable part of secondary education in Macau. Yet, since Macau is a small place, few scholars have been concerned about school science in this region; even research on Macau education and society does not address its curriculum or teaching issues of school science (e.g., Bray and Koo 2004). Furthermore, since most of the secondary schools are privately run—schools have strong autonomy in planning the curriculum, selecting teaching materials and methods, and setting standards for graduation examinations—there is a great diversity across various schools in terms of curriculum and instruction. Thus, it is difficult to describe what the typical science teaching and learning is like in this region. Fortunately, as a member of the Organization for Economic Cooperation and Development (OECD), Macau has participated in the Program for International

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Student Assessment (PISA) since 2003 as a special administrative region of China. Specifically, PISA 2006, with a focus on science performance, provided reliable data on science teaching and learning in Macau, which can help us better understand its current status. According to the PISA results in 2006, among the 57 participating countries/regions, Macau's 15-year-olds' scientific literacy performance was significantly above the OECD average, and Macau ranked between 15 and 20 on the combined science scales; among the three content areas of science, Macau's 15-year-olds performed best in "living systems," moderately well in "physical systems" and less well in "earth and space systems"; among the three key scientific competencies, Macau's 15-year-olds performed best in "explaining phenomena scientifically," moderately well in "using scientific evidence," and less well in "identifying scientific issues" (Cheung and Sit 2007). I argue that the performances of Macau's 15-year-olds in PISA 2006 not only reflected the actual state of school science in Macau but also shed light on the problems and challenges encountered by science teaching and learning in this region.

As universally recognized, school science in a given society occurs in a wide range of educational, social, cultural, and political contexts, and students' learning is an important aspect of the school science system. When using a school-based model to delineate the interrelationship of the factors within a school science system, it can be inferred that students' learning outcomes might be affected by both internal and external factors of this system (Guo 2007). This statement has been verified by successful experiences of Finland in PISA 2006, in which Finnish 15-year-olds' performances ranked first among the 57 participant countries/regions. According to Lavonen and Laaksonen (2009), students' success in Finland can be explained by a combination of education polices of this country (commitment to a vision of a knowledge-based society, educational equality, and strong local autonomy), the practice of science teacher education (higher requirements of teachers' credentials in tertiary education and higher level of professionalism), the school science curriculum (more science hours), and students' positive attitudes to science and science learning. This chapter attempted to analyze the following issues concerning science teaching in Macau—school science curriculum, science textbooks and their uses in practice, science teaching methods, science learning environments, and students' attitudes to science and science learning, with the purpose of providing explanations for performances of Macau's students in PISA 2006 based on the data collected from an evaluation project of science education in primary and secondary schools in Macau. The reason in this project why I focused on these five issues was that they are the salient "internal factors" that influenced students' learning outcomes in the school-based model of science learning proposed by Guo (2007). In the following two sections, I briefly describe the background of the evaluation project and methods employed in it in turn.

4.2 Background of the Evaluation Project

With the sovereignty returning to China in 1999, especially the liberalization of the gambling industry in 2002, Macau, the former Portuguese colony in Asia, has experienced tremendous changes in its social and economic aspects. In 2006, the government of Macau stipulated the *Non-Tertiary Education System Law* (The Law of Number 9/2006, Macau) with the purpose of establishing a new system of basic education and ensuring the quality of schooling in this special administrative region of China. Under this social environment, was the evaluation project initiated by the Education and Youth Bureau (EYB)—the education administrative authority in Macau in 2007. The aim of this evaluation project was stated as follows:

> judging and analyzing the current situations of primary and secondary school science education, and giving evaluations and suggestions on the basis of the collected data, to be used as references for the administrative authority and schools to project the future development of science teaching and to ensure and promote its quality (EYB 2007, p. 1).

Commissioned by EYB, Faculty of Education in University of Macau was responsible for organizing a team for this evaluation project. The team comprised experts in science education, education evaluation, and science subjects, and I served as the coordinator of this project. According to the request of the BYU, the emphases of the evaluation should have been on curriculum and planning, curriculum organization and management, teaching quality, science teacher development, learning effects, learning environments and resources, and parents' expectations and cooperation (EYB 2007). Except for "parents' expectations and cooperation," all of these proposed evaluation emphases were addressed in this project. The perspectives and rationales of this project were underpinned by the local and international literature on science curriculum development, science teaching and learning, and science teacher education. Specifically, this project took scientific literacy as the overall standards for this science education evaluation based on two considerations. Firstly, as stipulated in the *Non-Tertiary Education System Law*, raising the level of scientific literacy of all students is one of the general goals of pre-college educational enterprise in Macau. Secondly, scientific literacy has been described as the overall aim, or general purpose, of science education in recent decades in the circle of science education (Bybee 1997; Miller 2006; Laugksch 2000) and has been used as the central concept in selecting science curriculum content and recommending teaching methods in a couple of internationally influential science education innovations, such as *Project 2061* (AAAS 1989), and the *National Science Education Standards* (NSES) (NRC 1996). Promoting the development of scientific literacy implicates changes of teaching and learning strategies in science classes. In the NSES, for instance, "changing emphases" were given in terms of science teaching (p. 52), assessment (p. 100), and science content (p. 113) in the formats of "less emphasis" and "more emphasis." Science teaching that has "more emphasis" can be seen as "effective science teaching," which is characterized with these features: (1) Students are encouraged to engage actively with ideas and evidence; (2) students are challenged to develop meaningful understandings; (3) science is linked with students' lives and interests; (4) students' individual learning needs and preferences are catered for; (5) assessment is embedded within the science learning strategy; (6) nature of science is represented in its different aspects; (7) the classroom is linked with the broader community; and (8) learning technologies are exploited for their learning potentialities (Tytler 2003). In this project, the recommended and suggested quality criteria of science teaching in the literature were used to describe the ideal pictures of school science education, against which the actual pictures of the school science education in Macau were described and evaluated (Wei et al. 2009).

4.3 Methods

Major efforts in this project were devoted to describe the actual pictures of the current science education in Macau by using a variety of research methods, including questionnaires, classroom observations, interviews, case study, and document analyses. Relevant data were collected from multiple sources, which have been typed into four levels; they areas follows: policies, schools, science teachers, and students, albeit interrelatedness among these four levels. Among the 46 secondary schools in Macau, which were the target of this evaluation project, six were selected as sample schools to conduct sample surveys, science classroom observations, and science teacher interviews. It should be noted that these six schools were typical in terms of numbers of students, teaching quality, and social reputation among the 46 schools in Macau. In the following, only the methods that yielded the data relevant for the purpose of the current study, which was to reflect on the current state of school science teaching and learning in Macau, are described.

4.3.1 Questionnaires

A school science curriculum and instruction questionnaire was used as the instrument of a population survey to provide general and basic information on the school science curriculum and teaching in all of the 46 secondary schools. This questionnaire was constructed primarily on the basis of researchers' extant knowledge of science teaching and learning at the school level in Macau and it was modified by a pilot test with 22 students (in-service science teachers) enrolled in the Postgraduate Certification in Education (PGCE) program in the Faculty of Education, University of Macau. The questionnaire contained 22 questions and each question was provided with several choices. These questions covered the topics of science curriculum, the composition and management of science department, science teacher development, the making-up of school-based science teaching outline (see below), teaching methods, curriculum resources, and extra-curriculum activities. There were both Chinese and English versions (the latter was translated from the former) to make sure that this questionnaire could be completed in both Chinese-speaking and English-speaking schools. The questionnaire was sent by post to the 46 secondary schools in Macau. Principals, vice principals, or heads of science departments, who were familiar with the situations of science teaching and learning in their schools, were asked to complete the questionnaire. Finally, we obtained 39 completed questionnaires. The results of this school science curriculum and instruction survey were selectively used to address the issues highlighted in this chapter.

Two questionnaires, "Constructivist Classroom Learning Environments" (CLES) (Taylor et al. 1997), and "Science Laboratory Environment Inventory" (SLEI) (Henderson et al. 2000), were used to examine learning environments in the situations of regular classrooms and laboratory, respectively, in the views of students. Each scale of the CLES was designed to obtain measures of students' perceptions of the frequency of occurrence of five dimensions of constructivist learning environments: personal relevance, uncertainty, critical voice, shared control, and student negotiation. The CLES contains 30 items in total, with six items in each of the five scales. Similar to the CLES, the SLEI purports to obtain measures of students' perceptions of the frequency of occurrence of five dimensions of constructivist learning environments in laboratory, containing 35 items, with seven items in each of the five scales: student cohesiveness, open-endedness, integration, rule clarity, and material environment. For both the questionnaires, the response alternatives for each item were Almost Always, Often, Sometimes, Seldom, and Almost Never. These two questionnaires were administered, respectively, to 411 senior secondary school students in the six sample schools. The Chinese versions of CLES and SLEI, which were validated by Taiwanese scholars Huang (1998) and Su and Huang (1999), respectively, were used in our evaluation study.

4.3.2 Classroom Observation

In order to learn what the real science teaching was like in science classroom, we conducted non-participant observations in science classes. The observation focused on the interaction between science teachers and students. The classroom observation instrument was adapted from "Science Lesson Observation Schedule," which was originally developed by Newton et al. (1999), and subsequently revised by Gwimbi and Monk (2003). This instrument defined teachers' activities as those including giving lectures, raising questions, demonstrating, encouraging students to ask questions, and students' activities as listening to teachers, observing, reading, doing exercising, listening to peers, discussing, answering questions, and asking questions. Our classroom observations were conducted in physics, chemistry, and biology lessons in the six schools, with each subject being observed once in each school. In total, 18 science lessons were observed.

The schedules of classroom observations were coordinated by the evaluation project and the schools in advance. Science teachers were voluntary to be observed.

In each class observation, a researcher with the relevant subject background and an assistant sat in the back of the classroom to independently note what occurred in the class on the observation instrument. The classroom observations were recorded with each minute as a recording unit. After the lessons, the researcher and the assistant checked the records with each other to ensure the consistency of their records. The minutes of teachers' and students' activities that occurred in the lessons for each subject were accumulated to compare and contrast the time of each activity in six lessons in a given subject in order to find the general patterns of science teaching in the classroom.

4.3.3 Interview

Interviews with students aimed to investigate their attitudes toward and perceptions of school science. The interviews were conducted with 29 students in a school, 14 grade-seven students and 15 grade-eleven students. These students were randomly selected by their master teachers. The interviews were conducted in groups and grade-seven and grade-eleven students were interviewed, respectively. Each group interview lasted for about 45 min. Students were interviewed by a researcher with the help of an assistant in the absence of their master teachers. The interviews were conducted in Cantonese, which is the native language of these students. The interviews were semi-structured. In the interview outline, there are six questions: (1) What science subjects do you like the most (and why)? (2) What science subjects do you dislike (and why)? (3) Which aspects of science teaching do you feel satisfied (and why)? (4) Which aspects of science teaching do you feel unsatisfied? (and why)? (5) Do you plan to study science at a higher level (and why)? (6) What extra-class activities have you participated in or do you want to participate in? In addition to these questions, further probes were used when needed. In order to provide free environments for students, the interviews were not taped. But the researcher and the assistant took notes of students' responses through the whole process. After interviews, they checked on the notes with each other in order to avoid missing important messages. The interview data were analyzed with the emphasis on finding the reasons why students liked or disliked school sciences and science teaching.

4.3.4 Case Study

In order to examine the actual science teaching and learning at the school level deeply and thoroughly, a case study was conducted in one of the schools. The case study, which lasted for about six weeks, was conducted by a researcher (myself) with the help of two assistants. We visited this school almost every day during this period and collected the information on science teaching and learning in the following ways: (1) reading extensively the written documents including school development plans, school-based teaching outlines, teaching plans, textbooks, teachers' reference books, and students' worksheets; (2) participating in the science department' activities and learning from the headmaster about the composition, professional development activities, and management of the science department; (3) visiting science classes and having talks with the teachers before and after the classes to make sense of the purposes and intentions of their teaching.

One of the focuses of the case study was to learn the actual uses of science textbooks in practice. Owing to my own background in chemistry, I put my energy on observing chemistry lessons and the actual uses of chemistry textbooks. I observed 12 lessons taught by two chemistry teachers during the six weeks and these lessons involved chemistry classes across grades seven to twelve. Before visiting classes, I used to do my best to know the status of the lessons I would observe and the perceptions of the teachers on the lessons (functions of the lessons on the whole textbooks, difficulties of students' learning, teaching methods that would be used). The classroom observations were accompanied by taking notes and impromptu comments were made on teachers' and students' activities. I took notes of any questions that arose from observations and would talk with the teachers after the classes on these questions. The after-class conversations took place in the intervals between two lessons; if the intervals were too short, I would make an appointment with the teachers to continue the conversation. The main purposes of the after-class conversations were to make sense of the intentions of the teachers in adopting a certain teaching approach or strategy.

4.4 Results

In this section, the data collected from the four kinds of methods—questionnaires, classroom observations, interviews, and case study—were used to describe the five salient issues concerning science teaching and learning in Macau. Specifically, some data from the school science curriculum and instruction survey were used to portray the school science curriculum; the data from the school science curriculum and instruction survey and the case study were used to describe science textbooks and their uses in practice. Science teaching methods were delineated by the data of school science curriculum and instruction survey and classroom observations. Furthermore, the data from the questionnaires CLES and SLEI were used to construct the science learning environments. Finally, students' attitudes to science and science learning were depicted by the data of the interviews.

4.4.1 School Science Curriculum

What types of science curriculum are offered at various grades and how many teaching hours are actually allotted to these science curricula at the school level were the major concerns in the evaluation project. Results of the school science curriculum and instruction survey indicated that all of the participating schools offered physics, chemistry, and biology, less than one quarter of these schools offered integrated science, and no school offered earth or space science. At the junior levels, physics, chemistry, biology, and integrated science were offered at different grades in different schools and the discrepancy among participating schools was significant. The average science hours for all grades was 13.2 per week, and for each grade the average was 4.4 h, which is much less than 6 h per week for each grade in Finland (Lavonen and Laaksonen 2009). At the senior levels, the splitting of students into science and arts streams was one of our concerns. As indicated in the survey, among the 39 participating schools, the splitting of two streams occurred at grade ten in 19 schools (48.7 %), at grade eleven in 9 schools (23.1 %), at grade twelve in 5 schools (12.3 %). And there were even 6 schools that split the two streams at grade nine at the junior levels. The survey also showed that in most of the participating schools (74.3 %), no science course was offered for the arts-stream students; and in those schools offering science courses for the arts stream, the courses were biology- or physiology-related but not on physics or chemistry. For the science stream, the average science hour was 25.4 per week, almost doubling that of the junior levels (13.2). And the average hours of physics and chemistry were much more than that of biology, which is usually not among the subjects tested in the university admission examinations. Based on these results, we can say that school science curriculum in Macau, especially at the senior levels, is heavily driven by the university admission examinations.

As mentioned earlier, most of the secondary schools in Macau are private, and thus, they have the autonomy on the forms of school science curriculum to adopt, and the teaching hours to allot to each subject science curriculum. It is not compulsory for them to implement the official science curriculum released by the Macau Government. Instead, science teachers usually produce the teaching outlines which serve as guidelines or progress charts for their daily teaching. To some degree, this kind of school-based teaching syllabus for each subject is the legitimated curriculum at schools. When making the teaching outlines, science teachers usually make references to the various kinds of official syllabi or curriculum standards released by Mainland China, Hong Kong, Taiwan, and the local government, and the textbooks used in these regions. As the results of the survey indicated, the frequencies of official teaching syllabi of these various regions that were referred to when making school-based teaching outlines were listed in a descending order: Mainland China (33 schools, 84.6 %), Macau (16 schools, 41.0 %), Hong Kong (8 schools, 20.5 %), and Taiwan (5 schools, 12.8 %). Obviously, school teaching in Macau is influenced by the neighboring regions and the most influential one is Mainland China. This is mainly because more and more secondary school graduates opted to go to the Mainland for their further tertiary study after 1999, when the sovereignty of this region was returned to China (Lee 2007). In most of the participating schools (22 schools, 56.4 %), the school-based teaching syllabi were designed by teachers collectively; in some schools (15 schools, 38.5 %), they were designed by teachers individually. But only in 4 schools, these school-based science teaching syllabi are coordinated by the school administration. That is to say, the designing of school-based teaching syllabi is science teachers' independent work but has little relation with schools' administration. This reflects that science teachers have high autonomy for their professionalism in Macau.

4.4.2 Science Textbooks and Their Uses

Like in other Chinese societies, textbooks play important roles in school teaching and learning in Macau. Since the market in Macau is so small and fragmented, commercial publishers are reluctant to invest in it, schools have to depend on imported textbooks (Lo 2004). Science textbooks used in secondary schools in this region are mostly dependent on neighboring Chinese societies (Mainland China, Hong Kong, Taiwan), and even foreign countries, such as the US and UK, in some English-as-the-medium schools. With the purpose of knowing more details about the science textbooks adopted at the junior and senior secondary levels in Macau, we designed a questionnaire item in the school science curriculum and instruction survey to ask from where science textbooks used in individual schools were imported. As shown by this survey, among the 39 participating schools, 31 (79.5 %) adopted textbooks from Mainland China, 12 (30.8 %) from Hong Kong, 3 (7.7 %) from Taiwan, and one (2.6 %) from the United Kingdom. Obviously, the textbooks from Mainland China took the biggest share of the science textbook market in Macau. It should be noted that most of the schools adopting textbooks from the Mainland indicated that they adopted the textbooks edited and published by the People's Education Press (PEP), a nationally designated textbook publisher in China, although there are various kinds of textbooks for each subject by other publishers in the current market.

As shown by the case study, which focused on how chemistry textbooks were used in practice (Wei et al. 2009), chemistry teachers usually determined the teaching content, projected the teaching progress, and allotting teaching hours according to the logic structure, content sequences of the textbooks (published by PEP). Thus, we dare to say that textbooks were the primary source of science teachers' routine teaching. However, teachers' reliance on textbooks does not mean that they teach science content in light of the intention of the textbook authors. As I found in the school, chemistry teachers usually "adapted" textbooks in light of their teaching experiences, learning experiences in high schools, loyalty to the subject of chemistry, and expectations for their students. One of the strategies of their adaptation is supplementing. For example, when talking about the teaching content in her lesson, a chemistry teacher teaching in grade one of the senior secondary school moaned to me that "surplus calculation," "equilibrium constant," "electronic formulation" had been deleted in the current textbook, but such content should be supplemented for students for the reason that they were often tested in the university admission examinations. If students did not study these content areas, she added, they would lose scores in examinations. The other reason was that their loyalty to the science subject made them sentimentally attached to some of the classical content areas. For instance, when talking about the subject matters mentioned above, the chemistry teacher unintentionally revealed her "sorrow": "They existed in the textbook when I was a high school student, but they do not any more." As she implied, it was acceptable that these content areas were absent from the textbook; therefore, they should be supplemented to students. The other strategy of supplementing is overlooking something in the textbook. In the current version of the textbooks, there were some special columns that reflected new ideas and pedagogy of science teaching such as "Extended Reading," "Discussion," and "Investigatory Study." As I observed in the classroom, however, little attention was given to these special columns. When I asked the teachers about this, they usually responded by saying "students will read these stuff after classes," "the class is highly scheduled," or not giving any comments as if the columns had not existed in those textbooks. Obviously, although science textbooks imported from the outside of Macau have changed, science teachers have not become aware of those changes. They do not seem to truly appreciate the intention of the new science textbooks that have incorporated the elements of scientific literacy (such as social applications of science, students-centered activities) in both science content and pedagogy.

4.4.3 Science Teaching Methods

Teaching in Chinese societies has often been portrayed as teacher-, textbook-, and test-centered (Potts 2003). However, we did not exactly know how science was delivered to students in science classrooms in Macau. In order to find it out, we designed a questionnaire item in the school science curriculum and instruction survey to ask which one/ones of the various science teaching methods is/are frequently used in science classes. As the results of the survey showed, lecturing was frequently used in all of the 39 schools, whereas laboratory work and multimedia were frequently used in most of the participating schools (29 schools, 74.4 %, and 28 schools, 71.8 %, respectively). In comparison, fewer schools adopted group discussion (10 schools, 25.6 %) and extra-class activities (6 schools, 15.4 %) as frequently used science teaching methods. It is obvious that in most of the schools, teacher-centered methods were more frequently adopted than the students-centered ones in Macau.

At the school level, we observed physics, chemistry, and biology lessons in each of the six schools with a total number of 6 lessons for each subject. For each subject, we synthesized the observation data from 6 lessons in terms of teachers' and students' activities. I would use the data of observations in physics lessons to further clarify the salient features of science teaching methods in Macau. The activities of teachers in the physics lessons were mainly focused on "giving lectures" (182 min), followed by raising questions (38 min), teachers' demonstrations (21 min), with the least time spent on encouraging students to ask questions (16 min). The activities of students in physics lessons were mainly focused on "listening to teachers" (178 min), followed by "answering questions" (27 min), "doing exercises" (22 min), "observing" (21 min). The total time spent on reading, listening to other pupils, and discussing was below 10 min, and no activity was recorded concerning students' raising questions. In the lessons of chemistry and biology, we observed the similar patterns of time distributions in teachers' and students' activities. That is to say, overall, in the science lessons, "giving lectures" and "listening to teachers" were teachers' and students' dominant activities, respectively. Although science teachers adopted methods such as "raising questions," "demonstrating" in science lessons, these methods were not used as often as "giving lectures," and "encouraging students to answer questions" is even less used. Although students were engaged in activities such as observing, doing exercises, doing experiments, discussing, and answering questions, they spent much more time on "listening to teachers." Generally speaking, science lessons were dominated by teachers while students studied in a passive way, and the active interactions rarely occurred between students and teachers, and between students and students.

4.4.4 Science Learning Environments

It is commonly recognized that students' perceptions can be used to contrast the external observer's observation in studying classroom environments. According to Fraser (1998), defining the classroom or school environment in terms of students' perceptions has the advantages of characterizing the setting through the eyes of the participants themselves and capturing the information that the observer could miss or consider unimportant. In the evaluation project, we defined the science learning environments at two settings, regular classrooms and laboratories. As for the regular classrooms, data were collected from the perceived version of the questionnaire of Constructivist Classroom Learning Environments (CLES), which consists of five scales, personal relevance, uncertainty, critical voice, shared control, and student negotiation, with 30 as the maximum and 6 as the minimum scores in each scale.

As shown by our evaluation project, science classroom environments in Macau can be described in this way: (1) Personal relevance—science teaching had a certain degree of relevance with students' daily lives but the degree was not high (18.73); (2) uncertainty—students were provided with the opportunities to learn the uncertainty of science in classes (22.35); (3) critical voices—students were given few opportunities to question teachers' pedagogical plans and methods or to express concerns about their learning impediments (16.11); (4) shared control—students were provided with few opportunities to design the objectives of science teaching, content of science learning, or standards for teaching assessment (11.15); and

(5) student negotiation—students were provided with opportunities to explain and justify their newly developed ideas to other students, and to listen and reflect on the viability of the other students' ideas (22.18).

For the laboratory environments, the questionnaire of Science Laboratory Environment Inventory (SLEI) was used, which consists of five scales: student cohesiveness, open-endedness, integration, rule clarity, and material environment with 35 as the maximum and 7 as the minimum in each scale. As shown by our evaluation project, the laboratory environments can be described in this way: (1) Student cohesiveness—students could support and help each other in the laboratory (24.26); (2) open-endedness—students were passive in the laboratory (15.46); (3) integration—laboratory work was related with routine learning, but the degree of relation was not high (24.33); (4) rule clarity—there were rules and regulations in the laboratory, but they were not clear enough (25.65); and (5) material environment—the equipment could satisfy students' needs and students were satisfied with laboratory, but the degree of satisfactory was not high (23.52).

Generally speaking, either the classroom environment or the laboratory environments in Macau was not very consistent with constructivist environments as perceived by students.

4.4.5 Students' Attitude to Science and Science Learning

As the results from the students' questionnaires in PISA 2006 showed, 15-year-olds in Macau expressed interest in and positive attitudes to science (Cheung and Sit 2007). This conclusion seems to have been confirmed in our evaluation project. The data from group interviews could be summarized into three categories. Firstly, a large proportion of the interviewed students, at both junior and senior secondary levels, were interested in science learning. More importantly, we found that the reasons for liking science varied among these students, and included the inherent interest of science, the recognized features of science learning (being logical and accompanied by hands-on activities), satisfaction with the outcomes of learning, and utility of science in daily lives. Secondly, students' satisfaction with school science was dependent upon teachers' personal characteristics, teaching styles, and textbooks. Specifically, the reasons that students were satisfied with school science included these factors: good lecturing, nice teachers, funny experiments, things with logic, and no need for rote learning. Thirdly, for students, whether continuing to learn science at higher stages (senior secondary schools or colleges) or not was dependent upon their interest in science, the future occupations they expected to do, and self-assessment of their potential abilities of studying science. But the number of students opting to study further in science was less than that of the students opting not to study further in science. This discrepancy is more significant for the group of senior secondary students mainly because they were worried that they could not find jobs in science-related industries in Macau, where gambling is the pillar industry, after graduating from universities with a degree in science.

4.5 Discussion

Based on the data of the evaluation project of science education in primary and secondary schools in Macau, I have attempted to portray secondary school science in this region in terms of these aspects: school-based science curriculum, science textbooks and their uses, science teaching methods, science learning environments, and students' attitudes to science and school science. Synthesizing the results of these five aspects, we can characterize the features of school science in Macau as follows. Firstly, with regard to the types and teaching hours (per week) of sciences courses offered, there were great discrepancies among the evaluated schools, with each school having a unique feature. Secondly, as indicated in the process of designing school-based teaching outlines, science teachers had a certain degree of autonomous power in planning daily science teaching. Thirdly, the teaching of the science curriculum and the use of science textbooks were to a great degree influenced by the neighboring regions with Mainland China being the most influential one, reflecting the remarkable impact of the university admission examinations on school science curriculum and teaching. Fourthly, routine science teaching was reliant on textbooks but the students-centered teaching ideas and strategies implicated in the textbooks had not been implemented in practice. Fifthly, science lessons were prominently dominated by science teachers and lecturing was the most prevalent teaching method, with few opportunities provided for the interactions between teachers and students. Sixthly, neither the regular classroom environment nor the laboratory environment was fully consistent with the constructivist tenets in the views of students: Science teaching is not highly relevant, students are passive in learning, the extent of openness of laboratory work is low, and students had few opportunities to give opinions on science teaching. Seventhly, students had positive attitudes to science and had interest in school science, but few students opted to choose science as their college majors owing to the worries of few job opportunities in science or related industries in Macau.

As argued earlier, science teaching and learning in a certain society is closely associated with its culture, history, and educational traditions. The first and second features reflect the strong autonomy of Macau's secondary schools in curriculum designing and science teaching, which are not intervened by the education administrative authority. The third feature is obviously associated with the values of education in the Chinese culture, which is dominated by the Confucian tradition, usually referred to as "Confucian-heritage cultures" (Ho 1991, cited in Leung 2001). In this tradition, schooling is mainly perceived as a means to gain access to tertiary education and to achieve a higher social status (Zhu 1992). The fourth, fifth, and sixth features highlight the actual problems related to science teacher education, science teachers' conceptions of science teaching, and science teaching resources. The seventh feature mirrors to some degree the facts that scientific knowledge and positive sides of sciences are highly valued but the situation that gambling dominates job markets potentially influences students' career choices in the society of Macau. Comparing with the experiences and social characteristics of Finland, a country which can be seen as a typical example of obtaining excellent achievements in student learning, we can see that some of these features we found are beneficial to achieving scientific literacy while others are not. This can, to some degree, explain the fact that students' performances in Macau are above the average of the OECD members but not good enough (below other Chinese regions, such as Taiwan and Hong Kong) (OECD 2007).

Given the current situations of science teaching and learning in Macau, how to exploit the advantages of these features and rectify their shortcomings is a challenge that Macau government, school administrations, teacher education institutes, and science teachers have to face. Since there is not a unified examination system in this region, it is commonly recognized in the community of educators that some measures must be taken to maintain the autonomy of schools and science teachers, and at the same time, to ensure the quality of teaching. Currently, the Education and Youth Bureau is promoting an initiative entitled *Establishing Excellence of Education and Improving All-round Development*, which intends to make "requirements of basic learning capacities" and "curriculum guidelines" for all learning areas and subjects, including science-related ones (EYB 2009). Particularly for the subject of natural science, so far, two official documents concerning the "requirements of basic learning capacities" for junior and senior high school students, respectively, have been completed and will be released by the government soon, and the "curriculum guides" accompanying these two documents are in the process of designing. I hope that this initiative will play important roles in consolidating the status of science education in the whole system of basic education, explicitly clarifying the goals of science education in achieving scientific literacy for all students, disseminating advanced ideas and strategies of science education, guaranteeing the minimum levels of teaching requirements, and raising the quality of science teaching. It should be noted that over half of the disadvantages in science teaching and learning in Macau are related to science teachers, who show the following characteristics as identified in our evaluation project: Young teachers account for the major proportion of this population; it is a prevalent phenomenon that science teachers teach more than one science subjects and some of them even teach humanity subjects besides sciences in their schools; teachers are usually overloaded in their teaching; a large number of science teachers have not received any form of teacher education—either learned in teachers' universities or obtained the Postgraduate Certification in Education (PGCE), which is admitted by the EYB as the minimum requirement for becoming a teacher (We et al. 2009). Furthermore, as another study showed, a large proportion of science teachers lack self-efficacy in their teaching (Wu 2009). Obviously, improving professionalism of science teachers is another problem in science education in Macau, and this should be solved by the close cooperation and collaboration of the educational administrative authority, teacher education institutes, and schools.

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Chapter 5
Science Education Research and Practice in Malaysia

Lilia Halim and T. Subahan Mohd Meerah

Abstract Science education is often seen as the vehicle for Malaysia to become a developed country based on science and technology. As a result, Malaysia has made the policy of producing 60 % of its critical mass of educated people, both at school and university, in the science and technology discipline. However, we have yet to reach the target because of the decline of interest in science among students. Various strategies and policies have been formulated and adapted to arrest the situation. This chapter begins by looking at the historical and social contexts that have driven developments in science education in Malaysia. With this context, it brings forth the research that has been embarked on looking at the issues, problems and effectiveness of the practices in science classrooms. This chapter also looks critically at the usefulness of research in informing practice including the barriers hampering the bridging of the gap between research and practice. To conclude, possible and future trends of research in science education are recommended.

5.1 Introduction

Malaysia, like any other developed countries, realises that the driving force of one's economy is largely on the innovation and commercialisation of scientific knowledge. Thus, it is not surprising to see Malaysia's strong emphasis on learning science in schools and universities, so as to have the critical mass in the field of science and technology. Science subjects are taught early in Malaysian education system. In the 1960s and 1970s, science as a subject was introduced from Year 1 in the primary level. In the 1980s, science was not taught as a core subject, but students still learnt science in the subject called 'Man and Environment' where science was one of the integrated elements. In the mid-1980s, science as a subject was reintroduced again and has since been taught in the primary education level starting from Year 3.

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Science continues to be offered as a core subject for all students at the lower secondary level (age 13–15 years old). Particular emphasis is given on the acquisition of scientific knowledge, mastery of scientific and thinking skills, and inculcation of moral values concurring with the premise that man is entrusted with the responsibility of managing the world and its resources wisely. In order to understand the current status of science education in Malaysia and suggest future directions in science, a historic review of the development of science education is presented next in this chapter.

5.2 Science Education in Malaysia

Science teaching had a humble beginning in Malaysia in 1937. Strong recommendations were made for the introduction of science in the curriculum in all English secondary schools for boys and girls. However, Malaysia was unable to do so because there was lack of adequate equipment and qualified science teachers available. A special education committee was then appointed in 1939 by the Government of the Straits Settlement and the Federated Malay States to formulate the aims of science education and draw up a science syllabus. This committee unanimously advocated that every young mind, whether boys or girls, should be led to appreciate the wide field of interest opened up by the study of science and should be trained to understand and apply the methods of scientific reasoning and investigation.

The Commission of Higher Education in Malaya in 1939 also recommended that general science should be taught in secondary schools. This school science course was to be planned as a self-contained whole, designed as preparation for life in a scientific age rather than as a mere preparation for examination or for a scientific career (since only a very small proportion of secondary pupils continued with the study of science after the School Certificate stage). The commission also recognised that the education needs of those following scientific or technical careers should not be allowed to overshadow the needs of the others who would form the ordinary educated citizens of the future.

After the Second World War, a four-year course in general science was to become an integral part of the curricula of all secondary schools. The syllabus followed contemporary patterns in Britain. A Post-School Certificate course in science was not then available, but a course of higher studies in science was taught at Raffles College, Singapore.

5.3 Post-independence Science Education

After Malaysia's Independence in 1957, science education was given a special place in the educational policy. It was seen as the area of the curriculum most likely to provide a stimulus to economic growth through increases in the supply of scientific and technical manpower on which development would depend. Another broad purpose of teaching and learning science was that it is seen as a cultural and educational discipline. In other words, a firm basis in science subjects is not only for research but also for development.

The five-year Malaysia Plans since then all have stressed the commitments to expand and improve the quality of science education. The government knows that the real, long-term solution lies in raising the quality of teaching and learning science, in its efforts to develop a progressive society committed to science and technology. This can be seen from its commitment in modernising the curriculum.

5.4 Curriculum Reform in Science

In the early 1960s, science was still offered in primary and lower secondary schools as a general science course. The pressure of nationalistic fervour to become a strong nation through the development of science and technology encouraged leaders to focus curriculum reform on science subjects. It was planned to develop in line with government goals for socio-economic development. In 1966, Malaysia started to update and reform the science curriculum, beginning with the lower secondary level. A decision to adopt existing new curricula from other countries had to be taken because of the shortage of local expertise and educational resources.

It was decided to base the revisions of the science curriculum on British models, for three reasons: first, the structure and organisation of the Malaysian education system reflected its colonial origin, whereas pedagogical traditions resembled those in the UK, and many science teachers and decision-makers had received at least some part of their training in Britain; second, initial assistance in terms of expertise in initial training and implementation was promised by the British Government if its curriculum was adopted; and third, the prestige of the British advisers working in Malaysia played a sizable role. In this light, the Scottish Science Project was adopted to provide a basis for integrated science for the lower secondary school science curriculum. The philosophy behind this curriculum was to enable children to learn science better through developing their interest and observation in what they were learning.

5.5 Integrated Science Course

Primary work in adopting the Scottish Science Project materials was conducted from 1968 through 1971. January 1969 saw 20 Malaysian schools begin teaching the first year of a Scottish-based Integrated Science Programme; in 1970, fifty more schools joined the programme, followed by 100 more in 1971. Because of large class sizes in Malaysia (40 plus students per class) as compared with the Scottish situation (20 per class), and anticipated difficulties in training and securing equipment, the two-year Scottish curriculum was extended to three years of study in Malaysia. Integrated science combined work in physics, chemistry and biology under broad topical headings. As a follow-up, Nuffield 'O'-level curriculum in the separate sciences was also adopted for the upper secondary level.

The new science courses have a list of specific learning–teaching goals. For example, for the Nuffield-based pure physics course, they were as follows:

- Learning for the future: to provide pupils with the necessary background so that they may pursue further studies in physics and be users of physics.
- Understanding physics: pupils should acquire a basic understanding of the primary concepts of physics.
- Understanding how scientists think: pupils should be introduced to the process of scientific inquiry.
- Learning how to handle ideas in physics and communicate them: pupils should learn the language of physics.
- Learning with enjoyment and interest: teaching must convey the idea that learning physics is more than just for passing examination.
- Awareness of the social significance of science: pupils must be made aware of the influence of physics on their society and environment.

Adherence to these aims would modify both the format and style of science teaching in Malaysia. In emulating British instructional models, it was hoped that a general strategy of learning through guided discovery would replace the traditional system of authoritarian lectures.

5.6 Modern Physics, Chemistry and Biology Course

In moving towards the adoption of a Nuffield science curriculum, a detailed schedule of activities was planned and a six-year period of development allowed for the following:

1968 Practical in-service courses were held for 120 teachers in physics, chemistry and biology. This familiarisation work was conducted by British instructors.

1969 Practical in-service courses were held for 60 teachers and education officials by visiting British instructors.
Thirty teachers combined efforts in writing sessions to produce Form IV Teachers' Guides and Students' Workbooks.

1970 British instructors again conducted practical in-service courses serving 90 teachers and officials.
Twenty-eight teachers continued the writing efforts of the previous year to produce Form IV materials.

1971 One hundred and twenty teachers received in-service training on the Form IV course of study. These teachers represented the three disciplines: physics, chemistry and biology.

The trial edition of the Form IV Teachers' Guides and Students' Workbooks was published.
Writing sessions begun to produce Form V Teachers' Guides and Students' Workbooks.

1972 Materials were tested in 30 pilot schools.
Practical in-service training was provided for 200 Form IV and V teachers.
Trial versions of Form V materials were completed and published.
Final versions of Form IV books were revised and published.

1973 Sixty more pilot schools were added to the teaching scheme.
In-service training for 200 teachers was conducted by local personnel.
Revision and publication of final version of Form V books took place.

All schools in Malaysia were required the new modern science, physics, chemistry and biology curriculum. All students taking the courses have been provided with the necessary textbooks; schools have obtained some additional laboratory equipment needed for the new experimental situations; and students were to carry out more hand-on activities. Thus, the logistics of implementing the reforms proceeded smoothly.

The national curriculum is regularly being required to ensure the relevance and quality of science education. In the 1980s, the Education Ministry decided to implement the recommendations made by the Cabinet Education Committee regarding the need to provide basic and general education at primary and secondary school levels. With the aim to provide basic education which encourages pupils to acquire full mastery of the basic skills (while providing opportunities to develop their talent, interests, and creativity), it was decided not to offer science as a separate subject at the primary level. Science forms part of an integrated subject and is offered in year four as discussed later. The new primary school curriculum was implemented nation-wide in 1983.

The secondary school science curriculum would also have to be modified to meet the current needs and as continuation of the effect made in the primary level. The Ministry of Education is in the process of developing a new secondary school curriculum in line with the recommendations made by the Cabinet Education Committee (1979) (MOE 1979).

5.7 Science in the Primary Curriculum

In 1979, a Cabinet Committee of Malaysia was formed to look into the implementation of the National Education Policy. Its report stated, among other things, '… *the content of the primary school curriculum is too heavy for children between the ages of six and twelve. Some pupils are not able to follow it, resulting in their mastery of only a few skills'* (para 193: p 100). In addition, it was found that '*the curriculum has been formulated separately according to subjects and there is little* *integration between the subjects in the curriculum*' (para 194: p 100). The Cabinet Committee recommended that:

> The Ministry of Education takes certain steps to ensure that education at the primary school level be in the form of basic education, with emphasis on the learning of the 3R's, that is Reading, Writing and Arithmetic. (para 196: p. 101)

Based on this recommendation and findings from other studies, a new primary school curriculum, which is in line with the recommendation in the Cabinet Committee Report, has been developed.

5.8 The Aims of the New Primary School Curriculum (NPSC)

The rationale of the NPSC is that the primary school should provide basic education. The aims of the primary school curriculum focus on ensuring that the overall development of pupils takes place. Overall development includes intellectual, spiritual, physical and emotional development as well as the development of talent and the fostering of moral, aesthetic and social values.

This curriculum ensures that every pupil acquires the necessary skills, knowledge, values and attitudes. Specifically, the NPSC aims to enable pupils to:

- Master Bahasa Malaysia (the National Language of Malaysia), in line with its status as the national and official language of the country;
- Master the basic language skills, that is, to converse, read and write in the medium of instruction of the school (the three media of instruction are Bahasa Malaysia, Chinese and Tamil);
- Acquire a strong foundation in mathematical skills;
- Acquire learning skills;
- Understand, read, write and converse in English;
- Develop desirable attitudes and behaviour based on human and spiritual values accepted by society as embodied in the Rukun Negara (Malaysian ideology) and to make these basis of daily life;
- Acquire knowledge and understanding of, an interest in, and sensitivity towards man and his environment;
- Interact socially, respect the rights and capabilities of others and possess the spirit of cooperation and tolerance;
- Develop their talents, leadership qualities and self-confidence;
- Show interest, understanding and appreciation in cultural and recreational activities within the context of the national culture and participate in these activities.

5.9 Structure of NPSC

The NPSC (see Table 5.1) is planned to enable pupils to acquire skills in three basic areas—in the area of communication, the area of man and his environment and the area of individual self-development—appropriate to the needs, interests, talents and mental abilities as well as the readiness of the pupils.

The area of man and his environment consists of two components: the humanities and environment component, and the spirituality, values and attitudes component. The humanities and environment component is integrated with the basic skills component at an early stage. Later, when the basic skills have become fairly established, the former is taught separately. The spirituality, values and attitudes component consists of Islamic Religious Education and moral education. These subjects are given special attention as they are crucial to the development of attitude, character and personality.

In 1982, the Ministry of Education of Malaysia launched its NPSC for its limited implementation stage in 305 schools. It was planned that the NPSC takes on the six-year primary education on a year-to-year basis. This meant that the NPSC in 1982 was only for the first-year (Year 1) children, and in the following year, the NPSC was carried on to the second year (Year 2) and onwards year-by-year in the same schools. Meanwhile in each following year, the NPSC went into its full implementation whereby Year 1 was launched in 1983 to all the approximately 6500 primary schools in Malaysia, as shown in Table 5.2.

The NPSC's structure is divided into two phases: Phase I for the first three years and Phase II for the later three years of the primary school education. In Phase I, teaching and learning emphasises the basics in reading, writing and computation.

Table 5.1 The new primary school curriculum

Area	Component	Subject	
		Phase I	Phase II
Communication	Basic skills	Language of instruction Bahasa Malaysia English language Mathematics	Language of instruction Bahasa Malaysia English language Mathematics
Man and his environment	Spiritual values and attitudes	Islamic religious Education for muslim pupils	Islamic religious Education for Muslim pupils
		Moral education for pupils of other religions	Moral education for pupils of other religions
Individual self-development	Humanities and environment Cultural and recreational	Music Art education Physical education	Man and his environment Music Art education Physical education

Source Kementerian Pelajaran Malaysia (1983), Kurikulum Baru Sekolah Rendah—Matlamat, Rasional, Bidang Pelajaran dan Strategi Pengajaran dan Pembelajaran (The new primary school curriculum—Aims, rationale, areas of study and teaching and learning strategies), p. 26

Table 5.2 Implementation of new primary school curriculum

Year	Limited implementation (305 schools)	Full implementation
1982	Year 1	–
1983	Year 2	Year 1
1984	Year 3	Year 2
1985	Year 4	Year 3
1986	Year 5	Year 4
1987	Year 6	Year 5
1988	–	Year 6

Elements in the humanities and environment and the cultural and recreational components are used in the teaching and learning of the basic skills. Apart from that, Muslim pupils study Islamic religious education, while pupils of other religions will attend moral education classes. For the whole duration of Phase II, teaching and learning will continue to reinforce the mastery of the basic skills. In this phase, the acquisition of knowledge and the utilisation of language for thinking and communication are emphasised. In addition, the utilisation of mathematical skills and knowledge to solve problems, to think logically and to understand societal issues, are emphasised together with manipulative skills and business practice. Opportunities are also provided for pupils to express themselves through music, drawing and writing, as well as to understand and use various means of acquiring knowledge.

5.10 Science Education in Primary Schools

In Malaysia, children start their formal education at the age of six, and the primary education extends for six years. Before the introduction of the NPSC in 1982, Malaysian primary school children learned science introduced as part of the subject called man and the environment, and this subject is only introduced at the 4th year of the primary education where basic science topics such as energy, water, air, light, shapes, structure, size, weight and volume are introduced to the students through this subject. The main aim of this subject is to develop an understanding of the interaction of man and his surroundings.

5.11 New Integrated Secondary Science School Curriculum

The Ministry of Education Malaysia then embarked on developing a new secondary school curriculum to replace the ‘modern’ physics curriculum that is more responsive and relevant to the country’s needs. The new curriculum aims to provide general education, as recommended by the Cabinet Education Committee which focusses on the following:

- The overall and balanced development of the individual and
- Orientation of the individual to society.

The entire school curriculum in all subjects from Forms 1–5 (Grades 6–11) has been reviewed, and appropriate changes are made. These changes include the following:

- The integration of the intellectual, spiritual, emotional and physical aspects in the curriculum design.
- The internalisation and practice of the spiritual, moral and citizenship values.
- The acquisition of the essential and basic skills and knowledge. There are profound changes with curriculum design, strategies and techniques of teaching and preparation for the materials and resources for learning of lifelong education.
- The focus is on providing a general education and preparation for lifelong education. The development and implementation of the new secondary curriculum in physics inevitably offer a challenge. The new curriculum was first implemented in 1989.

5.12 Realising 60:40 Policy

Since 1967, Malaysia has set the 60:40 policies for the purpose of ensuring the pool of students taking up science at school and university levels. Various efforts and strategies are planned by Ministry of Education to realise the 60:40 policy. One strategy is the streaming policy.

Prior to 1983, based on the students' performance on the PMR (lower secondary assessment) examination taken at the end of lower secondary school years, students were streamed into science, technical and non-science (arts) tracks at the upper secondary levels. Often, those who are qualified to do science were forced to do science regardless of their interest. In this science track, science was taught as separate subjects (biology, chemistry and physics) to students. Similarly, for those in technical tracks, they were taught science as separate subjects. Students in the non-science track, however, still continued to take science as one common subject.

This streaming policy was later seen to be rigid in that students were not given choice in deciding their future. Since 1983, students have been given more choices at the upper secondary level through the offering of various electives groups such as 'science electives', 'Quranic electives' and 'economic electives'. For those students who are interested in pursuing science and technology as their career can opt for the science electives (biology, chemistry, physics and additional science) in addition to the core science subject. Science is now offered as a common subject to all regardless of what track of studies the students are involved. Science as a common subject to all is in line with the view of providing science for all and a way to promote scientific literacy. With the current practice of 'open system', science education system aims to promote science for all and at the same time providing tracks for those pursuing studies that aim at becoming scientists and technologists.

Another strategy is to provide technical tracks in day schools in addition to building more technical boarding schools. The numbers of boarding (residential) schools that provide 100 % classes for learning science are also increased. Excellent students graduating from these fully residential science schools as well as from the day schools are offered scholarships to study abroad at the tertiary level in the science disciplines. MOE also realises the role of science and mathematics teachers in encouraging students to opt for science stream courses; thus, these teachers, including counselling teachers, are given seminars on the importance of science and information on science-related careers (Buang et al. 2010).

Science education is also supported by other governmental and non-governmental agencies in Malaysia (Syed Zin 2002). The Ministry of Science, Technology and Innovation (MOSTI) plays a crucial role in leading informal and non-formal science education. There are many agencies under MOSTI that operates to execute this aim. For instance, schools organised field trips to National Science Center and National Planetarium, agencies that are established under MOSTI. Non-governmental organizations, such as World Wide Fund for Nature, have actively provided support to the Ministry of Education (MOE) to conduct various co-curricular activities pertaining to environmental science. The Ministry of Education also realises that it has a lead role but this is not sufficient to popularise science; therefore, it emphasises that informal and non-formal learning of science can be the main contributors in the effort of increasing science literacy and interest of people in science and technology. Beginning in 2012, MOE has expanded the involvements of external agencies to support the informal learning of science (MOE 2012).

5.13 Current Status of Science Education

Despite the concerted and systematic efforts in enhancing the participation in science studies as well as fostering positive attitudes towards science and technology, the percentage of students enrolling in science stream at the upper secondary level is still below the targeted 60:40 science to arts ratio. Figure 5.1 depicts the trend of enrolment for students following the science and arts classes for the period between 1981 and 2009. The highest percentage of enrolment students doing science was 31.2 %, and it declined to 29.3 % in 2009.

A similar trend of enrolment is reflected at the tertiary level (see Tables 5.3 and 5.4). Again, between 1995 and 2005, the science enrolments at tertiary level

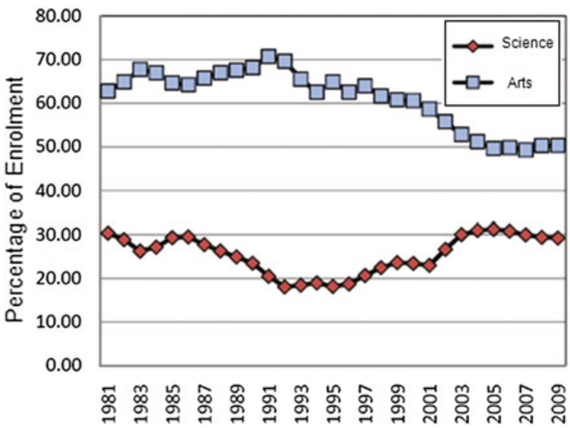

Fig. 5.1 Percentage of enrolment 16 and 17 years old according to science and arts classes between 1981 and 2009. *Source* Adapted from Abu et al. (2011). With permission from Mohd Salleh Abu: Kompilasi dan Review ke atas Penyelidikan Pendidikan Berkaitan Sains dan Matematik di Malaysia, p. 3, Mohd Salleh Abu, Mohammad Bilal Ali, Fatin Aliah Phang Abudllah dan Salmzia Salleh

Table 5.3 Enrolment of first degree courses from local public institutions 1995–2005

Courses	1995	2000	2005
Arts[a]	44886 (59.3 %)	81914 (48.0 %)	103846 (42.5 %)
Science[b]	18171 (24.0 %)	49575 (29.0 %)	71897 (29.4 %)
Technical[c]	12652 (16.7 %)	39305 (23.0 %)	68784 (28.1 %)

Note a Arts includes humanities, economics, business and law
b Science includes medicine and dentistry, agriculture and pure sciences
c Technical includes engineering, architecture and town planning and survey and others
Source Adapted from Awang (2004). With permission from Halimah Awang: Human capital and technology development in Malaysia. International Education Journal, 5(2), p. 241

showed only marginal increase from 24 to 29.4 %, that is far below the target of 60 % enrolment in science- and technology-related courses (see Table 5.3). Thus, Malaysia is in a dire need to create a critical mass of scientific and technical manpower to ensure that its economic growth is sustained and propelled in this era of knowledge- and innovation-based economy.

Reasons for the falling recruitment and interests in science and technological (S&T) studies and careers are many. One of the most cited reasons is the perceived view that school science is unexciting and abstract. Such perception is due to the learning experiences that students undergo including (a) examination-oriented teaching which led to teaching being mainly geared towards passing the national public examinations, (b) the ineffective teaching of abstract topics which resulted in failure to come up with right conception that results frustration to students and (c) lack of practical and experiment activities thus affecting students' interest in and their ability to engage in scientific inquiry (Buang et al. 2010; Phang et al. 2012). Similar reasons are also found among students from other developed countries.

Table 5.4 Student enrolment in public higher institution 2011–2012

Discipline	Year	Total
Education	2011	17824
	2012	19883
Arts and humanities	2011	15547
	2012	16218
Social science, business and law	2011	66432
	2012	67317
Science, mathematics and computer	2011	26075
	2012	27151
Engineering, manufacturing and construction	2011	35635
	2012	39331
Agriculture and veterinary	2011	4713
	2012	4099
Medicine	2011	8193
	2012	8893
Services	2011	6139
	2012	5874
Total	2011	180558
	2012	188766

Source http://www.mohe.gov.my/web_statistik/Indikator_PT-2011-2012.pdf

In a review of research in science and mathematics education in Malaysia, Abu et al. (2011) found that a high percentage of students showed interest in and positive attitudes towards science and mathematics. Results from the ROSE study also showed that the attitudes and interests of Malaysian secondary students towards S&T-related issues and topics were mostly very positive and ranked among the top few nations participating in the study (Schreiner and Sjoberg 2004). However, students still tend not to choose science-related courses at upper secondary and tertiary levels. Factors contributing to that are (a) students' perception that a 'special ability' is needed in learning science; hence, only certain people are able to learn science (Talib et al. 2009); (b) bleak career prospects associated with it; and (c) lack of parental support in pursuing science-related careers (MOE 2012).

The perception of science as a difficult subject—to learn and to excel in—has swayed those able and qualified students to do science to opt for arts-based courses at upper secondary level. As Talib et al. (2009) and Abu et al. (2011) indicated, part of the reason is due to the claim that art-based subjects (such as economics, accounting and Quranic studies) are supposedly 'relatively easier' to learn compared to science-based subjects. Opportunities gaining entry into university is wide since one is likely to get good results by taking arts-based subjects. Lack of knowledge and awareness of careers opportunities in science also hinders students from pursuing science at tertiary level.

The practice of 'open system' in the Malaysian education system at the upper secondary level has facilitated able students to pursue the arts-based courses; prior to 1983, these students would be 'automatically' streamed into the science tracks. The open system in education coupled with the misconception about learning science has further exacerbated the low enrolment in the sciences as compared to that in the arts stream at higher secondary level to be less than the expected 60:40 per cent ratio.

Low enrolment in science is also critical among the students from rural schools. These students fare poorly compared to their urban counterparts in terms of (a) their performance in national examination level in the PMR examination (Abu et al., 2011), (b) lack the motivation to further their studies to the extent the rate of dropouts is high in rural areas (Halim 2004) and (c) ineffective teaching strategies which do not meet their learning and ability needs (Meerah et al. 2010). Low participation in science among the rural students suggests that equal opportunities in learning science is not met and thus obstructs the promotion of science for all, which is one of the main tenets of science education in every science curriculum change and reform in Malaysia.

The results of TIMSS assessment are also an indication of Malaysian science education system, with reference to the other countries. In general, Malaysia performs slightly above the mean average indicating the quality of the science education is good. However, based on the TIMSS reports in 1999, 2003 and 2007, the performance of Malaysian students was found to decline; particularly, Malaysia had lower average achievement in 2007 (20th ranking in mathematics) than in 2003 (ranked 10th) and in 1999, despite an improvement from 1999 to 2003.

One of the factors associated with the declining trend especially from 2003 to 2007 is due to the language of instruction (Zain 2010). The TIMSS 2007 report indicated that countries with large proportions of students from homes where the language of the test (and consequently the language of instruction) is not often spoken had lower average science achievement than those who spoke it more often. In the case of Malaysia, this report indicated that the policy of teaching science and mathematics in English (PPSMI), introduced in 2003, might be the reason for this decline.

In a multicultural society like Malaysia, students speak in their mother tongue at home which would be Malay, varieties of Chinese's dialect or Tamil. The decision to switch the medium of instruction from Malay to English as the medium of instruction in science and mathematics was that the English is the language of scientific and technological knowledge; and thus, mastery of English in the field would ensure effective acquisition of the scientific and mathematics knowledge that is rapidly developed and widely disseminated in English. The implementation of the policy is supported by significant investments in training to improve the English proficiency of teachers as well as through the provision of instructional in materials such as courseware, textbooks, activity books and ICT facilities including computer laboratories, notebooks and LCD projectors.

Despite the systematic and strategic efforts in implementing the PPSMI policy that leads to significant curricular changes, there was much debate among parents, society, politicians and academicians on this policy. The debate revolves around among others (a) the status of Bahasa Melayu as the national language; (b) the readiness and capabilities of teachers teaching mathematics and science in English; and (c) effectiveness of the policy in enhancing science and mathematics learning. Major studies revealed that students in rural school often lag behind their counterparts in urban schools in terms of achievement in science, found that the gap is further widened with the introduction of teaching science and mathematics in English (Ong and Tan 2008; Hudson 2009; Na and Mostafa 2009) and showed that teachers are supportive of the policy, but they are struggling to implement it. Teachers need to deliver the subject matter in the form that can be understood by learners in a language which is either a second or third language to the majority of Malaysian learners.

The successful implementation of the policy also depends on teachers' own linguistic capabilities. Zain (2010) argued that based on 'one of the findings from UNESCO indicated that learning takes place effectively when the medium of instruction is in the mother tongue during the early years of schooling' (*Language Diversity in Multicultural Europe, Comparative Perspective on Immigrant Minority Languages at Home and at School* at www.unesco.org/most/discuss.htm). These pieces of evidence along with the various contentions around the policy led to this policy being abolished in 2012 and consequently replaced with the *To Uphold Bahasa Malaysia and To Strengthen English Language (*MBMMBI) policy. The MBMMBI policy involves the use of Bahasa Melayu as the medium of instruction in all National Schools and the use of the respective mother tongues in all national-typed schools for mathematics and science. At the same time, English language is enhanced through the improvement of methods of teaching English.

5.14 Future Directions

The state of school science education indicated earlier is due to many factors among which are curriculum, quality of teaching, assessment and quality of teachers. Thus, suggestions for future directions would be to improve in all aspects.

5.14.1 Science Curriculum

It is clear that the utmost aim of science education in Malaysia is to enable the country to have the manpower required in the science and technological field. The development of an updated and relevant science curriculum is ongoing. Currently, in the Malaysia Education Blueprint 2012–2025, the education system is giving emphasis on (a) strengthening critical thinking and character building; (b) cultivating creativity, innovation and entrepreneurship; and c) strengthening communication, resilience and self-confidence competencies. As a result, the 1987 New

Primary Science Curriculum and the New Integrated Secondary Science Curriculum are being revised. In the transformed curriculum, cultivating creativity and innovative thinking are being emphasised in the design subject (MOE 2013). Integrating engineering element such as design thinking and problem-solving in the curriculum presents opportunities for students to acquire skills such as problem-solving, creativity and innovation.

Similar initiatives are also implemented in the USA, and it has been shown that through engineering design thinking and activities, students are able to develop higher order thinking skills, problem-solving skills, skills for working collaboratively and increase interest in learning science (Macalalag and Jurado 2011; Becker and Park 2011; Stohlman et al. 2012). This initiative is known as science, technology, engineering and mathematics (STEM) education. STEM education has gained prominence in Malaysia since 2012; in 2014, the Ministry of Education developed a STEM education conceptual framework, and this framework encompasses all levels of education from preschool to tertiary level. The framework outlines the goals of STEM education in Malaysia, the outcome expected of the students, the role of the practitioner and the relevant modality to achieve the goals.

Another derivative of STEM is the integration of entrepreneurship discipline with the teaching of science (Buang et al. 2010). The concept of integrating elements of entrepreneurship with design thinking based on scientific knowledge is conceptualised as 'entrepreneurial science thinking'. Studies have shown that through the inculcation of entrepreneurial science thinking, students were able to use scientific knowledge to plan technology-based products that can be commercialised (Armstrong and Tomes 2000; Menzies 2010). Buang et al. (2010) created curriculum materials based on the entrepreneurial science thinking concept and found that students were motivated and saw the relevance of learning science after being exposed to the entrepreneurial science thinking activities. Students in Buang et al.'s study also mentioned that they would like to be scientists in the future, and some of them were able to see that career in science goes beyond being a scientist. Buang et al. believed that entrepreneurial science thinking-based curricula can fulfil the needs of Malaysia to develop manpower that is innovative and able to turn scientific discoveries into commercialised products as well as increase participation of students in science and technology disciplines.

5.14.2 Quality of Teaching

Quality of teaching is also a factor that determines students' interest in science and attainment levels. Research has shown (e.g., Osborne 2007) that inquiry-based methods are science teaching pedagogies that contribute more to increase student interest in science compared to didactic and deductive method that is still widely practised (Abu et al. 2011).

One way to encourage teachers to use innovative teaching methods that are often based on research drawn upon theories of education are to provide curriculum materials. However, science teachers lack the time and have difficulty in translating research evidence-based teaching into their practices. Ratcliffe et al. (2006) and de Jong (2005) suggested that science teachers will consider and adopt the research evidence-based teaching in their practices when facilitated through the provision of curriculum materials. Chances of teachers using and accepting as well as the success of the curriculum materials to be effective will increase, when teachers and researchers collaboratively develop the materials.

The newly released Malaysian Education Blueprint 2013–2025 also stresses developing students' higher order thinking skills. Thus, teachers and curriculum developers are directed to foster higher order thinking skills (HOTs) with the hope to understand and improve the dynamics of teaching and learning process including science teaching and learning. Consequently, the International Baccalaureate Middle Years Programme (IB-MYP) was deemed to be the way to change the teaching and learning approach in the national secondary schools with the purpose of developing students' thinking and innovative skills. As a pilot project, IB-MYP will be implemented in selected 10 national schools and projected to train a total of 800 teachers. Like any MOE projects emanated from specific policy, the impact of the programme is researched and serves as an input to further policy-making. In this instance, policy drives research, and in turn, research provides feedback to policy-making.

Science teachers should also adopt alternative pedagogies when teaching students from rural areas and those in the interior, where the schools lack the facilities such as laboratory and educational resources compared to their urban counterparts, so that the implementation of a centralised science curriculum as in Malaysia is felt by all. In Meerah et al. (2010) study on teachers teaching marginalised children using alternative pedagogies such as toys, the students' environment and games had managed to improve their interest in science; and the science teachers were facilitated to adopt the alternative teaching strategies through a collaborative action research.

5.14.3 Quality of Assessment

As indicated by Osborne (2007), there is still a lack of assessment in science education that engages students in higher order thinking such as constructing arguments, evaluating and interpreting data and asking questions. Similar situations also exist in Malaysia where the focus of assessment is still on content or cognitive skills related. Malaysia's performance in PISA is an indicator of the nature of assessment that focuses on low thinking skills. Malaysia ranked third in the bottom third of 74 participating countries in PISA 2009 and 2012.

Malaysia is currently moving towards implementing school-based assessment that would allow more opportunities in assessing for learning skills such as problem-solving or creative thinking. This innovation is still in the pilot stage since various issues need to be addressed in any curricular changes, namely the teachers' competency, as well as students' and parents' acceptance of the improvement.

Research also needs to be done on how to assess problem-solving or creative thinking. In the context of science education, school-based assessment related to assessing science process skills was introduced in 1995. The goals of evaluation of science laboratory skills, also known as PEKA, are commendable, but in a way similar to the implementation of the policy of teaching science and mathematics in English, teachers are unable to implement PEKA effectively.

Abu et al. (2011) found that science teachers lack the understanding of the concept of PEKA, that is developing students' proficiency in science process skills through a series of experimental work that students have carried out. Instead, teachers tend to evaluate their students with the aim of giving good grades at the end of the assessment. In other words, science teachers tend to perform summative rather than formative assessment for a process-based activity such as experiments. Yong and Sam (2008) asserted that there is yet available assessment frameworks for teachers to be used as a guide in executing school-based assessment. Hence, there is an urgent need to develop an assessment framework that is usable, valid and reliable. Thus, future directions would involve more research on how to raise the concern level of the teachers to curricular changes.

5.14.4 Quality of Science Teachers

Curriculum change is a continuous process, and there is a need for in-service and professional development courses for teachers in order for them to adapt to the changes as well as updating their content knowledge and the pedagogical and curriculum skills and knowledge. Professional development needs to be done constantly as Osborne (2007) highlighted changing teacher pedagogy cannot be done through on–off courses. Other than attending courses, ongoing professional development could be achieved through constant change of ideas, discussion and on ways to improve or adopt innovative teaching methods. Such teaching and learning collaborations, where teachers who are familiar with the realities of teaching are interacting together, are able to collaboratively improve teaching and learning.

The head of science department at the school has an important role in facilitating such collaboration; and these heads of department themselves also need professional development so that they can play a more effective role in the professional growth of their science colleagues. In addition, research evidence should also be integrated in the standards of science teachers; thus, this would ensure the adoption of innovative teaching based on research.

Besides these courses, teachers are also encouraged to further their studies. Some of them may receive scholarships to continue their postgraduate education to further improve their knowledge and skills in education fields. The expansion in postgraduate education has been tremendously brought about because of the increase in capacity of providing more opportunities to pursue higher education locally with the opening of more universities to concentrate only on postgraduate research education programmes while reducing the intake of undergraduate students.

Postgraduate programmes prepare students to acquire research skills and embark on research. Most research in Malaysia is from these graduate students, of course with their supervisors or their lecturers. There has been a flux of research work. This is also true in the field of science education, where students and their supervisor carry more research work than their lecturers on their own. However as argued by Ayob (2008), the impact of such research is lacking since the focus of the research conducted by postgraduate students is personally oriented. What is needed is more of longitudinal studies whereby the impact will be more meaningful.

Continuous professional development of science teachers could also be achieved through constant reflection on one's practice systematically. This self-reflection disposition is especially helpful and important for student teachers who are able to see how theory informs their practice, particularly during their teaching practice. An experience gained by a student teacher conducting action research on her own practice allowed her to realise the importance of teaching for understanding and the importance of research in teaching as a novice in research. Through action research, student teachers are able to develop reliable situational knowledge (Halim et al. 2014a) that promotes professional development.

In Malaysia, science teachers are encouraged to improve their teaching and their students' learning through conducting action research by themselves, either individually or collaboratively with other teachers or outside experts, by working in their own classroom. Teachers are also encouraged to present or share their research findings with others. The Ministry of Education even holds the national competition as well as offering recognition for the best action research award. It is hoped that such a systemic effort would encourage research culture on the part of the teachers in order to improve science teaching and learning in schools. This practice needs to be extended to all science teachers, and research could be done to see the impact of conducting action research on one's professional development growth.

5.14.5 Science Teacher Educators

Quality science student teacher depends on the quality of science teacher education programmes. If we are to prepare a high-quality science programme, we need to have quality teacher educator workforce. So far in Malaysia, there is no standard of science teacher educators. Having such a standard will ensure that science teacher educators have the capabilities to design and implement teacher education programmes, institutes and workshops. A tentative framework of the standard proposed by (Lederman et al. 1997) includes that science teacher educators, among others, have a strong science knowledge base and understand science pedagogy, curriculum, instruction and assessment, and research capabilities. Abell et al. (2009) suggested an additional standard that is knowledge for teaching preservice teachers. Research on validating these standards in the Malaysian context and its effect on the quality of science teachers should be a research agenda.

5.14.6 Research-Based Policy

Malaysia continuously reviews educational policies with the aim to constantly improve the quality of science education. Often, policy development and changes related to education have been based on emulating best practices. These best practices are drawn, normally, from outside of Malaysia such as Lesson Study (Japan), I-Think Programme (UK) and International Baccalaureate (IB) curricula. Often, these best practices are implemented as pilot projects.

Development of policies and monitoring of the execution of policies are now, however, increasingly based on research commissioned by the ministry. A task force has been set up in the ministry—Education Performance and Delivery Unit (PADU), and its role is to monitor and ensure success of the national blueprint. Policy research is often conducted in two ways by (a) foreign educational consultants and (b) local educational consultants namely the local academics. In both situations, ministry officials are involved as collaborators, and the research is supervised by the related departments in MOE.

Recent review of Malaysian education policy was led by UNESCO (2012). Pilot projects such as implementation of IB curricula in the Malaysian context was researched on and done collaboratively with foreign and local educational consultants. An example of local academics involved solely in policy research is the reviewing the 60:40 policy that is currently ongoing. Preliminary findings show that there is a gap between the understanding of the needs of the policy and the practice at the grass root level. Preliminary findings also indicate that the realisation of 60:40 needs to be looked in a holistic manner since the realisation of the policy is dependent on gamut of factors such as quality of science teachers, quality of science teaching and learning, careers in science and technology, and parents involvement.

While it is acknowledged that an independent review or research by foreign consultants has its benefits, nevertheless, they will be not be able to understand fully the culture and context of the educational system and practices. More participatory collaboration between local academics and policy-makers as well as practitioners should be encouraged. Ongoing formative evaluation should be carried out on the effectiveness of pilot projects so that the projects are adapted to the local context before nation-wide application. Drawing on outcomes from local research to inform policy should be enhanced. A national clearing house on educational research should be institutionalised, thus could benefit the research outcomes and inform the policy-makers in which the findings are grounded in the local context and understanding.

5.15 Gap Between Research and Practice

Malaysia believes in the influence of teachers on student's achievement, thus always maintains the need to improve teachers' quality. However, studies have failed to identify which teachers' characteristic is a strongly determinant of school achievements (Idris 2012). It has, nevertheless, been shown that teaching of effective teachers—namely how they behave when they were in the classroom—has impact on their students' achievement (MOE 2013; Idris 2012).

Research (Halim et al. 2014b; Stigmar 2010) has also shown that effective teachers are those who are able to communicate effectively, think critically and plan systematically. The researchers further suggested that effective teachers are those who acquire research skills and have the ability to accommodate needs of diverse abilities. In science education, knowledge of students' preconceptions and misconceptions is the knowledge base derived from research, and this knowledge base along with other types of knowledge base (Darling Hammond et al. 2005; Shulman 1987) is available for teachers to understand and value which needs to be adapted to within educators' specific contexts (Kreber 2002). One way to effectively influence the use of research in practice is by getting teachers to involve in action research.

In the Malaysian context, even though action research among teachers has been propagated since 1994 and it is still ongoing, the heavily centralised education system appears to be the main barrier to its effectiveness. The education system, centrally controlled, made it unnecessary for teacher to explore the use of research in their teaching. Instead, teachers will seek for directions and advice from the top; and the top-down approach seems to work well in this centralised system. The technical model of teacher competency, that is, one that is assumed to develop competencies through direct application of innovations without problems, appears to be strong in the Malaysian education system.

Thus far, no incentives for teachers who conduct research or completed their further studies were given. The action research culture programme, even though is ongoing with national awards being set up, has also been on a decline, to foster teachers to carry out research in order to improve students learning. Nevertheless, incentives are provided for teachers to do collaborative research with their university counterparts. Focus on teachers' quality improvement has been on development of teachers competencies in research.

In this highly centralised system, teachers have always concentrated on teaching students to perform very well at the end of the year external examination which has been used as a measure for accounting school performances. Since the performance in the examinations is what counts, parents have always pressured the schools and teachers to teach to the examination curriculum. Thus, teacher as a researcher is not considered as an important ideal that Malaysia schoolteachers have (Idris 2012).

Perhaps the use of research findings by teachers would be a culture when teachers seek for higher education. As shown earlier in this chapter, the Ministry of Education has propagated the need for teachers to seek for further education, and incentives are being planned to be given on completion of their student teaching education. There are also new changes being implemented such as the teaching of higher order thinking and lifelong learning concepts for teachers, and this would see new light on the use of research in teaching and learning. However, thus far, studies on teachers' quality according to the perception of higher education administrators and other stakeholders do not accord the research elements to the teachers.

5.16 Conclusion

The objectives of science education are to provide the majority of the students, as citizens in the twenty-first century, a firm foundation in science and at the same time to achieve the target number of students needed in the S&T workforce. In meeting both goals, science education in Malaysia has undergone various curricula and policy changes. These changes are still ongoing for the goals are not fully met as well as the need to keep in place to the ever-evolving knowledge in the improvement of science education.

Besides the development of an updated and relevant science curriculum, its delivery and implementation should always be enhanced and a concern to policy-makers and practitioners. Science education research has to some extent managed to influence the practice, and experience has shown that graduate students tend to appreciate and continue to think critically of their practice in light of theories and research findings. Efforts to improve teaching through research on one's own practice, sharing practices and employing research-based knowledge have been also institutionalised.

Nevertheless, the centrality of the Malaysian education system has impeded to some extent the mindset and practice of science teachers to use research evidence in their work. Schools are given the autonomy to determine teaching approaches and strategies. The curriculum specifications for science, however, do provide suggested teaching and learning activities to help teachers plan and implement more effective teaching and learning sessions. Even though the curriculum specifications for science serve as a guide, it is quite common for teachers to follow it religiously. The foundation to overcome, such mindset and practice that are bound by directive orders from the central, has being laid through the expansion of postgraduate studies, thus may be able to reduce the gap between science education and practice. In the meantime, continual improvement of science education in Malaysia through research at higher institutions and working collaboratively with teachers and the MOE, especially the development of curriculum materials and conducting longitudinal studies, should be the priority in science education research.

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Chapter 6
Historical Overview of Mongolian Science Education Development

Oyuntsetseg Nookoo

Abstract This chapter provides an overview of the development of science education in Mongolia. Research results related to science education, standards, curricula and policies are discussed here. However, changes of textbooks, other educational material, teacher training and the professional development of teachers, due to reforms of standards and curricula for science education, are not discussed. This chapter considers the accomplishments and experiences associated with over 100 years of development and changes of science education in Mongolia. It also introduces policies, strategies and the current status of science education. Finally, it presents difficulties encountered in science education in Mongolia, as well as conclusions drawn from this study.

6.1 Introduction

The scientific knowledge and way of thinking of ancient Mongolians were inseparable from their nomadic lifestyle. In order to adapt to living in different environments, they gained experience based on daily observations. Although there is evidence of science education conducted by Mongolian people, there has been a lack of comprehensive research and associated conclusions. Therefore, this chapter provides an overview of science education in this country since 1911, when new types of school were established to provide science education to Mongolians with following periods:

(1) Autonomous period (1911–1921),
(2) Socialist period (1921–1990),
(3) Democratic revolutionary and transitional period (1990–2000) and
(4) The twenty-first century.

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The first part of this text on the autonomous period of Mongolia briefly introduces new science schools established in the country and science education-related subjects taught in these schools. The next section on the socialist period introduces the development of the secondary education system and the changes made to the curricula in order to provide academic science knowledge. In the third part on the democratic, revolutionary and transitional period of Mongolia, an overview is provided on the reforms of science education in that period of transition to democracy. The last part introduces the reform of science education, the implemented projects, the curricula and other results of these changes, the current state of science education and the difficulties that have surfaced during the twenty-first century.

6.2 Autonomous Period of Mongolia (1911–1921)

After the declaration of Mongolian independence in 1911, a new forward-looking tendency focusing on the need to educate the younger generation was established. In 1911, under the rule of Bogd Khaan, a decree was issued to establish a science school. This decree required the establishment of education in the following subjects (Javzankhorloo 2001, p. 38):

- Primary school: subjects such as “mongolian landscape” and “improving Lifestyle”.
- Secondary school: subjects such as “exploring matters”, “processing goods” and “world map”.

This constituted the start of modern science education in Mongolia. Under the remit of the mongolian landscape and improving lifestyle subjects in primary school, some topics related to physics, chemistry and biology were taught. Lessons on finding and storing jewels or other stones and excursions to introduce production processes, such as distilling fermented milk of mares and processing cattle leather, were provided (Ministry of Education 1925a, pp. 5–7).

In the autonomous period, teachers were invited from the adjacent Republic of Buryatia, in present-day Russia, and England to teach science subjects. During this period, there was no centrally approved science curriculum. Teachers had to use materials and textbooks from abroad (Battsetseg 2005, p. 22).

Against this background, schools started to provide pupils with an elementary knowledge of science. Teaching in this period was characterised by an emphasis on practical applications and the natural environment. The teaching of science subjects in school first began in this period.

6.3 Socialist Period of Mongolia (1921–1990)

After the revolution in 1921, primary schools (currently named "The 3rd School") were established, and the first secondary school in Mongolia (currently named "The 1st School") was established in 1923. In these schools, subjects such as material science, astronomy, Earth studies, mathematics, history, physical education, music, literature and languages such as Mongolian, Russian, English, French, German and Chinese were taught. Although a natural science subject was on the curricula, it seems that, most of the time, only the Mongolian language and mathematics were taught due to a lack of teachers. In 1926, the 1st School celebrated its first graduation ceremony, at which 57 pupils were honoured (Begz 2012, p. 2). These graduates were subsequently educated in France, Germany and Russia. They became Mongolia's first citizens to be educated to a high level in science. However, there was only one secondary school in the country until 1929.

In 1925, the second Mongolian teachers' conference was held and approved the first curriculum for natural science for three-year primary schools. In that curriculum, the natural science subject was named "nature" (Ministry of Education 1925b, p. 7). Table 6.1 shows the curriculum.

In addition, a subject called "Mongolian nature" was taught for two hours per week in the second grade of the three-year primary schools.

In 1926, the three-year primary school system was changed to a four-year system and the sample curriculum was approved by the Ministry of Education. This new curriculum was developed to provide instruction on an expanded version of the subject nature that had been taught in the three-year primary schools. Table 6.2 shows the contents of the new curriculum.

This curriculum provides a simple understanding of natural science and the principles of traditional domestic manufacturing processes that were popular in Mongolia.

In 1927, a decision was made to add a new course "Earth" (presently geography) to the curriculum of secondary school (Battsetseg 2005, p. 23). However, according

Table 6.1 Contents of the first curriculum of the subject nature for three-year primary schools (1925)

Grade	Study hours per week	Topics
2	3	Earth, its resources Coal Rocks and minerals Iron, copper, gold, silver
3	3	Plants, effects of sulphur, phosphorus in the growth of plants Bacteria Humanity, life of humans Animals

Table 6.2 Contents of curriculum of the subject nature for four-year primary schools (Ministry of Education 1926, p. 5)

Year	Content
First year	Present local mountains, plains, rivers, trees, plants, soil, rocks and their forms
Second year	Take trips in warmer seasons to collect rocks and plants. Then, identify, name and use them and observe the adaptations of plants and animals to their surroundings for the four seasons of the year. In addition, understand the benefits of animals and the need to protect animals and nature.
Third year	Draw a map of the local area and identify animals. Try to study whether domestic animals and wild animals are beneficial to people's lives.
Fourth year	Understand the world, plants from countries with hot and cold climates, and forests, plains and deserts of the world. Also understand plains, mountains and animals of Asia and Europe. Explain dairy production processes and domestic manufacturing processes of hides and skins, tanning, wool washing, spinning, wool felt and rugs.

to the memories of teachers from that time and research results, until 1935, the science course was named "nature".

Because of the new national programme for general education in schools approved by the Council of Ministers of Mongolia in 1932, the Methodical Board of the Ministry of Education changed curricula for primary and secondary schools. The new curricula indicated that pupils in grades 1–4 must take 30 h of the "natural science" course per year; those in grades 3–4 must take 60 h of the Earth course per year; and those in grades 5–6 of secondary school must take Earth, natural science, chemistry and physics. However, from the school year 1933–1934, physics and chemistry subjects were taught as one course in grades 5, 6 and 7 for 210 h (Battsetseg 2005, p. 24).

Since the school year 1936–1937, physics and chemistry subjects started to be taught as separate courses. According to order No. 234 of the Minister of Education, the first curriculum for physics and chemistry courses was approved in 1938. For example, according to the chemistry curriculum, those in grade 6 had to undertake 34 h of study, those in grade 7 had 68 h of study and those in grade 8 had 102 h of study, forming a total of 204 h for the chemistry course. In addition, those in grade 4 had to study an organic chemistry subject named "organic substances" for 22 h (Dondog 1972, p. 36).

Thus, in 1938, high schools started to teach physics, chemistry, geography and biology courses individually and, after 1940, science courses became more important. From that time onwards, the geography course has been included in natural science studies.

The content of science education significantly changed and its scope was extended in the 1960s, 1970s and 1980s. For example, with regard to the chemistry course, organic chemistry was added to the curriculum in 1963.

In 1970, general education reform was undertaken, which required adaptations of scientific theory to the new school system. This reform increased the level of scientific theory taught in schools and extended polytechnic studies. For example,

Table 6.3 Changes of chemistry training plan and curriculum of secondary schools (years, grades, hours)

No	Years	Hours (grade)					Total hours
		VI	VII	VIII	IX	X	
1	1938	1/34	2/68	3/102			204
2	1951		2/66	2/66	3/99	3/99	330
3	1955		2/66	2/66	2/66	4/132	330
4	1963		2/66	2/66	3/99	4/132	370
5	1971		3/105	2/70	3/105	4/140	420
6	1976		2/70	2/70	4/140	4/140	420
7	1981		2/68	2/68	4/136	4/136	408
8	1983		2/70	2/70	3/105	3/105	350

new discoveries and important laws of science were taught from grade 8 and, in the chemistry course in grades 9–10, the theory of chemical bonds, the periodic table and the theory of the structure of organic compounds were taught as basic theory (Ministry of Education 1963, p. 12).

In the early 1980s, science started to be taught in secondary schools as more advanced subjects, such as “inorganic chemistry”, “organic chemistry”, “plants” and “animals” (Dashjamts 1972, p. 19).

In accordance with the demands of the national programme of secondary education, the curricula of all science courses changed eight times from 1938 to 1983, and the number of hours of science study advocated in the curriculum increased from 1971 to 1976. Table 6.3 shows the increase of study hours of chemistry (Oyuntsetseg 1999, p. 20).

A characteristic of this period is the greater focus on teaching scientific truths and providing academic knowledge.

6.4 Democratic Revolutionary and Transitional Period (1990–2000)

Starting in the 1980s, the social and political situation of the world changed, especially for the socialist countries, with the occurrence of numerous democratic revolutions. In Mongolia, by the end of 1988, people had started to criticise the socialist system that had endured for 70 years. On 22 July 1990, the first democratic election was held. Social revolutionary changes were made and a transitional period started, in which all sectors of the economy and public life in Mongolia were reformed.

In 1992, a new Mongolian constitution was approved. In line with this constitution, the education policy of the country was newly determined in 1995 and education laws and regulations were updated.

The main concept for this education reform was to establish favourable conditions and environment for the development of individuals who would not be ideologically fixated or dogmatic, but who would instead develop continuously into citizens capable of critical thinking and with the ability to resolve problems, make choices and take responsibility (Ministry of Education 1998). Educational plans and curricula for general education schools were changed in 1991 and 1996; however, significant changes were not made for the concept mentioned above.

During this time of change from a closed society, researchers became able to express their views freely, receive new information from around the world and learn about the latest scientific theories and practices, such as in the fields of psychology, physiology, pedagogy and science didactics.

In 1998, the Ministry of Education approved a policy for reform of the teaching content in general education schools and new curricula.[1]

Following the policy for education reform since 1998, Mongolian primary education standards were developed and implemented (National Centre for Standardisation and Metrology [NCSM] 1998a). These standards presented the areas in which pupils must learn skills and knowledge. These standards applied to preschool, elementary and secondary education levels. In addition, core curricula to implement standards were developed for each grade. For example, content standards (NCSM 1998b) of science for basic education were developed.

Standards of natural science were named "local and natural science" and consisted of three parts. The "local" part included 23 objectives, such as explaining the difference between organic and inorganic, determining the height above sea level and topography of local geographic features, learning and memorising the names of local areas, studying important natural features and protected places in the local area as well as learning the names of protected animals and their distribution. The "social" part (with a "human and society" course) contained seven objectives, such as studying the traditions and culture of local people, whereas the third part, "natural science", contained seven objectives, such as doing experiments and making observations to explain experimental processes and results, making predictions, writing conclusions and learning to use tools.

The core curriculum for grades 5–6 that was intended to implement these standards included content on studying and performing practical work for every topic. At this time, Mongolian general education schools followed a ten-year system, with the years being structured in a 4-4-2 arrangement. The content standards for basic and secondary education are shown in Table 6.4.

As shown in Table 6.4, the subject of geography had the most objectives (41 +27) and the subject of physics had the fewest (10+11). The core curricula were developed coherently from elementary (grades 1–4) to basic and secondary education (grades 9–10). For natural science in basic education, content standards and core curricula for basic education in geography (grades 7–8), biology (grades 7–8), plants and animals), physics (grades 7–8) and chemistry (grades 7–8) were developed and implemented. For example, the core curriculum included learning of

[1]Previously, curricula with a common purpose, and with the same content, teaching methodology and teaching materials, had been provided by the Institute of Education.

Table 6.4 Structure of education standards of science for basic and secondary education

Standards	Basic		Secondary	
	Direction	Number of objectives	Direction	Number of objectives
Geography	Physical geography	18	Physical geography	13
	Cartography	12	Socio-economic geography of the world	14
	Socio-economic geography of the world	11	–	–
Biology	Plants	9	Environment studies/ecology	8
	Animals	9	General biology	6
	The basis for healthy living	6	–	–
Physics—Astronomy	Physics—Astronomy	10	Physics—Astronomy	11
Chemistry	Chemical elements	2	Chemical elements	3
	Chemical substances	4	Chemical substances	3
	Chemical reactions	3	Chemical reactions	4
	–	–	To recognise and use substances	1

the vocabulary of chemistry in grade 7 and studying chemical substances and groups of substances in grade 8, as well as inorganic substances in grade 9 and organic substances in grade 10.

The content standards for science were set as follows: "Teach pupils the fundamentals of science and the basics of manufacturing technologies, develop their skills to use their obtained knowledge in real life, motivate their interest in exploring nature and give them the opportunity to choose a future profession" (NCSM 1998c, p. 98). The first content standards and core curricula were implemented from 1998 to 2005.

From this time, the Ministry of Education divided the content for teaching into stable content (70–75 %) and variable content (25–30 %); the core curricula contained only stable content, whereas the variable content was managed by the schools and teachers themselves. This was a major new initiative, as all content had previously been determined by the Ministry of Education. It was the first step to implementing the idea of an open curriculum because the selection of different teaching methods and content was allowed and this variable content allowed local characteristics and the experiences of teachers to be reflected in the classroom. Subsequently, researchers who studied the first education standards made the following conclusions: the study contents were based on current science subjects, only the contents of subjects were standardised and methodologically they were more focused on the educational actions of the teacher, and the methodology of information transfer dominated (Nergui et al. 2003, p. 4).

In 1999, the content standards for education were widely discussed and researched and the methodology used to implement the core curricula was reformed. Then, the concept of "How to learn" was discussed rather than "How to teach" (Ministry of education 1999a, p. 11) by the Ministry of Education. From the results of these discussions, the following main objectives for the reform of education were identified (Ministry of education 1999b, p. 13):

- To change the teaching to a pragmatic approach,
- To implement pupil-centred learning technologies,
- To make the content flexible and suggest alternative content in view of the particular interests of pupils and their needs and
- To increase the amount taught and to disclose its content to the general public.

Because the available human resources lacked the ability to achieve these objectives, teacher training for all the levels of staff in the education sector was required.

In 1999, several training schemes were organised regionally throughout the country to introduce new educational concepts and objectives to school administration staff, training managers and teachers. Subsequently, in 2000, a team of researchers was selected to develop training materials with the goal of interpreting the idea of changing the teaching methodology among teachers in general education schools. There were such teams for chemistry and physics within the science field among a total of eight teams that were selected. Teams of researchers for implementing new reforms in the subjects of biology and geography were not ready at that time.

Thus, training materials for "technological innovation of chemistry and physics teaching" were developed. During this period, many new ideas related to the standards of the content for chemistry and physics teaching emerged, and a methodology for implementing the core curricula and also new methods of didactical development of content were implemented (Oyuntsetseg et al. 2000; Burmaa et al. 2000). Not only teachers but also researchers could study the recent theories of the psychology of learning and constructivism for the first time. Subsequently, pupil-centred learning technology became more popular in the science subjects.

The cooperative projects between Mongolia and Denmark, namely the "Support Elementary and Secondary Education Development" and "Development of Rural Schools" projects were implemented by the end of the 1990s. Those programmes aimed to strengthen cooperation among the teachers, school administrative staff and study methodologists of the two countries and to exchange their experiences. Positive impacts were achieved on objectives such as improving school environments, increasing public participation in the development of schools and teacher development issues.

According to these projects, generally, teachers of social science and humanity learnt creative teaching methods and used them for their training. However, science teachers did not use such methods much. In addition, the Soros Foundation and the Mongolian Education Alliance worked very effectively in changing the methodology of teachers and made a real contribution to education reform.

6.5 The Twenty-First Century (2000–2014)

In 2000, the Government of Mongolia pledged in its action plan "to renew the educational curricula towards work and life skills development on the basis of traditional and modern industries" (Nergui et al. 2013, p. 11). Following this, school teachers convened in 2001 at the Development of Quality Assurance in Education conference to learn about the latest global trends in education, and to review the achievements and shortcomings of Mongolian educational system reform in the twenty-first century. The principal outcome of this event was the adoption of lifelong learning strategies as a basis for the entire educational system (Ministry of Education 2001, p. 54).

Within this framework, in 2002, the Ministry of Education and Science (MES) approved, via Resolution No. 202, the Development Concept for Revision of the Elementary and Secondary Education Curriculum and Standards.

In 2001, the MES established the Working Group on Reform of the Elementary and Secondary Education Standards, which included representatives of all levels of educational institutions. Despite the shortage of qualified experts and research institutions at the time, this working group was able to prepare 20 standards for general education, including five on the natural sciences: study of nature for grades 4 and 5, and physics, chemistry, biology and geography for secondary education (Ministry of Education 2002, p. 76).

At that time, the national education sector was undergoing a paradigm shift, and the nation lacked experts and expertise, as well as the necessary methodology to achieve the intended paradigm shift. Therefore, UNESCO's four pillars of core competencies: learning to know, learning to do, learning to be and learning to live together, as reflected in the Report to UNESCO of the International Commission on Education for the twenty-first century, were selected as the basis for the review and reform of the national educational standards. Although the UNESCO-recommended model was chosen for adaptation, the working group had to overcome the challenge of developing new standards for natural science subjects and other core educational competencies appropriate for the national context.

On the basis of a review of the latest global trends, general science methods and recent findings in cognitive psychology, the researchers formulated four core competencies necessary for science learning, as shown in Table 6.5.

These core competencies for the sciences were then integrated into each of the curriculum subjects, namely nature, physics, chemistry, biology and geography.

Looking back at the process of developing new standards, we can now see that numerous mistakes were made owing to a lack of experience and expertise, but can also identify a lot of positive results. For example, initially, the purpose of the

Table 6.5 Science competencies

Competencies	Skills
Learning to know	• Identify, recognise, categorise and explain common phenomena • Recognise and express scientific concepts
Learning to do	• Use of theoretical approaches • Use of experimental methods • Use of mathematical calculation methods • Design and modelling skills
Learning to be	• Select and use the environment, tools, equipment and materials properly • Safe and healthy lifestyle • Use media, collect data, make selections, develop and evaluate • Meaningfully write, speak and express oneself in one's native language • Perform self-assessment and development, and have the abilities to perform critical thinking and draw conclusions • Use appropriate ways for life issues • Differentiate positive and negative characteristics of phenomena, evaluate consequences and consider aesthetically and emotionally using one's beliefs
Learning to live together	• Respect others and share their views, and communication skills • Manage collaborative processes and teamwork • Contribute to safe living conditions in your environment • Assess the negative influences of scientific and technological achievements for the environment, and the prevention of and protection against these influences

standards for natural science subjects for elementary education was stated to be, "To be able to explain, using the scientific knowledge obtained at primary level, the general laws of the universe, natural phenomena and relationships in a comprehensive and multi-factor manner, to teach the skills to utilise knowledge and to lay down the basis for more specialised natural science learning" (NCSM 2004c). This example demonstrates that the statement of purpose was too general and the curricula were not clearly defined, with only one cluster domain and a disconnect between the contents (Ministry of Education, Culture and Science 2009). An example of how the standards define clusters, knowledge and skills for natural science subjects today is shown in Table 6.6.

Meanwhile, the content of other standards for the sciences was broadly defined as "matter", "qualities of matter" and "changes of matter and the environment" (domains) (NCSM 2004c). Table 6.7 shows domains of science education standards.

Each domain includes a specific set of knowledge and skills. For example, the standard for basic education in chemistry includes 71 skills in 3 domains of 10 knowledge areas (NCSM 2004b), the physics standard requires 115 skills in 3 domains of 19 areas (NCSM 2004e), geography 62 skills in 9 areas (NCSM 2004d) and biology 45 skills in 5 areas (NCSM 2004a).

Each standard comprises informative, normative and supplemental parts. The first of these includes an introduction and guidance, the normative parts consists of factors such as the educational concept, curricula, teaching and assessment

Table 6.6 Domains and knowledge of natural science education standards

Level of education	Domain	Knowledge
Elementary (grades 4–5)	Inanimate and animate nature	1. Inanimate objects, life and habitat 2. Nature of inanimate objects and living organisms
Basic (grade 6)	Natural phenomena	1. Light 2. Sounds 3. The electricity and magnetism 4. Phenomena of the surface and deep earth 5. Conversions of substances in nature 6. Life of organisms

Table 6.7 Domains of science education standards

Chemistry		Physics		Geography		Biology	
Domain	Code	Domain	Code	Domain	Code	Domain	Code
Chemical substances	2Ch1 3Ch1	Physical objects and phenomena	2Ph1 3Ph1	People and the environment	1Ge1 2Ge1 3Ge1	Organisms	2Bio1 3Bio1
Properties of chemical substances	2Ch2 3Ch2	Physical properties and their change	2Ph2 3Ph2	Environmental and social interactions	1Ge2 2Ge2 3Ge2	Biological species	2Bio2 3Bio2
Chemical reactions	2Ch3 3Ch3	Physical alterations and energy	2Ph3 3Ph3	Regions	1Ge3 2Ge3 3Ge3	Habitats	2Bio3 3Bio3

Note 1Ge1: 1-Elementary, geography, 1-domain-1; 3Ge2: 3-secondary, geography, 3-domain-3

methodology, whereas the supplemental part includes definitions and sample assessment exercises.

The second set of standards for general education in Mongolia, approved in 2004 by the National Centre for Standards and to be observed for five years, introduced the concept of assessment standards for the first time. The comparison of standards 1998 and standards 2004 is shown in Table 6.8.

From 2004, schools and teachers were required to develop their own curricula under the open curriculum policy. However, this new requirement posed problems. To address these, a sample framework for curricula was developed in 2005, which recommended teaching of the concepts of light, sound, electricity and earthquakes at grade 5, whereas ideas pertinent to human life, such as the origin of life, biological rhythms, photosynthesis and the genetic revolution, should be taught at grade 6 (Institute of Education 2005).

An assessment of the educational standards conducted in 2009 revealed that, while the concept was accepted and understood widely among the education circle, the enforcement of standards remained weak, with many teachers facing difficulties in implementing the standards due to their abstract nature.

Table 6.8 Comparison of 1998 standards and 2004 standards

Parameter	Content standards, 1998	Education standards, 2004
Type	Content standards	Competence-based education standards
Level	• Elementary education • Basic education • Secondary education	• Elementary education • Basic education • Secondary education
Structure	• Objectives (standard) • Core curriculum (non-standard)	• Introduction • Concepts • Content standards • Evaluation standards
Objectives	Knowledge Skills	UNESCO's four pillars of core competencies: learning to know, learning to do, learning to be and learning to live together
Appendix	Core curriculum	Principles of methodology development

Although the new educational standards were understood and accepted from a methodological point of view, the curricula tended to be overly academic and teachers did not know how to implement the child-centred teaching methods. There was a lack of support for the implementation of the natural science educational standards. At that time, the implementation of an appropriate assessment mechanism was delayed due to the transition from 10 to 11 years of teaching at schools, which sparked heated public debate. However, overall, it can be concluded that we still do not have specific data on the implementation of these standards, even today.

In 2006, the Government of Mongolia approved the Master Plan for the Development of Mongolian Education in 2006–2015, and the State Great Khural (Parliament) adopted the Mongolian Millennium Development Goals-based Comprehensive National Development Strategy in 2008 (Government of Mongolia 2007), which defined the overall goals and development indicators, implementation strategy, required resources and funding opportunities from multiple sources.

Under this strategy, the state decided to switch from a general education system lasting 10 years in line with that of the former Soviet Union to a 12-year system. The associated Policy on General Education Schools was approved via Resolution No. 236 by the Minister of Education in 2006 (Ministry of Education 2008). The switch to a 12-year education system allowed education to be started at a younger age, improvement of the quality of education by adopting internationally accepted standards and the introduction of educational certification that is recognised by other countries.

Under this policy, the secondary school curriculum was modified in 2007, 2010 and 2011. The reform of 2007 introduced two teaching plans for teaching sciences, with one approach being the study of these subjects as integrated science, and chemistry, physics, biology and geography being offered as electives. The second approach was to differentiate the study subjects and make them compulsory for all pupils. School teachers had to decide for themselves which of these two approaches to choose and utilise. However, in practice, it was demonstrated that the first approach listed above posed problems for teachers because standards, curricula and textbooks were not integrated well enough, and there was a shortage of teachers trained to teach the subjects as an integrated course. Given these outcomes, most researchers agree that the second approach listed above is more suitable for Mongolia, which is characterised by a small and widely dispersed population.

The transition of schools to a 12-year education system began in the autumn of 2008 and is planned to be completed by academic year 2014–2015. A sample of the science curriculum, as approved via Resolution No. 369 by the Minister of Education and Sciences on 28 September 2011 (Institute of Education 2011), is shown in Table 6.9.

The preparation of the national curricula for 12-year education in the course of implementing the transition since 2007 became a significant step for the curriculum reform working group. The contribution of each academic year to the development of pupils' comprehensive competencies in natural sciences was formulated in the general expectation part, and the components of curricula were broken down further into expected outcomes, knowledge, skills, uses and evaluation sections. A consultancy team from New Zealand advised on the preparation of this target outcome-based programme. Since no follow-up assessment has been conducted on the overall quality, it is too early to comment on the impact of this reform. Such assessment can only be carried out by monitoring the results at graduation, the awarding of certificates and the scores in university entrance exams.

Despite the fact that many projects and programmes were implemented for the reform of teaching methods, numerous problems and challenges still remain. In 2004, it was necessary to abandon teacher-centred education and replace it with a child-centred approach. Although a training module for the development of new education standards and curricula was widely promoted among all school teachers and other employees, the regular use of the standards in classes was rather limited (Luvsandorj et al. 2005).

How can pupils' interest in the sciences be increased? How can lessons be taught in an instructive way that also makes the subject more interesting? How can the development of pupils be promoted through science classes? These were the prominent questions at the beginning of the twenty-first century. In order to find answers to these questions, the MES prepared and distributed teacher guides on the Development of Classroom Culture for Science and a training module (Oyuntsetseg et al. 2005). The task was managed and implemented at the request of the MES by a research team at the Education Research Centre at National University of Mongolia (NUM). The team reviewed the priorities and significance of teaching science subjects at schools, examined curricula, experiences and lesson assessment methods in selected foreign countries, and introduced the best practice examples for each at grades 1–10.

The implementation of the joint MES and Japan International Cooperation Agency's (JICA) "Teaching Methods Improvement towards Children's Development Project" to provide methodological support to secondary schools brought significant change in terms of the way the sciences were taught at secondary schools. At Phase

Table 6.9 Science subjects in curriculum for 12-year schools (grades, hours)

Contents	Subject/grades	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Fixed hours	Biology	–	–	–	–	–	–	**70**	**35**	**35**	**70**	**70**	**70**	**1734**
	Geography	–	–	–	–	–	–	**70**	**35**	**35**	**70**	**70**	**70**	
	Physics	–	–	–	–	–	–	**35**	**70**	**70**	**70**	**70**	**105**	
	Chemistry	–	–	–	–	–	–		**70**	**70**	**70**	**70**	**70**	
	Health	**28**	**32**	**34**	**34**	**34**	**34**	**35**	**35**	**35**	**35**	**35**	**35**	**406**
	Humans and nature	**28**	**32**	**34**	**34**	**68**	**68**	–	–	–	–	–	–	**264**
Total time	–	668	672	714	714	782	782	1085	1120	1120	1015	1015	1015	**10702**
Time for science	–	**56**	**64**	**68**	**68**	**102**	**102**	**210**	**245**	**245**	**315**	**315**	**350**	**2140**
School discretionary hours	Civil education	28	32	34	34	34	34	35	35	35	35	35	35	**406**
	Electives	28	32	34	34	34	34	70	70	70	175	175	175	**931**
	Project work	–	–	34	34	34	34	–	35	35	–	–	–	**136**
Annual load		724	736	816	816	884	884	1190	1225	1225	1225	1225	1225	**12175**
Average load per week		22.6	23	24	24	26	26	34	35	35	35	35	35	–
Daily load		4.5	4.6	4.8	5.2	5.2	5.2	6.8	7	7	7	7	7	–

Note When this curriculum was used, the duration of elementary education was six years, but it was then changed to five years by the Education Law of 2012

1 of the project in 2006–2009, eight elementary education subjects, under the categories of humans and nature, and humans and the environment, such as mathematics, physics, chemistry and IT, were selected for reform of their curricula. The project allowed Mongolian teachers and education managers to learn about methods of studying in lessons and more than 100 lesson plans together with Japanese experts, to select the best cases and develop their own curricula, appropriate for the national context, and then to test and improve them by applying them at nine selected schools in the capital city and two provinces. As a direct result of this project, eight training videos and 24 teachers' guides for eight subjects were produced and disseminated over three years. Two more manuals were prepared based on lesson monitoring. In total, more than 100 teachers and experts from pedagogical institutions were involved in the project implementation activities (JICA/KRI International Corp. 2009, p. 15).

After the completion of Phase 1 of this project, a follow-up study was conducted at selected schools, revealing that the Learning-Based Teachers' Guide recommendations were difficult for teachers to use, so it was agreed that a mechanism to elaborate them further and emulate this methodology is necessary. On this basis, the MES requested that the JICA continue the funding of this project. Following approval, the JICA Phase 2 Project "Strengthening Systems for Improving and Disseminating Child-Centred Teaching Methods" was successfully implemented during 2010–2013. Under this project, child-centred teaching methods were introduced and tested at 23 selected schools in four provinces and one capital city district. The Sciences Education Centre, based at the NUM, and the Primary Education Centre at the State University of Education (SUE) played important roles in developing the national methodology for lesson study.

A dedicated taskforce comprised of province/district-level educational experts, school principals and teachers was established to disseminate the child-centred teaching methods across selected schools. Along with this, training courses for national, regional and local "trainers for trainers" were conducted on a regular basis. Among more than 120 school principals, teachers and education managers who attended professional development training in Japan, 80 % of the trainees were teachers of mathematics and science.

As a result of these efforts, an initial pool of teachers and national experts on child-centred teaching, school-based professional training and lesson study-based science teaching methods was created. Table 6.10 lists published guidebooks related to science according to the project.

The project results were published and disseminated to all schools and teachers in Mongolia. As of August 2013, 487 out of 752 schools nationwide (about 65 %) conducted lesson study exercises more than twice in the 2012–2013 academic year, and methodology training was conducted in 16 out of 21 provinces and in Ulaanbaatar City (JICA/KRI International Corp. 2013 p. 11).

It was expected that the project's overall goal would be achieved by 2016. Two organisations, namely the Institute of Teachers' Professional Development, which was disbanded during the transition period of 1990s and restored in 2012, as well as the Mongolian Association of Lesson Study, established in 2013 with the aim of developing lesson assessment management, took on the responsibility that, once the

Table 6.10 Published guidebooks related to science according to the project

Subject	Guidebook and training module	Year of publication
Humans and nature (Elementary education)	Building knowledge by experimentation methods, Guidebooks I–III	2007–2009
	Development of teachers, Training module	2013
Humans and the environment (Elementary education)	Teaching methods on the development of living organisms	2007
	Teaching methods on the regional and social domestic interdependence of Mongolia	2008
	Game-based methods to teach about the environment	2009
	Teacher development, training module	2013
Physics (Basic education)	Methods to build knowledge by simple experiments	2007
	Teaching method based on misconception of pupils	2008
	Methods to teach communication competencies by context-based learning	2009
	Development of teachers, Training module	2013
Chemistry (Basic education)	Building knowledge by experimentation methods, Guidebook I	2007
	Teaching methods to build chemical knowledge by information processing, Guidebook II	2008
	Teaching methods based on context to build chemical knowledge, Guidebook III	2009
	Development of teachers, training module	2013

project was completed by 2016, they would disseminate the lesson study methods nationwide. These institutions are primarily focusing on joint research, facilitation of cooperation between the SUE's faculty members and school teachers, introduction of new teaching methods, monitoring and training of teachers, consultancy and foreign relations for researchers.

Given the broad support given to the research team by the MES and international organisations, the members were able to master the new methodology quickly and even to present their study results at several international and domestic scientific conferences. For example, the chemistry team attended conferences in Singapore in 2012 and Sweden in 2013 (the World Association of Lesson Study, WALS), while two members from the physics team and the humans and nature team presented their findings at the 63rd Conference of Japan Science Education in Hokkaido, Japan, in 2013 (JICA/KRI International Corp. 2009, p. 66).

These activities have laid the basis for teaching process reform based on lesson study and have also created an environment for more active involvement of schools and teachers in this process. The elaboration of methods of lesson study facilitated closer cooperation and coordination between the faculty and researchers of pedagogical training institutions and secondary schools, as well as the identification of best approaches for delivering good lessons in various educational institutions. Teachers now know where to seek professional training and expert advice when needed. The main outcome of this project is an increased interest in the natural sciences among pupils and, as a result, their improved performance in various exams and tests. The researchers gained the opportunity to access schools in order to conduct first-hand monitoring, evaluation and lesson assessment, which helped them carry out more targeted and objective studies. Such exposure to real-life teaching practices in schools allowed researchers and experts to develop more practical solutions for evaluating curricula, textbooks, teacher training methods, correcting mistakes and learning about best practices in science education.

Another important outcome of the project was a switch from expensive laboratory equipment and chemicals used in teaching to more available and inexpensive teaching resources. A study by the Education Cooperation Society from 2013 states that, "technology and chemistry courses tend to be the most expensive, requiring sophisticated laboratory equipment and consuming large amounts of chemicals. However, the teachers were able to use readily available, daily-use chemical consumables such as soft drinks to demonstrate the oxidation process and washing powder for alkaline reactions" (Mongolian Education Society 2013, p. 42). Among the problems identified by teachers when teaching science subjects were that the curricula were too extensive and the assessment system was outdated.

The next major step towards reforming the standards, curricula and quality of science education was the MES-commissioned appraisal of the feasibility of adopting the Cambridge International Programme (CIP) for the Mongolian context in 2009. Consequently, the Government of Mongolia decided to adopt and use the Cambridge International teaching methods and assessment standards in Mongolia, with the aim of training a globally competitive, skilled labour force.

On 13 April 2011, the Government of Mongolia signed a Memorandum of Understanding with Cambridge International Examinations (CIE) for cooperation on the reform of standards and curricula for elementary and secondary education. Under the Mongolia–Cambridge Education Initiative programme, the curricula for mathematics, science and English language shall be adjusted to the Cambridge International standards, and currently a pilot programme is being implemented at selected schools. This educational programme was developed in 1988 based on the Cambridge University secondary education standards and has served as an international benchmark. Its aims include the development of academic knowledge and skills for pupils aged 5–19 and it is considered to be one of the most reputable teaching and testing programmes globally. The fact that most international universities recognise CIE certification is the main advantage of the programme, designed for the following age groups:

- Cambridge International Primary Program: 5–11 years old,
- Cambridge Checkpoint: 11–14 years old,
- Cambridge IGCSE/Cambridge O level ICE: 14–16 years old and
- International A and AS level (Cambridge Pre-U, AICE Diploma): 16–18 years old.

The objectives of the curricula for sciences include the development of comprehensive skills (detailed, tangible, practical) and utilisation of a differentiated approach comprising core and supplemental curricula, cross-connections, conceptual frameworks and active learning methods that clearly define the knowledge and skills that pupils must learn. For example, the IGCSE-level curriculum is based on a clear set of educational aims to encourage:

- Problem solving and critical enquiry,
- Engagement,
- Initiative and confidence,
- Independent learning and teamwork,
- Essential skills in numeracy and communication,
- Creativity,
- International outlook and cross-cultural awareness,
- Individual talents and interests,
- Solid foundation of knowledge and skills for higher levels of study and
- Lifelong learning.

The differentiation of curricula is based on having core and supplemental subjects, continuity, conceptualisation of ideas and active learning methods. Furthermore, the attitude, knowledge and skills required for pupils are also defined. The main prerequisite for successful achievement of the learning objectives is to have a detailed "Scheme of Work", which provides clear guidance to schools and teachers on how to implement the standards. This Scheme of Work includes detailed guidelines to teachers on the learning objectives and the methods to be used in the teaching process. For example, the IGCSE-level, two-year chemistry course specifies 180 learning objectives (Lkhamsuren 2011, p. 26).

In order to introduce this programme, a pilot study was undertaken in Mongolia in 2011–2012 for the science curricula for grades 1–5; physics, chemistry and biology courses for grades 6–10; as well as testing in the 2013–2014 academic year, namely the International Certificate of Education (ICE), AS and A Level specialisation course for grade 11. Preparation for the testing of these modules at grade 12 is currently underway, including the development of textbooks and teacher guidelines.

The teaching of science in primary school is characterised by encouraging pupils' interest in exploration, and the subsequent development of science research skills. The learning indicators of each class and course are focused on instilling scientific inquiry skills, which include "ideas and evidence", "planning investigative work", "obtaining and presenting evidence" and "considering evidence and approach" skills.

More than two decades of educational sector reform were marked by many successful examples of introducing teaching methods and curricula from abroad. However, heated public discussion and debates—on whether foreign curricula can be borrowed and adapted for national schools or whether such curricula should be developed purely based on national traditions—are still going on. Our view is that the teaching of natural sciences in schools should combine both the best international standards/curricula and careful consideration of the domestic conditions and the existing knowledge base.

The new government that took office after the general election in 2012 is now working towards the implementation of the Education Quality Reform policy and Educated Mongolian Citizens national programmes (Institute of Teacher's Professional Development 2012). Within the framework of these programmes, the elementary education curricula at grades 1–5 were revised and tested in pilot projects at schools in 2013–2014. Following this, the decision was made to expand the programme in 2014–2015 to all schools nationally. Under this programme, the main goals of natural science education are defined as follows: "to nourish curiosity in understanding nature and natural phenomena, to develop the basic skills to observe and experiment, to use scientific methods to solve problems and to instil love of and ways of proper interaction with nature" (Ministry of Education National curricula 2013). The new curricula for natural sciences in grades 1–3 shall focus on humans and the environment, which stresses the socialisation of children, learning, basic hygiene and health skills, as well as nurturing the ability to ask questions, plan and implement study projects, and present and discuss the obtained findings. Meanwhile, the curricula for grades 4–5 shall concentrate more on the humans and nature aspect, with the aim of developing skills for observation of the environment, hypothesis formulation, research project planning and implementation, experimentation and testing, proving of assumptions and the presentation of findings. Contents of curriculum for humans and nature are shown in Table 6.11.

The renewed curricula for humans and nature for grades 4–5 borrowed heavily from the principles and methods of the Cambridge International Standards.

Work on the preparation and testing of the new science curricula for grades 6–7 would begin in 2014. The MES is dedicated to using the Cambridge Programme concept for the future development of science curricula for other education levels,

Table 6.11 Contents of curriculum for humans and nature

Grades	Season 1	Season 2	Season 3	Season 4
4	Chapter 4.1 Human and animal organs and systems	Chapter 4.3 Electricity	Chapter 4.4 Leverage	Chapter 4.6 Life and the living environment
	Chapter 4.2 How do we see?		Chapter 4.5 Properties of materials	
5	Chapter 5.1 Movements of the sun, moon and earth, as well as the stars and constellations	Chapter 5.2 Energy	Chapter 5.4 Reversible and irreversible changes	Chapter 5.6 Plant germination, growth and fruiting
		Chapter 5.3 Forces and mass	Chapter 5.5 Separation of a mixture	Chapter 5.7 Animal breeding, growth, development and use of a simple taxonomic key

although no specific work plan or timeframe, as well as funding source, has been decided. The MES is also focusing on the development of validation and quality assessment mechanisms for sciences and other subjects.

Although the educational system in Mongolia has undergone many reforms over the last 20 years, the approaches used for assessment were not reformed. While it is expected that review and reform of assessment and validation will have profoundly beneficial effects on the quality of education, there are currently no specific plans on how this will be implemented. However, the education standards, curricula, and teaching environment and methods for natural sciences will continue to evolve and improve in Mongolia.

6.6 Conclusion

Mongolian science education started in 1911, when a science school was established. Since the development of first curriculum in 1925, science lessons have been conducted at primary and secondary schools based on the curriculum. Natural science education was divided into physics, chemistry, geography, and biology in 1938. Afterwards, the instruction time has been updated in accordance with the demands of the national programme of secondary education.

Processes of transition from the previous societal order and the moulding of a new society have been taking place in Mongolia for more than two decades. This period has witnessed drastic reforms of the national educational sector, with achievement in tangible successes and accumulation of new experiences in the process. The legislative framework for education continues to evolve, with new standards and requirements being approved, school curricula being changed and new organisational forms continuously being tested. We consider that the most critical threshold for education reform has been crossed, and the national development priorities, namely the introduction of new mining and industrial technologies, will only increase the future demand for natural science education. However, a number of problems still remain:

- The knowledge among primary education teachers about the natural science teaching methods is insufficient, requiring review and reform of primary school teachers' training programmes in order to strengthen the theoretical base of the teaching process.
- There is a shortage of expertise and experience on resolving the numerous problems related to the development of new natural science standards and curricula, teacher training and the creation of an adequate study environment in the course of transition to a 12-year teaching model.
- Little support is provided for research on natural science education methodology, little research is carried out and the experts' recommendations are often overlooked.

- Despite sufficient funding for natural science education in Mongolia, it is difficult to assess the progress, impact and efficiency of the reform of curricula due to the absence of validation and quality assurance mechanisms. The inclusion of only two natural science subjects, namely physics and chemistry, into university entrance exams is also insufficient.
- While the significant efforts by successive governments to reform the education sector should be applauded, it should be noted that frequent modifications of the curricula for natural sciences also pose some risks. Facing the pressure of a four-year election cycle, governments are keen to experiment with various programmes, hoping to achieve results that boost support among voters. This often results in the negation of past achievements, discontinuation of the previous government's policies and programmes, and confusion among school teachers about state policies in the education sector.

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Chapter 7
Commentary: Developments and Reforms in Science Education for Improving the Quality of Teaching and Research

David Treagust and Chi-Yan Tsui

7.1 Introduction

Reviewing colleagues' work and providing a review, a commentary, or reflections is always a privilege because it enables the reader to be more aware of his or her own research contributions. The reader may provide critical and constructive comments as in the case of a journal manuscript submitted for consideration or as in the case of this chapter to reflect how the reading relates to the reviewers' knowledge and experiences and then comment. In this chapter, we comment on some aspects—it is not possible to comment on all—and reflect upon the chapter authors' work from Mainland China, Lebanon, Macau, Malaysia, and Mongolia about science education research (SER) and practice in their countries/regions.

These five chapters are written with slightly different themes as a review, an overview, or a history of the science education in the countries/regions concerned but each chapter is comprehensive and informative allowing readers to have a good understanding of the status of science education there in one way or the other. After reading through these chapters, we provide comments and attempt to critically scrutinize the science education in these countries from international perspectives with the intents of highlighting some areas that other countries/regions could emulate. We also comment on other areas that are gaps in the research that could shape future directions for improvement. There are indeed common social, political, and educational problems and challenges facing these four countries and Macau, China's Special Administrative Region (SAR). Apart from discussing each chapter, we make comments based on the relevant literature, our personal and/or research experiences associated with the science education in each chapter and/or our collaborative work with the authors concerned.

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7.2 Mainland China: Internationalization of Science Education Research and Practices and Some Constraints

The current status of SER in Mainland China (hereinafter, simply "China") as reviewed in Chap. 2 by Wang et al. appears to be an important part of the book not just because that one fifth of humanity in the world are living in China, also because of the increasingly influential impart of China—the world's second-largest economy—on global climate changes, environmental pollution, biodiversity, food safety, health issues, and so forth, most of which are related to science education.

Wang et al.'s review of SER in China is both comprehensive and informative about three major science domains on six aspects: curriculum and textbooks, teaching, learning, teachers' professional development, scientific inquiry, and learning progressions and students' domain-specific cognitive development. As the authors conclude, SER in China is subject-wise so that educational research is reviewed separately in the three major science subjects: physics, chemistry, and biology, and claimed that "all have had fruitful achievements in all the six aspects above" (p. xx). The various research studies showed that these studies were underpinned by the common theoretical frameworks or models in international SER (e.g., NOS, BSCS course, 5E learning, constructivism etc.) and some were also part of the ongoing projects in other countries (e.g., WISE, TELS etc.), as well as being conducted using common quantitative and qualitative methodologies, including the latest Rasch model method and the popular semistructured interview method.

Here we attempt to comment on a few aspects from international perspectives. First, for the aspect of learning, conceptual change learning—the dominant research agenda for learning science since the 1970s (Amin et al. 2014)—is also a focus in the review of studies on learning including some comparative studies with other countries and with Taiwan. From the perspective of multi-dimensional conceptual change in learning science (see Duit et al. 2013; Tyson et al. 1997), we believe that the major focus in science education in China is on the epistemological dimension, and that teaching and learning of science is more or less teacher-centered and examination-oriented compared to many other countries. Indeed, China has sought to learn from the American-style flexibility in schooling, for example, less lectures, less drills or memorization but more discussion and student-led activities (Cavanagh 2007). More improvement in this regard has since been done, as reported in Chap. 2.

Second, for the aspect of the research on curriculum areas of science education, environmental education is not mentioned, whereas it is discussed in the chapters on Lebanon, Malaysia, and Mongolia, which like Chap. 2 on China, also provide an overview of SER in their respective countries. Environmental education is increasingly important in international SER—especially in countries with extensive industrialization and urbanization—and therefore, could be a focus of science education in China where some of the most urgent reported science-related problems include environmental pollution and food safety. China is currently undergoing more changes while it is striving to become a world economic power alongside the USA. Meanwhile, people in China are developing more public awareness of the environmental issues and citizens' rights vis-à-vis the vested interests of private and state-led capitalists, for example, Chinese officials halted construction of a p-xylene (PX) factory in Shifang city in 2012 after violent protests from residents (BBC 2012). As is well known, there are always tensions of this kind in both developed and developing countries; earlier this year while China championed the importance of environmental protection, it blocked web access to an online popular documentary on air pollution in China (Wong 2015).

Third, another area worthy of our comments is about the research on nature of science (NOS) reported in Chap. 2 in studies on four aspects including teachers' professional development. However, the authors and readers may also be interested in the work of Hong Kong colleagues (Wan et al. 2011, 2013) who found that when Chinese science educators were compared to those of the Western countries in their NOS values, "[t]he most prominent difference is the absence of the democratic argument" (Wan et al. 2011, p. 1118). More notable is Wan et al.'s (2013) study and discussion of the impact of Marxist thinking on how China's science educators taught NOS to prospective science teachers. This hidden ideological factor affecting teaching and teacher education in modern China and its implications on research and practice has received no mention in the research literature, not even in Lederman and Abell's (2014) latest handbook on SER. Science education researchers may recall that Lysenkoism of the pseudoscientist Lysenko[1] in the former Soviet Union was once embraced by China under Mao Zedong—for agricultural developments—but was soon discarded as fraudulent pseudoscience after Mao had died and reforms in China started in the late 1970s (Dikötter 2010; Schneider 1989). Those events conjure up the second author's memories of his personal experience of learning the Soviet-style school science as a primary school student in China during the late 1950s.

Many changes and innovations in science education practice and research—"to improve Chinese citizens' scientific literacy, build up human resources, enhance the country's capacity for independent innovation, and realize the great rejuvenation of the Chinese nation" (p. xx)—have been taking place since China's eighth curriculum reform started in 2001. Indeed, China has since produced many talented scientists and engineers for the needs of the country's development. Wang et al. have pointed out in their concluding remarks that:

> the internationalization of SER in Mainland China is not enough, especially in publishing studies in international journals. How to bring the native [local] studies to overseas and how to get recognition of international peers are important tasks for the researchers in Mainland China. (p. xx).

We agree, and recognize this challenge applies to all authors of the chapters we reviewed and is especially difficult for nations new to international SER.

[1]Trofim Denisovich Lysenko (1898–1976) was a protégé of Stalin; his Lysenkoism "denied the validity of classical genetics from Mendel to Morgan and promoted its own theory of heredity based on the belief that acquired characters can be inherited" (Schneider 1989, p. 45).

On the whole, Wang et al.'s chapter has analyzed a huge collection of SER studies in China and presented readers with a *big picture* of how research has been translated into practice, as well as their implications and future directions. We look forward to seeing SER and practice in China continue its path toward internationalization despite some constraints.

7.3 Lebanon: Science Teaching and Learning as Inquiry in Students' Mother Tongue or in a Lingua Franca of Science

At NARST 2001, the first author of this chapter was part of a symposium involving colleagues from Lebanon, the USA, Israel, Venezuela, Taiwan, and Australia that examined the role of inquiry in science education. All presenters learned about the status of inquiry teaching and learning in their own and the other countries/regions, the essential issues of which were published in *Science Education* (Abd-El-Khalick et al. 2004). In his country contribution to this article, Saouma BouJaoude (Chap. 3 's first author) explained how, in a then new Ministry-designed and developed curriculum, inquiry teaching was being implemented at the pre-college level. He commented that while much of the curriculum is well intended for inquiry in the classrooms, anecdotal evidence showed that most science teaching tended to be traditional. "The curricular emphasis on inquiry, while necessary, is not sufficient for the fruitful implementation of inquiry approaches to the teaching and learning of science in Lebanon" (p. 401). BouJaoude also noted that there was a mismatch between the proposed teaching approach and the high stakes assessment system that is part of Lebanese education.

In Chap. 3, among the identified four challenges facing schools, BouJaoude and El-Hage refer to inquiry as the second challenge "equipping schools with the necessary material, laboratory and ICT equipment to provide students with the opportunity to participate in minds-on and hands-on inquiry science" (p. xx). Like many school systems, inquiry learning is seen as an important and worthwhile outcome though this goal is often not achieved for two reasons: the need for adequate professional development opportunities for teachers and the need for examinations to match the teaching goals, continue to be two important educational challenges in Lebanon identified by BouJaoude and El-Hage. In reviewing research by Lebanese authors over a 15-year period, these authors reported a continued emphasis on qualitative methods, a trend to understand the status of science education in Arab states, and emerging theoretical frameworks using French SER traditions.

When we read the ranking of countries based on TIMSS or PISA scores, unless one knows the school system and the history of the country, especially in recent times, one has no idea about the language of instruction. We learn from Chap. 3 that the language of instruction in science is English or French whereas the students' mother tongue is Arabic and that students do not have strong language skills in English or French. We wonder how many other countries also face this situation and hence their students might have lower scores on TIMMS and PISA than might have been the case if the language of science instruction were the students' mother tongue. This reminds the first author of this chapter about a visit to the University of San Carlos in Cebu, the Philippines, where Dr. Malou Gallos was a faculty member, following her successful doctoral studies at Curtin University (see Gallos et al. 2005). The first author wanted to see firsthand the teaching of an adapted lecture style involving an instructional cycle of three phases: a plenary or mini-lecture, seatwork activity, and a summary or closure. The language of instruction was English. The first author also interviewed students about their experiences and almost incidentally asked them when they used English and Cebuano, their mother tongue. Almost all students stated that they stopped speaking English as soon as they left the classroom or lecture. Here is an issue of teaching and learning science that deserves more attention—the language of instruction as opposed to the mother tongue in international assessments. Chapter 3 on Lebanon also comments that many teachers in Lebanon "lack foreign language skills that influence the quality of their teaching because the language of science is English or French" (p. xx). We shall see in Chap. 4 on Macau (a former Portuguese colony) and Chap. 5 on Malaysia (a former British colony) that the language of instruction in science is also an issue that affects the quality of science education. The issue using non-mother tongue language of instruction also reminded the second author of his many years teaching biology and science in Hong Kong (a former British colony) and a case study on Cantonese-speaking students in Hong Kong learning genetics in English (see Tsui and Treagust 2013).

7.4 Macau: Encouraging Efforts to Improve Science Education Research and Practice

In Chap. 4, Wei reports on a region-wide SER study in Macau, an SAR of China. Macau's schools, mostly private, enjoy autonomy in their own way of teaching and learning. The study followed a common mixed-methods research design using questionnaire surveys, classroom observations, semistructured interviews, case study, and document analyses to collect data from multiple sources. Both the quantitative and qualitative data can then be analyzed, compared, or triangulated to increase the research rigor and to yield results with better reliability and validity. For a small region with only 46 secondary schools, this study design serves well to explore the various aspects of science education in the region: school-based science curriculum, science textbooks and their uses, science teaching methods, science learning environments, and students' attitudes to science and school science. The analyses and interpretations of the rich corpus of data in the region-wide study appear to yield meaningful findings that should have important implications for improving science education in Macau in one way or another and to solve the problems and meet the challenges concerned. One of the aims of the study was to find out if the features of current teaching and learning were associated with students' development of scientific literacy. Indeed, the PISA 2006 results showed that the 15-year-old students in Macau performed above the OECD average and that they internationally ranked between 15 and 20 on the combined science scales.

However, the issue of the language of instruction raised in Chap. 3 on Lebanon and Chap. 5 on Malaysia could also be one that warrants investigation in Macau. Wei notes that there are both Chinese-speaking and English-speaking schools in Macau where, we assume, that the medium of instruction (MOI), as it is called in Macau and Hong Kong, is Chinese in the former type of schools and English in the latter type. For those schools which use English as the MOI, the students and teachers are likely to face the same problems and challenges as those in Lebanon where Arabic-speaking students/teachers are using either English or French as the MOI or those in Malaysia where different ethnic groups with different mother tongues are using Bahasa Malaysia or English as their MOI in learning science.

Macau, one of the two SARs of China (Hong Kong is another one), was a former Portuguese colony, which was returned to China in 1999 and is maintaining its capitalist system under the policy of "one-country-two-system" of the Basic Law[2] for 50 years. As Wei points out, because of the need of schools to prepare for many students to further their studies in China, textbooks are mostly from Mainland China. This may also create some tensions due to the differences of two educational systems in China and in Macau and the teachers' thinking and beliefs. An emerging challenge in science education in Macau could be about how to strike a balance between, and to resolve the possible tensions arising from, the differences of the local (capitalist) and the national (socialist[3]) science contents and contexts.

7.5 Malaysia: Challenges with Curriculum Reform and Changing the Language of Instruction

The first author's initial experience of the education system of Malaysia was through his work as a consultant to academic staff at the Regional Education Centre for Science and Mathematics Education (RECSAM) administered by the Southeast Asia Ministers of Education Organization (SEAMEO) in Penang, Malaysia. At this Centre, courses are offered to science and mathematics teachers in the 11 SEAMEO Member Countries, including Brunei, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam. In addition to teaching courses on teaching methods and how to conduct research projects, the first author conducted research

[2]http://www.umac.mo/basiclaw/english/main.html.

[3]Or "socialism with Chinese characteristics" as the political system under the Communist Party of China's one-party rule (see recent official news from China at http://news.xinhuanet.com/english/china/2013-01/05/c_132082389.htm).

in local schools (see Liau and Treagust 1989) with multilingual colleagues. Through RECSAM, the first author met Dr. Molly Lee, then at the Universiti Sains Malaysia, and read her highly informative paper about science curriculum reforms in Malaysia (prior to 1992). Lee's (1992) review is in many ways similar to that of Nookoo's Chap. 6 which describes the periods of development of science education in Mongolia.

In Chap. 5 by Halim and Meerah, the first dozen pages describe these same developments of science education as reviewed by Lee, including the influence of British educational models like Nuffield and the Scottish Science Project, as well as the New Primary Science Curriculum and the New Integrated Secondary Science School Curriculum. Lee's article which was not cited also explained the rationale for some of these curriculum changes that came not only from Western countries but also from Islamic countries. In discussing the current status of science education in Malaysia, Halim, and Meerah present data about falling recruitment and interest in science and technological studies and careers; they offer reasons for these data that are similar to other countries where science enrolments are in decline—examination-oriented teaching, ineffective teaching of abstract concepts, and lack of practical and experimental activities.

An important issue addressed by Halim and Meerah is that of the language of instruction for science has changed from Bahasa Malaysia to English (in 2003) and back to Bahasa Malaysia (in 2012). One reason for the more recent change is the declining TIMSS assessment scores. As noted earlier, this situation about language of instruction is similar to that of Lebanon, Macau, and the Philippines. To address this language issue, recent research conducted in Malaysian schools (Damanhuri et al. 2016) used an instrument written in both English and Bahasa Malaysia.

An important aspect of Chap. 5, which has currency in many nations, is the need for the education system to produce graduates in science (and mathematics and technology) that meet future needs for employment possibilities and opportunities in these sectors. Malaysia has set a very high 60 % Science compared to 40 % Arts enrolments in upper secondary school. Halim and Meerah note that science enrolments are only about half the target percentage. The reasons for the issues described in Chap. 5 are supported in a recent report by Ibrahim (2015) from the Academy of Science Malaysia.

7.6 Mongolia: Challenges to Meet the Needs of Contemporary Society

Prior to 2008, the first author's knowledge of Mongolia learned through books or television was of the capital city, Ulaanbaatar, people on horseback with nomadic lifestyles and an open landscape like the outback of Australia. This knowledge changed in September 2008 when the first author attended the Celebration Colloquium at the University of Kiel's Leibniz Institute for Science and Mathematics Education (IPN) to honor Professor Dr Reinders Duit prior to his retirement. Professor Duit had been awarded an honorary doctorate from the University of Ulaanbaatar in recognition of his work during 2005–2008 in Mongolia to help develop physics instruction by supporting the work of Professor Burmaa Banzragch who also was a visiting scholar at the IPN.

It is very helpful for readers with little knowledge about the Mongolian educational systems to learn about these systems from Nookoo's Chap. 6 that chronicles the systems and their changes in four periods. Reading about Chap. 6, one has a clear conception of the curriculum changes from being highly structured and contextualized to one, from 2004, with new education standards where "schools and teachers were required to develop their own curricula under the open curriculum policy" (p. xx) with more attention to the abstractness of the science concepts and a more overall academic orientation. Such changes seem to us as being quite dramatic and as might be expected. Nookoo reports that there was "a lack of support for the implementation of the natural science educational standards and that teachers did not know how to implement student-centred teaching methods" (p. xx). We know that these issues are of international concern. As reported by Abd-El-Khalick et al. (2004), many countries reported similar issues. However, a recent European project, PROFILES[4] showed that student-centered teaching—in the case of inquiry learning—can be effective when teachers work directly with university-based academics. Some evidence of such cooperation in Mongolia is evident in Nookoo's chapter but, as in PROFILES, for the majority of teachers this kind of cooperation is not possible. Another challenge for science teachers implementing the new curriculum in Mongolia was that it had an outcomes-based approach—for knowledge, skills, uses, and evaluation—and to integrate content from different science domains. These goals are difficult to achieve even in more mature educational systems, especially when "the approaches used for assessment were not reformed" (p. xx). Nevertheless, international cooperation with teams from New Zealand and Japan have been instrumental in ensuring that the changes put forth by the Ministry of Education and Sciences could be assessed and implemented.

Chapter 6 concludes by ensuring readers that two decades of change from the previous social order to a new society has resulted in tangible successes and new experiences and that "the critical threshold for educational reform has been crossed" (p. xx). In any reforms, the goal has been to "combine the best international standards/curricula and careful consideration of the domestic conditions and the existing knowledge base" (p. xx). Like many resource rich countries, Mongolia will need an increasing number of scientists and engineers, and as Nookoo writes, there will be an increased demand for natural science education and the efforts to date will hopefully see the reforms come to fruition. However, for bringing about successful changes in the science curriculum in Mongolia, there are still problems in science teaching and learning which are likely fruitful agendas of research for further reforms.

[4] http://www.profiles-project.eu.

7.7 Coda

We hope that SER as reported in the previous five chapters can translate into practice and make contributions to create a more peaceful and prosperous world with “a more scientifically literate citizenry, a more ecologically balanced global environment, and a more socially just and democratic global community” (Treagust and Tsui 2013, p. 364). We suggest readers to think about the challenges and issues concerned and seek some further readings.

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Chapter 8
Science Education Research in Oman: Opportunities, Trends, and Challenges

Sulaiman M. Al-Balushi

Abstract The aim of the current chapter is to give the reader an overview of the opportunities, trends, and challenges related to science education research in Oman. The chapter starts by describing the contextual background focusing on the Omani educational system, the field of science education in the country, and the research activities and related funding systems. The chapter admits that science education research in Oman has a short history. It gained momentum in 2000 with the establishment of the first postgraduate program at Sultan Qaboos University (SQU). On the other hand, there are different opportunities for science education research to prosper. Among these are the different funding systems by The Research Council (TRC) and SQU; and the establishment of a new SQU Ph.D. program in science education. Also, the diverse nature of the country provides a considerable number of underresearched issues related to science learning. The main trends in science education research in Oman are its tendency toward the quantitative school of research, its focus on exploring and implementing modern science teaching methodologies, and its equal engagement of male and female students as research participants. However, there is limited focus on lower school grade levels, private schools, and sociocultural factors. There are a number of challenges facing science education research in Oman. The main one is the limited number of science education researchers in the country. Also, the number of female researchers is very low. The author proposes that some of the pitfalls and challenges that face science education research in Oman could be resolved by establishing a national science education research center that coordinates the research efforts and directs them toward the most pressing issues related to science teaching and learning. In addition, providing more scholarships to science education researchers to complete their PhDs and founding a national professional science education research association could help in increasing the number of science education researchers and foster the research activities in the country.

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Research has recently been gaining much support in Oman. With the establishment of The Research Council (TRC) in 2005, Oman has chosen research as one of the influential players in guiding the growth and productivity of its society and economy and the development of its future (TRC 2014; Al Shmeli 2009).

8.1 Contextual Background

Oman is a member of the Gulf Cooperative Council (GCC), which includes, besides Oman, Bahrain, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates (UAE). Oman is located in the southeast of the Arabian Peninsula. It is neighboring the UAE (north), Saudi Arabia (west), and Yemen (south). Its total area is 309,500 km^2 with a coastline of 3165 km that runs northwards from the Arabian Sea to the Sea of Oman, to the Strait of Hormuz at the entrance of the Arabian Gulf (Ministry of Information 2013). Its population is 3.62 million, composed of 2.09 million Omanis and 1.53 non-Omanis. Of the Omani population, males represent 51 % and females 49 % (The National Centre of Statistics and Information 2013).

Oman is a modest oil country (Peterson 2004a). Its economy depends heavily on its resources of oil and natural gas with little contribution from tourism, mining, and agriculture. The World Bank classifies Oman as a high-income country (Ministry of Education and the World Bank 2012). The United Nations Development Programme (UNDP) ranks Oman as 56th among 182 countries on the Human Development Index (UNDP 2009). Omanis are predominantly Muslims and Arabic is the formal language of the country.

8.1.1 The School Educational System in Oman

The form of schooling in Oman and in the rest of the GCC countries during the first half of the last century (pre-oil era) was called *Katateeb*, where students were taught by the clerk of the mosque. The teaching focused on reading and memorizing the holy book of Quran. In the *Katateeb* students rarely had the chance to learn writing or mathematics (Davidson 2010). As for formal schooling before the 1970s, there were three public schools in Oman. Since then, with the aid of oil discoveries and the leadership's dedication to promote education, the number of schools has jumped to 1043 public schools and 483 private schools with more than half a million students (51 % males and 49 % females) (The National Centre of Statistics and Information 2013). Education receives 17.5 % of total government recurrent expenditure (Ministry of Education and the World Bank 2012). Access to school is free for all girls and boys.

The educational system in Oman underwent a major reform with the establishment of the Basic Education system in 1998. The aim of the reform was to prepare students to become productive members of society. More emphasis was placed on science, mathematics, foreign languages, and technological and life skills. The Basic Education system is now defined as:

> A ten-year unified education that provides learners with basic and necessary knowledge, skills, attitudes and values enabling them to continue with their education or training based on their interests, aptitudes, and dispositions, and enabling them to face the challengesof their present circumstances and future developments, in the context of comprehensive social development (Ministry of Education 2007, p. 23).

This new reform has brought major changes in different aspects of the educational system in Oman. It has involved:

> an updating of the curriculum, a shift in emphasis towards student-centered teaching and learning methodologies, the upgrading of resources including the use of information technologies in schools, introducing both higher thinking skills into the assessment system, upgrading the skills of teachers and encouraging students to stay longer in school by introducing a revised educational ladder. (Ministry of Education 2007, p. 12).

The educational system in Oman is composed of two main stages: Stage I which is the Basic Education and it is for grades one to ten; and Stage II which is called the Post-Basic Education and it is for grades eleven and twelve. The Basic Education is composed of two main cycles: Cycle I is for grades one to four and Cycle II is for grades five to ten. Cycle I schools are mixed gender and taught by female teachers. Cycle II schools are gender separated and taught by same gender teachers.

The school day is composed of an eight-period schedule. Science comes fifth in the number of weekly class periods after Arabic language, Mathematics, Islamic studies, and English language. In Cycle I, there are five class periods per week for science. In Cycle II, there are five class periods for grades five and six, six class periods for grades seven to nine, and eight class periods for grade ten. In this cycle, science becomes third in the number of weekly class periods after Arabic language and Mathematics.

8.1.2 Higher Education in Oman

There are 95,146 students studying in different Higher Education Institutes (HEIs) inside and outside the country. Males represent 45.3 % and females 54.7 %. The number of students studying in different HEIs inside the country is 87,615 among which 38,899 (44.4 %) students study in public HEIs (The National Centre of Statistics and Information 2013). The first university in Oman is Sultan Qaboos University (SQU), which was established in 1986. It is an independent entity and is the only public university in the country. SQU encompasses nine colleges: Agriculture and Marine Sciences, Arts and Social Sciences, Commerce and Political Science, Education, Engineering, Law, Medicine and Health Sciences, Nursing, and Science. Aside from SQU, there are a number of public HEIs run by different ministries. These institutes are: six applied science colleges, seven technical colleges, thirteen health institutes, and one institute for Islamic sciences. There is a new project in the country to establish a new public university called the University of Oman (The National Centre of Statistics and Information 2013).

There are about 60 private HEIs, of which six are universities. Private HEIs comprise 55.6 % of all students who do their postsecondary education in the country. Also, there are 14,361 students who complete their postsecondary education abroad (56.9 % males and 43.1 % females). GCC countries, Egypt, Jordan, UK, USA, Australia, Germany, Ireland, Malaysia, and New Zealand have been the main destinations for Omani students (The National Centre of Statistics and Information 2013).

Omani science teachers are currently prepared mainly in SQU.This program is jointly offered by College of Education and College of Science. Recently, the program has gained the *National Recognition* by the National Science Teachers Association (NSTA) in the United States. This international achievement was sought as part of the efforts by SQU to gain the international accreditation of its teacher education program through the Council for the Accreditation of Educator Preparation (CAEP)—formally called the National Council for Accreditation of Teacher Education (NCATE)—in the United States.

8.1.3 Science Education in Oman

Promoting scientific thinking is considered one of the fundamental principles of education in Oman:

> Adopting a scientific thinking approach by developing the mental abilities of individuals and providing them with scientific and critical thinking capabilities to enable them to employ these skills in their daily lives. (Ministry of Education 2009, p. 31).

It is also considered to be one of the main aims of the Basic Education system in Oman:

> To Provide a learner-centered education which furnishes the learner with appropriate life skills through the development of self-learning, scientific and critical thinking and the ability to understand and apply contemporary scientific and technological innovations (Ministry of Education 2007, p. 16).

Consequently, in the Basic Education system, students spend 89 % more time in science and 90 % more time in mathematics compared to the old system (Ministry of Education 2007).

Although the goals of science education in Oman do not differ from international ones, being a Muslim country it adds a number of religion-related goals. Their purpose is to strengthen theological beliefs by exploring God's creations (Ambusaidi and Alzain 2008; Mansour 2009). In addition, science curriculums in Muslim countries stress the appreciation of the role of Arab and Muslim scientists in preserving the development of different sciences during the Middle Ages (Ambusaidi and Alzain 2008).

There is one national science curriculum for each grade level in Oman. The curriculum emphasizes the use of inquiry-based, student-centered, modern educational technology and problem-solving strategies (Ambusaidi and Al-Shuaili 2009; Ambusaidi and Alzain 2008). However, the teaching practice in science classrooms does not reflect these themes, as traditional teacher-centered methods are still dominant in science education (Al-Hajri 2006, 2008; Al-Zadjali 2006).

Assessment practices have seen revolutionary changes with the introduction of the Basic Education system. Less emphasis has been put on paper-and-pencil examinations. A combination of formative and summative assessment strategies has been formally enforced by the science curriculum. Formative assessment techniques focus on problem-solving skills, namely initiating and planning, collecting and presenting evidence, analyzing and interpreting, communicating, teamwork, and report writing (Ambusaidi and Al-Shuaili 2009; Ambusaidi and Alzain 2008).

On the other hand, Omani students' scores in the Trends in International Mathematics and Science Study (TIMSS) do not show that the new reform on science learning in the country has had any positive impact. The results of TIMSS 2011 show that the science scores of grades four and eight students in Oman were 377 and 420, respectively. These scores are much lower than the TIMSS Centerpoint Scale (500) (Martin et al. 2012). The results of the questionnaires given to students in both grades showed that only about half of the students in both in Oman grades liked learning science and got engaged in science lesson, and more than two-third of them valued the importance of science. In addition, more than 70 % of science teachers in both grades in Oman felt that they were confident of teaching science, and most of them were either satisfied or somewhat satisfied with their profession. Also, more than 70 % of science teachers reported that they used science investigations in about half the lessons or more. Most of them related lessons to students' daily lives, and engaged students in learning most lessons. On the other hand, very low emphasis on computer-based instruction was reported. Also, the majority of science teachers felt that their science instruction was limited by students lacking prerequisite knowledge and skills (Martin et al. 2012).

Responding to these low TIMSS results, the Ministry of Education has launched different school science projects to help enhance students' performance in science, mathematics, and innovative thinking. These projects are devised as science fairs during which students design their scientific projects to solve different local problems. These projects are believed to contribute to discovering students' talents and fostering their problem-solving skills (Ministry of Education 2014).

8.2 Science Education Research in Oman: History

Research is a growing enterprise in Oman. Its physical and conceptual infrastructures are still under construction. However, the future-oriented vision of the economy in Oman (vision 2020) considers research as a crucial player in shaping Oman's knowledge-based economy (Al Shmeli 2009). Research in science education in Oman does not have a long history. Before the turn of the twenty-first century, few science education studies were recorded in Oman. With no postgraduate program in science education during that period and with very few master's and Ph.D. holders, these studies were mainly completed by Omanis who were doing their postgraduate studies abroad. In 2000, SQU launched its postgraduate master's program in science education, which provided momentum for science education research to prosper (Ambusaidi and Al-Shuaili 2009).

8.3 Science Education Research in Oman: Opportunities

There are different funding opportunities for science education research in Oman. The first one is through the Open Research Grant Program (ORGP) through TRC. TRC is the national research council that oversees and funds research projects undertaken by different higher education institutions and ministries in the country. Since its establishment in 2005, TRC has played a significant role in funding different strategic research projects since (TRC 2014).The second funding source comes from SQU, the only national university. SQU has two systems for funding research projects led by its faculty members. The first is His Majesty Grant (HMG) system which provides an annual research budget that reaches half a million Omani Rials (US$1,250,000). The HMG targets strategic research projects that have the potential to have an impact on the country and its development. The second SQU grant system is the Internal Grant (IG) system which funds small-scale research projects. Its annual budget exceeds often half a million Omani Rials (US$1,250,000) (SQU 2014).

With these different research funding systems available for research projects in Oman, science education research has started to become more systematic and to be conducted on a larger scale. Since 2010, four major research projects in science education have won funds from SQU and TRC with a total value of approximately one million US dollars. The first project investigates students' common misconceptions in biology, chemistry, and physics (Ambusaidi et al. 2010). This SQU-funded research project involves a large-scale sample across different regions in Oman. Different research papers and a "misconceptions booklet" have resulted from this project, to help science teachers become aware of the common misconceptions that Omani students have. The second project is related to the use of virtual laboratories in science teaching (Al-Musawi et al. 2013). This TRC-funded research project has brought new technologies to the participating schools. The project uses two- and three-dimensional simulation technologies through tablet computers that are distributed to students. The third project is the school garden project funded by TRC (Ambusaidi et al. 2013). It aims to construct school gardens in a number of public schools, in which the education environment is designed to facilitate learning of different ecological and biological concepts. The fourth project aims to investigate cognitive and metacognitive variables which might affect students' performance in the TIMSS science test items and use these data to construct learning profiles (Al-Balushi et al. 2014).

In addition, there is a new promising opportunity for science education research to prosper further: SQU has established a new Ph.D. program in science education. The first cohort was admitted in September 2013. This program is expected to enhance the abundance and richness of science education research in Oman. Also, the school's willingness to receive researchers, support them, and supply them with necessary data provides a unique opportunity not only for science education research but also for different types of educational research. This welcoming environment has facilitated the smooth operation of research in Omani schools. Finally, there are a number of different underresearched sociocultural factors that might affect science learning (Al-Balushi and Ambusaidi in press), which provide an original research topic in the Omani context.

8.4 Science Education Research in Oman: Trends

8.4.1 Research Done by Science Education Researchers

Al-Balushi and Ambusaidi (2015) explored the main trends of science education research in Oman. For this purpose they surveyed science education researchers in Oman. The results of their study revealed some of the main trends for science education research in Oman. These trends are illustrated in Table 8.1.

Table 8.1 Main trends in science education research in Oman as described by Al-Balushi and Ambusaidi (2015)

Category	Main results
1. Research topics	The most frequently investigated topics were teaching methods, thinking skills, learning difficulties, learning theories, science attitudes, textbooks, science teachers' beliefs, science processes, and classroom practices
2. Subject matter	General science, chemistry, biology, and physics are the most researched subjects. Less emphasis is given to astronomy and earth sciences
3. Grade levels	More focus is given to Cycle II (grades 5–10), Post-Basic Education (grades 11 & 12), and college level than Cycle I (grades 1–4). Very few researchers approach young children
4. Students gender	Male and female students are almost equally represented in the research studies
5. Geographical regions	Three geographical regions in Oman seem to attract the attention of science education researchers more than the other eight regions. These regions are Muscat, South Batina, and Dhakhelya. Regions that are far from the Capital attract fewer researchers
6. Research methods	Quantitative research methods are the dominant research methods used by science education researchers in Oman. These include quasi-experimentation, analytical approaches, survey research, and correlational studies. A very limited number of researchers use case studies and phenomenographic research

(continued)

Table 8.1 (continued)

Category	Main results
7. Research instruments	Questionnaires, achievement tests, psychological instruments, thinking skills instruments, and visual-based instruments are frequently used by science education researchers in Oman. However, few researchers use interviews (open, structured, and focus group)
8. Dependent variables	Researchers tend to focus on certain dependent variables such as science achievement, thinking skills, science attitudes, classroom environment, science processes, and problem-solving skills. Motivation, metacognitive strategies, self-regulation, and scientific literacy are measured by a limited number of researchers
9. Statistical analyses	Frequencies, t-test, ANOVA, correlation coefficients, MANOVA, and chi-square are used by most of the researchers. Very few researchers use factorial analysis, regression analysis, and MANCOVA
10. Publications	Most researchers publish both in Arabic and in English. Some publish in international science education research journals such as International Journal of Science Education, International Journal of Science and Mathematics Education, Chemistry Education: Research & Practice, Eurasia Journal of Mathematics, Science & Technology Education, Science Education International, and International Journal of Environmental and Science Education. However, much of the research publications are published in Arabic in the GCC Arabic periodicals or in other Arabic periodicals
11. Impact of research	Science education researchers in Oman believe that their research has contributed in setting the foundation for future research studies, improved preservice and in-service training, and developed modern science teaching practices in public schools
12. Sociocultural factors	The diversification of sociocultural factors such as religious beliefs, age, non-Arabic languages spoken, school location, mixed gender school settings, and school type (public vs. private) in science education research in Oman is limited

8.4.2 Research Done by Science Education Postgraduate Students

Thesis and dissertations represent another important contributor to science education research in Oman. For the purpose of the current chapter, I conducted an analytical review of the science education theses done by Omani postgraduate students. This analytical review had two main purposes:

1. To help understand the trends in science education research done as part of postgraduate studies.
2. To compare research trends associated with science education research done by postgraduate students as part of their theses (analyzed in this section by the author of this book chapter) and science education researchers [investigated by Al-Balushi and Ambusaidi (in press)].

The author used a library guide that listed science education theses done by Omani postgraduate students since 2000 (The Main Library 2013). The guide is considered to be comprehensive since it is produced by the Main Library at SQU, which has the largest number of postgraduate theses in the country. Further, the current author is of the view that analyzing the lists included in the guide provides a reliable indication of research trends in postgraduate theses.

The guide lists theses in all specializations. Most of the theses have been completed at SQU. However, some of them have been written in other institutions outside Oman. The author identified 81 theses in science education. They were analyzed for

1. Gender of the researcher
2. Gender of the participants
3. University location
4. Main topic
5. Dependent variable
6. Grade level
7. School level
8. Participant type
9. Subject matter
10. Research design

Tables 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10, and 8.11 illustrate the results of the analysis based on these indicators.

In summary, most postgraduate research in Oman is done by students who complete their studies in local HEIs. Survey and quasi-experimental settings are the dominant research methods in these studies. In terms of gender representation, although postgraduate research in science education in Oman is conducted by

Table 8.2 Science education theses by the gender of the researcher

Researcher gender	n	%
– Female	39	48.1
– Male	42	51.9

Table 8.3 Science education theses by gender of the participants

Participants' gender	n	%
– Females only	25	30.9
– Males only	10	12.3
– Both male and female	36	44.4
– No human participants	10	12.3

Table 8.4 Science education theses by the university location

University location	n	%
– In Oman	66	81.5
– Outside Oman	15	18.5

Table 8.5 Science education theses by main topic

Main topic	n	%
– Hands-on *E.g., discovery learning; inquiry-based learning; learning cycle*	13	13.8
– Visualization *E.g., concept maps; mind maps; Vee diagrams; textbook figures*	11	11.7
– Thinking *E.g., creative thinking; critical thinking; reflective thinking; spatial thinking*	10	10.6
– Textbook	9	9.6
– Interdisciplinary *Science Technology & Society (STS); Science Technology, Society & Environment (STS); integration of science and mathematics; integration of science and arts*	9	9.6
– Science laboratory	7	7.4
– Professionalism	6	6.4
– Learning styles *E.g., multiple intelligences; brain-based learning*	5	5.3
– Constructivism	4	4.3
– Technology *E.g., Moodle; computerized modeling; Facebook*	4	4.3
– Alternative concepts	3	3.2
– Cognitive processes	3	3.2
– Others	10	10.6

Table 8.6 Science education theses by dependent variable

Variable	n	%
– Achievement	41	39
– Attitudes	16	15.2
– Thinking skills	10	9.5
– Classroom practice	7	6.7
– Science process skills	7	6.7
– Postponed achievement	6	5.7
– Alternative concepts	5	4.8
– Beliefs	4	3.8
– Others	9	8.6

almost equal number of male and female researchers, male students are underrepresented as research participants, especially in quasi-experimental studies. Most of these studies have been conducted in grades nine, ten, or eleven. In addition, school students and their science teachers are the primary subjects of postgraduate studies in Oman. There is a great focus on examining the effectiveness of hands-on instructional approaches, visualization methods, and thinking skills. On the other hand, achievement and different types of attitudes are considered as dependent variables most of the time. Also, the sociocultural factors such as religion, income,

Table 8.7 Science education theses by grade level

Grade level	n	%
– One	0	0
– Two	0	0
– Three	1	2.2
– Four	1	2.2
– Five	2	4.4
– Six	0	0
– Seven	3	6.7
– Eight	2	4.4
– Nine	8	17.8
– Ten	10	22.2
– Eleven	14	31.1
– Twelve	4	8.9

Table 8.8 Science education theses by school level

School level	n	%
– Basic Education cycle one (1–4)	3	4.5
– Basic Education cycle two (5–10)	30	45.5
– Post-Basic Education (11 and 12)	23	34.8
– College	10	15.2

Table 8.9 Science education theses by participant group

Participant group	n	%
– School students	50	62.5
– In-service teachers	19	23.8
– Preservice teachers	8	10
– Lab technicians	2	2.5
– Supervisors	1	1.3

Table 8.10 Science education theses by subject matter

Subject matter	n	%
– General science	29	58
– Biology	6	12
– Chemistry	7	14
– Physics	8	16

Table 8.11 Science education theses by research design

Research design	n	%
– Quasi-experimental	40	45.5
– Survey	26	29.5
– Documentation analysis	10	11.4
– Correlation	7	8.0
– Structured observation	4	4.5
– Case study	1	1.1

and language are rarely considered as research topics in these science education postgraduate studies. The results presented in Tables 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10, and 8.11 are further summarized in Table 8.12 which allows us to construct a comparison between science education research done by science education researchers (professional researchers) and science education theses done by postgraduate students (potential researchers).

8.4.3 Implementation of Different Teaching Methods

Research studies done by science education researchers in Oman and studies done by Omani postgraduate students show some similarities. There appears to be a high tendency by both groups to explore the practicability of implementing modern teaching methodologies in the Omani school context. Different teaching methods have been tested. These methods cover different types of inquiry-related techniques, thinking-related techniques, visualization-related techniques, and linguistic techniques. Science education researchers affirm that one positive effect of their research into science education in Oman has been the introduction of science teachers to different modern teaching methods. They claim that their work has influenced teaching techniques or that it has helped new techniques to make their way into science classrooms in Oman (Al-Balushi and Ambusaidi in press). The following review of literature illustrates studies done on different types of teaching methods:

Inquiry-based teaching methods: different inquiry-based methods have been tested in the Omani educational context. Al-Balushi and Al-Maqbali (2006) trained grade nine students to use an inquiry-based chart during their laboratory work. Different inquiry skills were emphasized in this chart such as experimentation, predicting, variable control, recording observations, taking measurements, reasoning, and explanation. Although science achievement did not improve significantly, there was a significant impact on science process skills. On the other hand, Al-Shuaili (2005) found that using Suchman's inquiry approach improved grade seven students' science achievement. Also, Al-Jahwari et al. (2011) used guided inquiry to enhance grade ten students' scientific conceptual understanding. In addition, Ambusaidi and Al-Afifi (2013) and Ambusaidi et al. (2011) investigated the effectiveness of using coupled inquiry cycle on eighth grade students' science achievement and their performance of different inquiry skills. Results showed a positive impact on inquiry skills but not on the achievement. In addition, inquiry iterative approach was explored by Al-Jabri (2013). Findings indicated that science achievement and science processes skills of eleventh grade students in chemistry improved significantly. On the other hand, when Al-Abri (2004) investigated the effectiveness of using discovery leaning on science process skills and achievement of grade nine students, no significant differences between the control and experimental group were observed.

Table 8.12 Main trends in science education theses in Oman

Category	Main results
1. Researchers' gender	Both females and males are almost equally represented in the science education postgraduate researchers' population
2. Participants' gender	Male students appear to be underrepresented in science education postgraduate research. There is a tendency to focus on female students in quasi-experimental studies
3. University location	Most of the science education theses are done in local institutions. Some Omani students go abroad to do their postgraduate studies in science education
4. Main topic	There is a tendency toward hands-on learning approaches, visualization tools, and thinking skills. Less emphasis is given to technology and alternative concepts. Classroom dialogue, student–teacher relationship, learning environments; assessment techniques; reading comprehension; learning difficulties; and informal science do not seem to attract postgraduate students
5. Dependent variable	More students choose achievement and attitudes as their dependent variables
6. Grade level	Grades nine, ten, and eleven attract more postgraduate students than the rest of the grade levels. More than 70 % of postgraduate theses that are associated with a single grade level are done in one of these three grade levels. None of the postgraduate science education theses was conducted on grades one, two, or six
7. School level	Cycle I schools are severely underrepresented in science education theses by postgraduate students
8. Participant group	School students and in-service teachers get most of the attention from postgraduate students. Supervisors and lab technicians are involved least frequently in postgraduate research. Other groups of people who might be related to science and science learning such as scientists, university instructors, parents, the public, museum educators, and museum visitors are not represented in postgraduate theses
9. Subject matter	Since much of the research is done in Cycle II (5–10), general science subject is the most researched subject. Biology, chemistry, and physics receive almost equal attention. Earth science, environmental science, and astronomy are not represented in postgraduate research
10. Research design	Quasi-experimental design and survey studies are the research design most used by postgraduate students. Qualitative research is almost never used. The observations used in some of the studies are structured observations with predesigned observation form
11. Sociocultural factors	*Gender*: Both genders are almost equally represented in postgraduate research *Religion*: There is no study that addresses the impact of religious beliefs on science beliefs *Language*: There is no study that investigates the effect of students' spoken non-Arabic language on their achievement in science *School type*: None of the studies were done in a private school setting *Age*: Young students and old people are excluded from postgraduate research *Income*: No attention is given to the role of family income on children's science achievement

Graphical teaching methods: the effectiveness of different graphic organizers has been investigated by different researchers. Ambusaidi and Al-Balushi (2006) found that using Vee diagram in science laboratory enhanced ninth grade students' science achievement and improved their performance of science process skills. Al-Ghafri (2006) investigated the impact of using different advance organizers on eleventh grade students' biology achievement. Results indicated a significant impact. Similar findings were reached by Ambusaidi and Awadh (2006). Also, Al-Salmi (2012) explored the effectiveness of using comprehensive concept maps which enhanced eleventh grade students' chemistry achievement. In addition, Al-Jahwari (2012) used the KWLH model to improve grade eight students' metacognitive awareness and their understanding of physics concepts. An interesting study by Al-Zehymi (2010) found that using tactile thinking maps and concepts maps with fifth grade students of blindness enhanced their science achievement and improved their attitudes toward science.

Targeting different thinking styles: Multiple intelligences techniques attracted different Omani science education researchers. Results of their studies revealed positive impact of using different multiple-based techniques on students' chemistry achievement (Al-Omori 2005), physics achievement and science process skills (Al-Shaqsi 2013), and science attitudes (Al-Balushi and Al-Maqbali 2009; Al-Omori 2005). In addition, different instructional models were adopted to improve students' thinking skills during science lessons. Problem-based learning (Al-Balushi 2005), explicit problem-solving strategy (Al-Yaqubi 2005), Gil and Martinez-Torregrosa model (Ambusaidi and Al-Sinani 2009, 2011), Bayer's strategy for direct teaching (Al-Hamidi 2011), accelerated learning (Al-Naqbi 2013), and brainstorming method (Al-Ismaili 2013) were used to improve students' problem-solving skills. Al-Balushi and Al-Fari (Al-Balushi and Al-Fari 2009) examined the impact of using CoRT (Cognitive Research Trust) model on students' critical thinking skills. No significant difference was observed between the experimental and control group. Al-Shuaili and Al-Ghafri (2006a, b) examined the impact of the Constructivist Learning Model (CLM) on grade eleven students' creative thinking skills. Positive impact was observed. Also, metacognitive skills were investigated by Al-Rawahi and Al-Balushi (2015) who found that using different active learning strategies enhanced grade ten students' self-regulated strategies.

Multidisciplinary approaches: Al Orime and Ambusaidi (2011) used an integrated approach between science and mathematics to teach science to grade four students. Both science achievement and problem-solving skills improved significantly. Another interesting study was by Al-Saadi (2012) who integrated science with plastic art in teaching fifth grade students. Although there was no significant impact on students' science achievement, their science processes skills improved significantly.

Technology-based teaching methods: investigating the use of technology in teaching focused mainly on the use of simulation (Al-Huraizi 2008) and animation (Al-Balushi and Al-Hajri 2014) in teaching chemistry. In addition, there was an attempt to explore the use of Facebook in teaching environmental issues (Al-Balushi 2013a).

Training teachers on teaching methods: different training programs were conducted to test their effectiveness on teachers' understanding and implementation of different teaching methods. Al-Muqaimi (2012) trained physics teachers on strategies that targeted students' critical thinking skills. Findings indicated that teachers' understanding and practices of these strategies improved significantly. Al-Balushi and Al-Abdali (2014) trained science teachers on creative thinking teaching strategies. The researcher used Moodle as an e-learning platform for training teachers whose classroom practices were positively enhanced as a result of this training program.

8.4.4 Visualization in Science Education

A good number of science education studies in Oman have been directed to issues related to visualization. Some of these studies focused on: (1) learners' imagination of different submicroscopic scientific entities (Al-Balushi 2009), and its relationship with their spatial ability (Al-Balushi and Al-Shuaili 2011); (2) their evaluation of the credibility of different scientific models (Al-Balushi 2011), and its relationship with their spatial ability (Al-Balushi 2013c), (3) their visualization of different macroscopic and microscopic dynamic interactions (Al-Balushi and Coll 2013); and (4) the presence of anthropomorphism and animism in learners' mental images in science (Al-Balushi 2012b, 2013b). These studies have contributed the following, among others, to the literature in science education: (1) a new taxonomy for classifying students' opinions of different scientific entities and phenomena (Al-Balushi 2011, 2012b, 2013c), (2) the use of guided imagery as an effective tool to explore students' mental images of different unobservable entities (Al-Balushi 2004, 2009, 2013b; Al-Balushi and Coll 2013); (3) anthropomorphism as a phenomenal pattern in learners' mental images (Al-Balushi 2012b, 2013b), (4) the difference between students' perceptions of concrete and theoretical models (Al-Balushi 2009, 2011, 2012b, 2013b; Al-Balushi and Coll 2013); and (5) the differentiation between schematic, visual, and verbal learners with regard to their visualization of different scientific entities and phenomena (Al-Balushi and Coll 2013).

Another set of publications explored the effectiveness of different macroscopic and submicroscopic delivery means that targeted enhancing students' visualization in chemistry such as different textual narrations (Al-Balushi 2013a), different diagrams (Al-Balushi 2012a), and different computerized instructional methods (Al-Balushi and Al-Hajri 2014).

8.4.5 Analyzing Textbooks

A good number of studies have analyzed Omani science textbooks for different science education aspects. Examples of these aspects were: (1) the American Science

Education Standards (Al-Shuaili and Al-Mahrooqi 2012; Al-Shuaili and Al-Mazeedi 2009), different elements of visual representations (Al-Hosni 2011), health education domains (Al-Hajji 2005), Science, Technology, Society and Environment (STSE) principals (Al-Jahwari et al. 2013; Al-Rumhi 2004), science processes (Al-Sawafi 2006; Al-Shuaili and Khataybah 2003), the principals of protective education (Al-Beraiki 2011), and the scientific literacy aspects (Al-Bahri 2011).

8.4.6 Teachers' Beliefs and Classroom Practice

Another main trend in science education studies in Oman is the comparison between science teachers' beliefs of certain science education issues and approaches and the relationship between these beliefs and their classroom practices. Examples of these studies are science teachers' beliefs and practices of: (1) the principles of constructivism (Al-Zedjali 2006), nature of science (Al-Hajri 2006), inquiry-based learning (Al-Harthi 2008), brain-based learning (Al-Farsi 2010), sustainable development issues (Al-Saadi 2012), and scientific argumentation (Al-Harthi 2014). The main observation out of these studies was that although the beliefs of science teachers regarding these approaches and issues were moderate or high, their related classroom practices were low.

8.4.7 Research Methodology

Both science education researchers and science education postgraduates pay little attention to qualitative research methods; an observation which is true not only for Oman but for the Arab region more widely (Mazawi 2010). While quantitative research methods courses occupy a permanent status in educational postgraduate programs in Oman, qualitative research methods courses are ignored. The quantitative research school dominates the scene. In addition, qualitative educational researchers are rare in Oman and thus qualitative research projects are gaining no momentum. Relying almost exclusively on quantitative research methodologies does not help enrich our understanding of the processes related to science teaching and learning in Oman.

8.4.8 Grade Level

Another similarity between the two groups is their hesitancy to conduct research on young children. Grades one to four are almost completely ignored by both groups. This phenomenon represents a serious gap in science education research in Oman. Learning science by the very young in Oman remains a black box. For instance, little is known about young children's perceptions of science and scientific concepts, their conceptualization of natural phenomena, their interaction with new teaching methodologies, their classroom dialogue and interaction, their scientific skills, and their attitudes toward science and science learning.

8.4.9 Sociocultural Factors

An important observation is that sociocultural factors are not given enough considerations by both groups. The main focus is on the learning of concepts in the general population, modern teaching methods and beliefs related to these methods. The variety in sociocultural factors such as religion, language, age, income status, geographical location, and learning difficulties is limited. The importance of exploring some of these issues stems from the unique nature of the Omani society which differs from its neighboring countries in a number of aspects. Language provides one example. Oman's historical interactions with civilizations emerged in Persia, Africa, India, Yemen, Portugal, and Britain resulted in the unique diversification in spoken languages in Oman. Thus, other than Arabic, there are more than 14 different spoken languages in Oman. For instance, Balochi, Hindi, Urdu, English, Swahili, Persian, and Mehri are widely spoken by large groups in Oman. There are also small groups in Oman that speak Khojki, Kumzari, Harsusi, Bathari, Zidgali, Hobyot, and Jibbali (Ghaudhuri 2013; Peterson 2004b, c). The question of whether learning science by students who speak these languages at home is different from their counterparts whose only language is Arabic which has not been investigated. Another aspect which is unique to Oman is the diversity of its cultures across different geographical regions (Peterson 2004b, c). People who live in large Omani cities have different lifestyles and are exposed to different forms of technology than those who live in small villages or in the mountains. For instance, while many of the fishermen and shepherds' sons spend most of their after-school time helping their fathers in their occupations, many children who live in cities engage in extracurricular activities provided by private institutes. Whether learning science is similar for city, village, and mountain students remains an unanswered question.

8.5 Science Research in Oman: Challenges

One important challenge for science education in Oman is the low number of researchers. When Al-Balushi and Ambusaidi (in press) conducted their study, they counted 16 researchers with PhDs who carry out science education research in Oman. Among them there were nine whose specialization was science education and seven whose specializations were educational psychology, educational technology, statistics and measurements, but they had also done some science education research. The low number of science education researchers in Oman represents a crucial challenge for science education research in Oman. It is difficult for such a limited number of researchers to cover all the different issues and tackle the different problems that face science education research in a country with such varied geographical and cultural contexts.

The number of female students completing their master's postgraduate science education is equivalent to the number of male students. Unfortunately, this ratio is not reflected in science education research specialists. There are few female science education researchers in Oman (Al-Balushi and Ambusaidi in press). It appears that fewer females find their way into a career in the science education research than males. The small number of science education researchers represents another challenge for science education research in Oman. In a society where grades 5–12 study in gender-divided schools, female researchers would find their way easier than male researchers in female schools. Thus conducting interviews, making classroom observations, and interacting with female participants are more comfortable for female researchers. The low number of female science education researchers means this opportunity is limited.

The tendency toward quantitative research represents another challenge for science education research in Oman. Those issues that are researched are not done so in sufficient depth and therefore do not reflect much of the detail that would lead to a proper understanding of the phenomena under investigation. The unique diversity in Omani society presents another challenge to science education research. Science education researchers are faced with a wide range of issues that to date have not been researched, relating to the influence of sociocultural issues such as religion, language, age, income status, and geographical location on learning of science (Al-Balushi and Ambusaidi in press).

8.6 Conclusions and Recommendations

Although science education research in Oman has a short history, some of its publications have reached international audience (Examples are: Al-Abdali and Al-Balushi 2015; Al-Balushi 2009, 2011, 2012a, 2013a, b, c; Al-Abdali and Al-Balushi 2015; Al-Balushi and Al-Amri 2014; Al-Balushi and Al-Battashi 2013; Al-Balushi and Al-Hajri 2014; Al-Balushi and Al-Harthy 2015; Al-Rawahi and Al-Balushi 2015; Al-Balushi et al. 2012; Al-Balushi and Coll 2013; Al-Shuaili 2011; Al-Shuaili and Johnstone 2001; Al Orime and Ambusaidi 2011; Almahrouqi 2011; Almahrouqi and Scott 2012; Ambusaidi and Al-Shuaili 2009; Ambusaidi et al. 2012; Ambusaidi and Johnstone 2000, 2001).

There are examples of unique intellectual contributions of science education research in Oman at the international level. One example is proposing a new taxonomy to classify learners' perspectives regarding the existence of submicroscopic entities (Al-Balushi 2011). This taxonomy is composed of four epistemological levels: Certainty, Imaginary, Suspicion, and Denial (CISD). The CISD taxonomy contributes in filling a gap in previous literatures in science education which do not provide a comprehensive classification of learners' perspectives regarding the existence of submicroscopic entities. Another contribution is the use of guided imagery technique to investigate learners' mental static and dynamic images (Al-Balushi 2009; Al-Balushi and Coll 2013). This think aloud technique helps not only in describing learners' imagination at the submicroscopic level, but also in detecting their ability to create dynamic mental images of submicroscopic entities and to mentally manipulate three-dimensional structures of these entities. A third example of the international intellectual contribution of the science education research in Oman is that it has made the voice of learners and science teachers in Oman to be heard by researchers around the globe. Examples are students' views about global warming (Ambusaidi et al. 2012); classroom discourse in Omani science classrooms (Almahrouqi and Scott 2012); and learners' most common misconceptions in chemistry (Al-Balushi et al. 2012). A fourth example of the intellectual contribution of science education research is studies on students' anthropomorphic mental images (Al-Balushi 2012b, 2013b). The main outcome from these studies has altered the traditional belief that enhancing these images produces fruitful learning. On the contrary, these studies show that the anthropomorphic learners produce detailed mental images that contribute in hindering their spatial thinking; an important ability in science learning, especially at the submicroscopic level of matter.

At the local and national level, there has been a strong impact of science education research on the science teaching and learning practices. New instructional methods have found their way into the educational system. Examples are inquiry-based instruction (Ambusaidi and Al-Afifi 2013; Ambusaidi et al. 2011), project-based instruction (Al-Balushi and Al-Amri 2014), guided imagery (Al-Balushi 2009), advanced organizers (Al-Ghafri 2006); brainstorming (Al-Ismaili 2013); computer simulations (Al-Huraizi 2008; Al-Musawi et al. 2013), and problem-solving strategy (Al-Yaqubi 2005). These teaching methods are now practiced by science teachers more frequently day after day. In addition, schools have received funds for high-quality projects such as school gardens (Ambusaidi et al. 2013) and three-dimensional virtual labs (Al-Musawi et al. 2013).

In addition, science education research in Oman is presented with a number of good opportunities to develop and expand. These include the availability of research funds from different resources, the establishment of a new Ph.D. program in science education at SQU, the existence of issues in the field which have not yet been researched, and schools' willingness to receive researchers and collaborate with them. In addition, the gaining of the *National Recognition* by the National Science Teachers Association (NSTA) in the United States for the science education program at SQU gives the science education practices in the Sultanate more international credibility.

A set of trends characterize science education research in Oman: these include its tendency toward the quantitative research school, its exploration of the effectiveness of different modern teaching methodologies, its equal inclusion of male and female participants, its focus on upper grade levels and its limited diversification in terms of sociocultural issues.

A number of challenges remain that might hinder the proper development of science education research in Oman. The main challenge is the limited number of science education researchers. Other challenges include the low number of female science education researchers, the reliance on quantitative research studies, and the limited attention to sociocultural issues. The current author puts forward a number of suggestions to tackle these challenges. First, a national science education research center could be established to tackle different issues related to science learning in the country. This center would be the incubation hub for producing science education researchers. Second, more scholarships should be created to enable science education researchers to complete their Ph.D. abroad. Equal opportunities for male and female researchers should be encouraged. Third, conducting science education research should not be limited to university teams. The Ministry of Education should form research teams to tackle critical issues facing science learning in its public schools such as the low TIMSS scores of Omani schools (Martin et al. 2012). Fourth, a science education professional association could be established to facilitate further research activities in science education in the country such as conferences, forums, and publications.

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Chapter 9
Singapore Science Education

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Abstract Singapore is a small country with a total land area of about 716 km^2 and a population of about 5.4 million, comprising 3.8 million citizens and permanent residents and 1.5 million foreigners. Apart from her deepwater harbour, the only other natural resource that Singapore has is her people, so the education and development of the people is crucial to the prosperity and progress of the country. Thus the education system in Singapore aims to help the young to discover and develop their talents and potential to the fullest, and cultivate a passion for lifelong learning. To achieve these aims, the educational system is becoming more flexible, diverse and broad-based, and these characteristics are also reflected in the teaching and learning of science in Singapore. The science curriculum, from the primary to high school levels, is centred on science as inquiry and focusses on the knowledge, skills and processes, ethics and attitudes required in the practice of science, as well as the understanding of the impact of science in daily life, society and environment. It seeks to cultivate the scientific literacy, competencies and values necessary for the young to take on challenges, present and future, and thrive in a fast changing world.

9.1 Introduction

Singapore is a sovereign city-state with a land area of 716.1 km^2, and a total population of 5.4 million, of which 3.31 million are Singapore citizens and 0.53 million are permanent residents (Department of Statistics Singapore 2013). Apart from its strategic position fronting the Straits of Malacca, its deepwater harbour and its people, Singapore has very few natural resources and has to import almost everything that it needs. Thus, the country places great importance on the education and development of its people as they are crucial to nation building and the

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economy of the country. A key function of the educational institutions in Singapore is to build the workforce required for its high value, technology-intensive manufacturing industries and its world-class service sector to meet its Global-Asia hub aspirations (Ministry of Trade and Industry Singapore 2012). The Singapore government's commitment to education can be seen in the allocation of SGD 11.6 billion (about USD 9.1 billion, or 20 % of total government expenditure) to education for the financial year 2013, the second highest government expenditure after defence, with a total of SGD 5.6 billion going to the national primary, secondary, pre-university and special education schools and a total of SGD 5.1 billion for six local universities, five polytechnics, one institute of technical education and two tertiary institutions for the arts (Ministry of Finance Singapore 2012).

9.2 Singapore Education System

The education system in Singapore seeks to help "students to discover their own talents, to make the best of these talents and realise their full potential, and to develop a passion for learning that lasts through life" (Ministry of Education Singapore 2013d) as well as to support economic growth and nation building (Ministry of Education Singapore 2010a). In the national school system in 2012, there were 14,000 teachers and 246,000 students in 175 primary schools (Primary 1–6), 13,000 teachers and 184,000 students in 154 secondary schools (Secondary 1–5), 3000 teachers and 38,000 students in 15 mixed level schools (primary and secondary or secondary and pre-university) and 2000 teachers and 20,000 students in 13 institutions catering for pre-university students (Ministry of Education Singapore 2013a).

Primary school education is compulsory in Singapore. After 6 years of primary schooling (Grades 1–6), a student proceeds on to 4 or 5 years of secondary school education (equivalent to Grades 7–10). There are various pathways of study for post-secondary education. About one-fifth of each school cohort enrols into the Institute of Technical Education for one to two years of vocational education (Ministry of Education Singapore 2011a). More than 4 in 10 students go on to pursue a 3-year diploma programme in a polytechnic or institution for the arts. The rest continue their study for 2 or 3 years in a pre-university institution (equivalent to Grades 11–12). About a quarter of each school cohort studies at one of the five local autonomous universities funded by the government. The plan is to increase this to about 40 % by 2020 (Ministry of Education Singapore 2012b). Another one-fifth of the cohort enrols in privately funded local universities or universities overseas.

9.3 Development of the Singapore Education System

The Singapore education system has undergone three phases of development and is now into its fourth phase. The first three phases that the country has undergone, from the time it became self-governing in 1959 and independent in 1965, are the survival-driven phase in 1959–1978, the efficiency-driven phase in 1979–1996, and the ability-driven phase in 1997–2011 (Goh and Gopinathan 2008; Ministry of Education Singapore 2010b). The survival-driven phase focussed on "the development of a literate and technically trained workforce" (Goh and Gopinathan 2008, p. 14) to support the country's shift from entrepôt trade to export-oriented industrialisation and to attract multinational corporations to Singapore in order to ensure its economic survival. This resulted in much emphasis being placed on bilingualism, mathematics, science and technology education, as well as vocational training, to provide workers with the competencies required for the new industries being set up during the period.

In the late 1970s, although economic prosperity was evident in Singapore, there was a realisation that the country had to move away from labour-intensive industries into higher technology, capital-intensive areas as other developing countries had a greater labour cost advantage over Singapore (Goh and Gopinathan 2008; OECD 2011). This meant that the strong emphasis on mathematics, science and technical education which was started in the earlier phase was maintained. In addition, Singapore embarked on an efficiency-driven education system in 1979 to address the high attrition rates in schools and the low levels of English language proficiency, which affected the learning of other subjects and contributed to the attrition rates. Streaming of students into different academic tracks was introduced to allow them to progress at a pace that was more appropriate to the individuals (Ministry of Education Singapore 2008a; OECD 2011). The national curricula and assessments were also revised "to enable each pupil to go as far as possible in school, and thereby achieve the best educational takeoff for training and employment" (Goh and Gopinathan 2008, p. 23). The changes resulted in a reduction in the school attrition rate. By 2009, only 1.2 % of each cohort did not complete secondary education, compared to dropout rates of 6 % among primary school students and 13 % among secondary school students in the 1970s (Ministry of Education Singapore 2012b). At the end of the efficiency phase, Singapore students took part in the Third International Mathematics and Science Study in 1995 and emerged among the top performing countries for both Grades 4 and 8 (TIMSS International Study Center 1996, 1997).

Rapid globalisation and technological advances led to the transition to a knowledge-based economy for Singapore. The education system responded and entered into its third phase, the ability-driven phase, from 1997 to 2011 (Goh and Gopinathan 2008) to better prepare the young to meet the challenges of the twenty-first century and instil passion for lifelong learning. The key features of this approach were "maximal development of talents and abilities, and maximal harnessing of talents and abilities" (Ministry of Education Singapore 1998). The approach was implemented by encouraging schools to develop innovative programmes and differentiated curricula as well as through the provision of multiple pathways for a child to realise his/her potential (Ministry of Education Singapore 2010a). These multiple pathways include greater opportunity for lateral transfer between different academic tracks, integrated programmes for high-ability students (Ministry of Education Singapore 2011b) and specialised schools for science and mathematics, science and technology, the arts, sports, as well as for students who are more inclined towards vocational learning (Ministry of Education Singapore 2012a).

The fourth and current phase of educational development—the student-centric, values driven phase—was launched in 2011 to build upon the ability-driven phase and with a stronger focus on the holistic development of the child "centred on values and character development", while maintaining the rigour of the curriculum and ensuring that there is a diversity of pathways and opportunities for educational and career progression (Ministry of Education Singapore 2011c). Schools began developing applied learning and learning for life programmes for their students to help them apply thinking skills and knowledge across all subjects to real-life situations, and to provide "real-life experiential learning to develop their character and values, cultivate positive attitudes, self-expression and strengthen their people skills" (Ministry of Education Singapore 2013b). Areas in which applied learning programmes could be developed include engineering and robotics, environmental science and technology, and health services, while programmes for learning for life could include outdoor adventure learning and sports (Ministry of Education Singapore 2013b).

9.4 Science Education in Singapore

Science education mirrored the transformation that took place in the general education landscape in Singapore. In the early years of national survival, science education played a key role in developing skills and capabilities that fuelled the industrialisation process. Standardisation was a hallmark of the efficiency-driven phase. Science textbooks, workbooks and teaching guides were locally published for the first time, and large numbers of teachers, including those with little science education background, were trained to teach science using these resources. This helped to ensure that a certain minimum level of fidelity in curriculum implementation was maintained (Poon 2014).

The ability-driven phase saw the need for nurturing inquiring minds and citizens comfortable with using and harnessing technology for work and leisure in the twenty-first century. Carrying over into the current student-centric, values-driven phase, there is a continued drive for inquiry coupled with a new emphasis on applying knowledge to new contexts to solve real-life problems. The current stated goal of science education is to enable "students to be sufficiently adept as effective citizens, able to function in and contribute to an increasingly technologically-driven world" (Ministry of Education Singapore 2012c, p. 1). The development of scientific literacy in students is part of the twenty-first century competencies framework adopted by the Ministry of Education Singapore to prepare students to "thrive in a future driven by globalisation and technological advancements" (Ministry of Education Singapore 2010c). The Singapore science curriculum framework is implemented through a "science as an inquiry" platform and it includes the "integral domains of (a) Knowledge, Understanding and Application, (b) Skills and Processes and (c) Ethics and Attitudes" (Ministry of Education Singapore 2012c, p. 1). Both the student and the teacher are involved in the inquiry process with the student as the inquirer who determines ways to solve problems by asking appropriate questions, planning and conducting experiments, analysing the data collected, drawing conclusions, communicating and defending their findings (Chinn and Malhotra 2002). The curriculum positions the teacher as the leader of inquiry (Ministry of Education Singapore 2012c), facilitating the inquiry process in the classroom and encouraging the student to explore novel situations, build new understandings, and apply his/her knowledge and skills to solve problems relevant to daily life.

Through three waves of the Information, Communications and Technology (ICT) Masterplan since 1997, ICT has been innovatively harnessed as a tool for enhancing teaching and learning. In particular, innovations in the use of ICT centred on learning of twenty-first century competencies, self-directed learning, and collaborative learning (Ministry of Education Singapore 2008b, c). As such, the development of ICT tools, such as multi-player games, virtual reality and mobile technologies are strongly encouraged, and education labs and schools (e.g. FutureSchools@Singapore) have been established for this purpose. There is also a dedicated translational unit to scale up the use of innovative practices in the school system.

9.5 Primary Science

Unlike most education systems around the world, students in Singapore first encounter formal science lessons at the age of nine, in the third year of primary schooling (Primary 3). English is the main language of instruction in school, but is not the predominant language spoken at home. Therefore, there is a strong focus on literacy development in the first two years of primary education to build a firm foundation for students to read to learn (Chall 1983, 1996). Curriculum time allocated for science, which ranges from two hours per week in Primary 3 to two and a half hours per week in Primary 6, is also lower when compared to that of mathematics and English (see comparison at G4 in Mullis et al. 2012a, b).

The aims of the national primary science curriculum are to give students the experiences, knowledge and opportunities "to stimulate their curiosity about their environment", to "understand themselves and the world around them", "develop

Table 9.1 Overview of the 2014 primary science syllabus

Themes	Key inquiry questions	Lower block (Primary 3 and 4)	Upper block (Primary 5 and 6)
Diversity	• What can we find around us? • How can we classify the great variety of living and non-living things? • Why is it important to maintain diversity?	• Diversity of living and non-living things (General characteristics and classification) • Diversity of materials	
Cycles	• What makes a cycle? • Why are cycles important to life?	• Cycles in plants and animals (Life cycles) • Cycles in matter and water (Matter)	• Cycles in plants and animals (Reproduction) • Cycles in matter and water (Water)
Systems	• What is a system? • How do parts/systems interact to perform function(s)?	• Plant system (Plant parts and functions) • Human system (Digestive system)	• Plant system (Respiratory and circulatory systems) • Human system (Respiratory and circulatory systems) • Cell system • Electrical system
Interactions	• How does man better understand the environment? • What are the consequences of man's interactions with the environment?	• Interaction of forces (Magnets)	• Interaction of forces (Frictional force, gravitational force, force in springs) • Interaction within the environment
Energy	• Why is energy important? • How is energy used in everyday life? • Why is it important to conserve energy?	• Energy forms and uses (Light and heat)	• Energy forms and uses (Photosynthesis) • Energy conversion

Source Ministry of Education Singapore (2013e)

skills, habits of mind and attitudes necessary for scientific inquiry", use "scientific knowledge and methods in making personal decisions", and "appreciate how science influences people and the environment" (Ministry of Education Singapore 2013e, p. 5). The overview of the primary science syllabus is given in Table 9.1. A thematic approach is adopted in the primary science syllabus to present an integrated perspective of scientific ideas. The five themes of Diversity, Cycles, Systems, Energy and Interactions are chosen to embody concepts in both the life and physical sciences.

Key inquiry questions and essential takeaways are also spelt out in the primary science syllabus to help teachers and students understand the big ideas and key concepts in each theme. In the theme of Diversity, for example, the Key Inquiry Questions focus on the components of the environment, the diversity of living and non-living things and the importance of maintaining such diversity (Ministry of Education Singapore 2013e). Instead of memorising classical taxonomy of living things, the syllabus encourages students to observe similarities and differences in the characteristics and properties of living and non-living things in their classrooms, homes, school gardens or nearby public parks. They learn about ways of classifying using dichotomous keys, and the usefulness and applications of classification. Students learn about the nature of science when they understand that classifications, like the ones that scientists give to groups of objects, are not permanent and that advances in technology could modify properties of materials or create new materials to suit different uses. For example, students observe that boat models made from paper disintegrates and sink in water but paper cups can hold water, so the properties of paper are not fixed but can be modified to cater to the intended use of the paper. Key inquiry questions are developed for all the other themes and are shown in Table 9.1.

The syllabus also suggests specific teaching and learning strategies to engage students' interest in science, including activities using concept cartoon, concept mapping, role play, stories, field trips and so on. Teachers are encouraged to incorporate experimental investigations. An example of the inquiry experiments include determining the factors that affect the rate of evaporation and investigating whether the material of the cloth (e.g. cotton or Dri-FIT) affects the rate of evaporation. Students could also make a model of the human lungs, study the movement of water in a plant, explore how heart rate changes with exercise, compare cheek and onion cells, and discover the components of an electrical circuit and how they interact in the circuit. Professional development programmes such as the Advanced Diploma in Primary Science Education conducted by the National Institute of Education Singapore (National Institute of Education Singapore n.d.) enable teachers to learn how to use these activities in their own classroom teaching to engage their students.

In Primary 5, school-wide subject-based banding of students is implemented with students who are stronger in certain subjects, including science, to learn the subject at the standard level. If students are weaker in certain subjects, they can learn the subjects at the foundation level, which is less demanding for them. For example, in foundation science, students do not have to learn the cell system, force in springs, and energy conversion, which are included in the standard science syllabus. Generally, more curricular time is allocated to the learning of each topic in foundation science and pedagogical approaches are also chosen to meet the needs of the students. The object of the subject-based banding is to cater to the different abilities of the student, to allow them to learn more in the subjects that they are strong in while ensuring that all students, regardless of ability, learn the fundamentals well (Ministry of Education Singapore 2013c).

9.6 Lower Secondary Science

All students in lower secondary (Grades 7–8) will learn science, which is designed as a general integrated science syllabus to develop students' scientific literacy. Lower secondary science builds upon what students learn in primary science. The aims of lower secondary science are to "cultivate students' perception of Science as a collective effort and a way of thinking rather than just a body of facts", engage them in "Science-related issues that concern their lives, the society and the environment" and "help students develop the domains that are integral to the conduct of Science Inquiry" (Ministry of Education Singapore 2012c, p. 5). Strategies recommended by the curriculum developers to achieve these aims through inquiry-based learning include brainstorming, case study, concept cartoons and mapping, collaborative learning, field trips, model building, project work and role play. The curricular time allocated to science in Secondary 1 and 2 is about three and a half hours per week.

In addition to scientific knowledge, skills and attitudes, students continue to learn more about the nature and practice of science, and the links between science, technology, society and environment in a section on The Scientific Endeavour and through the entire four themes of Diversity, Models, Systems and Interactions. As Singapore adopts a spiral curricular design, many of the lower secondary science topics in the three themes of Diversity, Systems and Interactions are coherently developed from the primary science syllabus (see Table 9.2). Consistent with the primary science curriculum, the lower secondary science curriculum is inquiry-centric. Key Inquiry Questions in the lower secondary science syllabus serve to guide students and teachers to explore the big ideas and important concepts in the themes (Ministry of Education Singapore 2012c). Again, teachers are encouraged to help students make links between the concepts taught in the different themes to reduce compartmentalisation of knowledge.

The Scientific Endeavour is a new strand introduced in the 2013 Lower Secondary Science syllabus. It incorporates the topics of "scientific inquiry" and "science and technology in society" from the 2008 syllabus and introduces elements of the nature of science. Lederman (2007) describes the nature of science as "ways of knowing, or the values and beliefs inherent to scientific knowledge and its development" (p. 833). Prior to 2013, the study of the nature of science was not common among Singapore schools (Tan et al. 2006) and was not explicitly articulated in previous science syllabuses. These changes in the syllabus bring it in line with research on the importance of incorporating epistemic discourse and dialogical reasoning (Kelly 2008) and on the nature of science into school science (Abell and McDonald 2004; Bybee 2004; Lederman 2007). The learning outcomes include developing awareness that science is a human endeavour that is socially constructed based on systematic collection and analyses of evidence and rigorous reasoning. Students are exposed to the idea that scientific evidence can be subjected to multiple interpretations and that claims and supporting evidence must stand up to scrutiny by the scientific community. Students are encouraged to develop attitudes such as

Table 9.2 Overview of the lower secondary science syllabus

Themes	Topics	Key inquiry questions
The scientific endeavour		• Why did this event, phenomenon or problem happen? • What is science? • How does science affect our lives?
Diversity	• Exploring diversity of matter by their physical properties • Exploring diversity of matter by their chemical properties • Exploring diversity of matter using separation techniques • Understanding diversity of living things	• How does the diversity of living and non-living things contribute to our lives? • How do we classify things in our world? • How do we find out the properties and characteristics of things around us?
Models	• Model of cells—the basic units of life • Model of matter—the particulate nature of matter • Model of matter—atoms and molecules • Ray model of light	• Why are models important? • How do we know that the models used are good representations of the real system?
Systems	• Transport system in living things • Human digestive system • Human sexual reproductive system • Electrical systems	• How do parts of a system or different systems work together to perform a function? • How could parts of a system affect the function of other parts?
Interactions	• Interactions through the application of forces • Energy and work done • Transfer of sound energy through vibrations • Effects of heat and its transmission • Chemical changes • Interactions with ecosystems	• How does knowledge of interactions between and within systems help man better understand his environment? • What are the interactions between physical phenomena and life processes?

Source Ministry of Education Singapore (2012c)

integrity, open-mindedness and perseverance in carrying out scientific inquiry. Topics such as genetically modified food, nuclear energy, and clearing of forests for agriculture are used as authentic and engaging contexts for students to reflect and debate on the social and ethical issues arising from the impact of science and technology on society, especially when there are conflicting claims on the same issue. The Scientific Endeavour is not taught only as a standalone topic, but is also infused and integrated into the teaching of the other four themes.

Diversity in lower secondary science builds upon what students have learnt in primary science about the diversity of living and non-living things, and they explore how such diversity contributes to their lives (Ministry of Education Singapore 2012c). For example, in addition to the learning of the properties and uses of materials, they also discuss sustainable use of materials and the environmental impact of some materials such as paper and plastics. More chemistry concepts are introduced in lower secondary science as compared to primary science. They learn about elements, compounds and mixtures, solubility of substances and simple separation techniques.

In terms of pedagogical approaches, field trips lend themselves well to the teaching of diversity. For example, the Bukit Timah Nature Reserve (National Parks 2009), a primary forest, and the Sungei Buloh Nature Reserve (Sungei Buloh Wetland Reserve n.d.), a mangrove swamp, are excellent places that students can experience biodiversity in Singapore and learn how flora and fauna interact with each other in the respective ecosystems. Singapore has also been building technology enriched resources for the teaching and learning of science. For example, *Legends of Alkhimia* (Chee and Tan 2012) is a locally developed game-based learning tool that provides students with an immersive environment to inquire into the basic concepts involved in the separation of mixtures. The game provides the context and motivation for learning, and the virtual in-game laboratory allows students to try out various ways of separating mixtures and gain virtual experience of the consequences of their actions that might otherwise be dangerous to them. Students can thus, carry out the 'wrong' procedures and find out why these procedures are not suitable or less desirable than the 'right' methods, something which is not encouraged in normal practical work because of safety considerations. As such, the virtual learning platform provides opportunities for students to make and learn from their mistakes.

The theme, Models, is not encountered in primary science, a possible reason being that the concepts associated with the theme may be too abstract for younger students. The lower secondary students need to know that a model is not a true description of a phenomenon or entity, "but rather a set of assumptions that include theoretical entities and relations among them" (Snir et al. 2003, p. 797) to help people to describe, think and make predictions about a phenomenon or entity. Students learn the model of cells, the particulate nature of matter, models of atoms and molecules, and the ray model of light. They will already have some basic knowledge about the structure of a cell and the functions of the various parts of the cell, as well as some properties of light. More advanced skills such as the use of a microscope to observe and identify cell parts, and concepts such as the reflection, refraction and dispersion of light are taught at this level. However, the chemistry models will be new to students. Studies have shown that these particulate nature of matter and models of atoms and molecules are difficult to learn (e.g. Harrison and Treagust 1996, 2002) as students do not encounter them in their daily lives and they involve abstract invisible sub-microscopic entities and their interactions (Carr 1984). During teacher education and professional development programmes, teachers are encouraged to take additional care in teaching these models, allowing students time to make sense of the models and test their understanding of them. Animations, illustrations, concrete models and analogy are resources available for teachers to help students visualise the particles. Inquiry activities, such as how to remove the odour quickly from a room in which perfume has been spilled, are suggested to allow students to grapple with the relevant particulate nature of matter concepts.

In addition to similar inquiry questions in primary science about the parts of a system or different systems interacting together to perform a function, an additional inquiry question that lower secondary students have to grapple with under the theme of Systems is how parts of a system can affect the function of other parts in the same system. Students learn about the transport system in plants and animals again, this time taking into account the processes of diffusion and osmosis in the transport of substances. Advanced concepts in the human digestive system such as the function of enzymes and the use of the products of digestion by the cells are also learning outcomes at this level. The importance of personal hygiene and proper food handling procedures in the prevention of food-borne diseases are included in the syllabus (Ministry of Education Singapore 2012c) and news reports of outbreaks of food-borne diseases are excellent starting points for discussions. Learning the human reproductive system in lower secondary involves understanding in greater detail the reproductive systems in males and females, fertilisation and combination of genetic material from the father and mother, puberty, birth control and sexually transmitted diseases. The social and moral issues of pre-marital sex and abortion are important and relevant to students' lives, and teachers use debates and drama to help students explore these socio-scientific issues.

The final theme in lower secondary science is Interactions and it focusses on the "interactions between and within systems" as well as the "interactions between physical phenomena and life processes" (Ministry of Education Singapore 2012c, p. 30). This builds upon the students' primary science knowledge of forces, the interactions between living things and their environment. In addition to forces, students encounter pressure, energy and work done, sound and heat energy in lower secondary science. Activities to promote student learning include investigating the damage that the heels of different shoes can inflict on different flooring, creating music by varying the depth of water in containers and blowing over or striking these containers, and determining the fastest way to cool a container of hot water. Students learn various chemical interactions such as combustion, neutralisation and thermal decomposition, write word equations and see demonstrations or carry out experiments to experience these interactions. They also discuss the importance of chemical reactions in daily life such as rusting, cooking, combustion of fuels, fermentation and decay. In the ecology part of Interactions, the student continues to learn about interactions within various ecosystems, the flow of energy and recycling of nutrients within the systems, the need to conserve resources and protect the environment, and examples of sustainable living practices. Field trips, as mentioned previously in the discussion on Diversity, are essential in helping students experience and understand these interactions.

9.7 Upper Secondary and Pre-university Science

Science is an elective subject at the upper secondary and pre-university levels, although the majority of students choose to study at least one science subject. Upper secondary students (age 15–17) can choose to study combined science subjects such as chemistry-physics, chemistry-biology, or biology-physics or single "pure" science subjects, namely biology, chemistry or physics. At the end of the final year of secondary education, students will sit for a national examination, the Singapore-Cambridge General Certificate of Education (Ordinary Level) Examinations. The science examinations include written as well as practical papers. For biology, chemistry and physics as single subjects, the practical examinations are school-based and assessed by the students' teachers, while combined science subjects have one-off practical examinations at the end of Secondary 4 or 5. Curricular time allocated to one upper secondary science subject ranges from three to four hours a week.

Pre-university education is the final phase in the national school system and students (age 17–20) at this level can choose to study science subjects as major subjects (Higher 2 level or abbreviated as H2) in the Singapore-Cambridge General Certificate of Education (Advanced Level) Examinations. Science as minor subjects (H1 level) are also offered to students who wish to study science as a contrasting subject (in contrast to majors in the humanities and social sciences). Chemistry as a major science subject is the most popular science subject in pre-university as it is a prerequisite for the undergraduate medical, chemical and biomedical engineering programmes in local universities. Students who are outstanding in science can also be offered advanced science courses (H3 level) such as modern physics, pharmaceutical chemistry or proteomics, or carry out a research project supervised by science or engineering faculty members of local universities. About five hours a week are allocated to one science subject in pre-university.

The aims of the science subjects in upper secondary and pre-university are to equip students with the scientific knowledge, skills and attitudes to "become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific importance" (Singapore Examinations and Assessment Board 2013a, b), understand the limitations of science as well as its applicability in daily life, and be adequately prepared to study science or science-related courses at their next level of education. Inquiry activities do not feature as much in upper secondary and pre-university science classrooms as in primary and lower secondary science as more emphasis is placed on the third aim of preparing students for higher education. Furthermore, curriculum time is limited and much time is devoted to teaching the prescribed examination syllabuses (Singapore Examinations and Assessment Board 2013a, b) in preparation for the national examinations. However, students do laboratory investigations as an integral part of the curriculum, and have opportunities to do science projects and this will be discussed in the next section.

Thorough understanding of concepts is important for the examinations and this is generally achieved in school by allowing students to have experience with the concepts through experiments or demonstrations and by using concept analysis

(Herron 1996) to help students grapple with the critical and variable attributes of the concepts. For example, secondary students can do experiments and find out that acids have a pH value less than 7, turn red litmus blue, and react with bases and carbonates, but may still not be able to explain what exactly an acid is. Concept analysis of acids based on the Arrhenius model used in secondary chemistry will reveal that they are substances that ionise in water to form hydrogen ions, and it is these ions that give the acids the properties that they observe in the experiments. To link associated concepts together, concept mapping (Novak 1996) is carried out by students to obtain a big picture of the concepts involved, especially in the larger topic, acids, bases and salts. Teachers will also help students to understand and use the representations involved in the various science subject. In chemistry, students need to be able to use chemical symbols and equations effectively to describe and explain the interactions of particles at the sub-microscopic level, which gives rise to the phenomena that they see at the macroscopic level (Kozma et al. 2000). As ICT is used rather extensively in Singapore, animations and simulations are normally employed to allow students to visualise the particles and their interactions.

9.8 Cultivating Students' Interest and Talents in Science

Secondary and pre-university students who have the aptitude and interest in science are given opportunities to participate in programmes such as the Science Mentorship Programmes (Ministry of Education Singapore 2006) where they work on research projects guided by mentors in tertiary and research institutions such as Nanyang Technological University and the Defence Science and Technology Agency. Students work about three hours a week on their projects for seven months when schools are in session and two weeks full time during their mid-year vacation. When they complete their projects, they are expected to write a scientific paper to be presented at the annual Youth Science Conference. Those who have produced high quality work usually go on to participate in the Singapore Science and Engineering Fair or even represent Singapore at the prestigious Intel International Science and Engineering Fair (Science Centre Singapore 2009). Some schools are very well-equipped with science research facilities and have teachers with masters and doctoral degrees in science. These schools organise their own in-house science research programmes where teachers will mentor their own school students to do science research in the school laboratories and then present their research findings at a school-based science event day. In addition to research and science fairs, students can also participate in science-based competitions such as the national and international science Olympiads, be attached to industry to experience science-related work, and participate in talks and forums given by distinguished international scientists and Nobel Laureates.

Singapore has two specialised schools for science. The NUS High School of Mathematics and Science, which is affiliated to the National University of Singapore (NUS), was established in 2005 to provide a 6-year programme (combining secondary and pre-university education) to students with special talents in, and passion for, mathematics and science. The school awards its own diploma at the end of Year 6, unlike most other pre-university institutions which offer the Singapore-Cambridge General Certificate of Education (Advanced Level). It attracts the top 10 % of the national cohort of Primary 6 students (NUS High School n.d.). There are special programmes in the school such as the Da Vinci research programme with full time research attachment with scientist mentors, and the Einstein + programme which involves exceptional talented students taking university-level modules in NUS, being mentored by NUS professors and undergoing Olympiad training.

Another specialised school is the School of Science and Technology, which recruited its first batch of students in January 2010 (School of Science and Technology 2012b). The school partners with Nanyang Technology University and Ngee Ann Polytechnic to design its curriculum and enrichment programmes. It offers a 4-year programme that has an enriched curriculum focusing on applied learning that has stronger connection to applications in real-life contexts. Students sit for the Singapore-Cambridge General Certificate of Education Ordinary Level Examinations at the end of Year 4 but they are also able to select applied subjects such as biotechnology and fundamentals of electronics (School of Science and Technology 2012a). Innovation and entrepreneurship is strongly emphasised in the school and students attend courses providing the necessary knowledge and skills, fostering the requisite attitudes and habits of mind, and offering students opportunities to engage in "innovation and entrepreneurship in simulated and authentic contexts" (School of Science and Technology 2012c).

9.9 Science Education Research

Tan (2010) reviewed the state of science education research in Singapore from 1971 to 2008 and found that studies conducted before 1990 were focused mainly on local issues and were rarely published in international journals. She argued that research in science education in Singapore started to grow after the launch of policy initiatives by the Ministry of Education such as the use of ICT in schools and the development of students' creativity and thinking skills. The establishment of the Centre of Research in Pedagogy and Practice by the National Institute of Education and the Ministry of Education in 2004 also played a large part in the progress of science education research as the provision of grants supported larger scale research, and publication in international journals was an important performance indicator for grant recipients. Studies conducted were researcher-driven, resulting in a diversity of research and publication in areas such as science teachers' pedagogical content knowledge, classroom learning environment, ICT in science, inquiry-based learning, argumentation, scientific discourse, student understanding and alternative conceptions, and affective learning in science. While studies elsewhere have suggested that research appears to have limited influence on classroom practice and policy (Davies and Nutley 2008; Levin 2013; Nelson et al. 2009), studies have yet to be conducted to determine how the uniquely close relationship between the National Institute of Education, the Ministry of Education and schools influence the impact of science education research on classroom practices.

9.10 Future Directions

Singapore's education system is constantly evolving to help students take on challenges of the present and future, and the Singapore science curriculum moves in tandem with it. We are of the view that five recent developments will have a significant impact on science teaching and learning in Singapore for the next decade:

(a) Singapore's curriculum is reviewed about every 6 years. In the last two cycles of curricular review, there has been a strong emphasis to coherently develop themes and big ideas across the spiral curriculum. This will help teachers and students integrate and transcend scientific concepts and focus on "big ideas" of science and will be most impactful in applied fields of science. Our view, however, is that conspicuously missing in the science syllabuses are big ideas in earth and space science. While there are considerations of adequate curricular time to include earth and space science topics, it might be worthwhile for the curriculum specialists and science educators to examine whether this has resulted in fundamental knowledge gaps in today's context. After all, earth and space science concepts and big ideas such as the continuously changing planet, natural hazards, our dependence on resources from the earth, atmosphere and weather, and changes to the planet caused by human activities (American Geosciences Institute 2014; National Aeronautics and Space Administration 2011) are fundamental to understanding some of the most critical environmental and security issues plaguing nations today.

(b) Our view is that the inquiry-centric science syllabuses and suggested teaching and learning approaches are in the right direction to shift the focus of teachers from just teaching science as bodies of knowledge to also include teaching science as a way of thinking to make decisions in daily life, solve problems and create new ideas and products for the benefit of mankind. It also equips students with skills and dispositions that are useful beyond the realm of the science discipline, for example reasoning and problem-solving skills, and an inquiring mind that is open to alternative and novel ideas.

(c) The recent initiative on applied learning that go beyond textbook knowledge to real-life hands-on application of scientific principles would enrich the learning experiences of students and better equip them with relevant skills for the twenty-first century. To bring in an anecdotal example, a group of students saw very little relevance in learning chemical bonding as it was abstract to them. Their interest was, however, invoked when their science teacher demonstrated that the creases in his shirt was actually due to chemical bonding between the molecules of the shirt material which prevented parts of the material from unfolding. Shirts could thus be made more crease-resistant by modifying the interactions between the molecules in the material. This focus on how humans can harness scientific knowledge and technology to create solutions to problems they encounter in everyday life has the potential of developing minds that are flexible and ensuring that the general population is scientifically literate and able to thrive in the twenty-first century with its rapid scientific and technological advances, even if they do not study science or science-related disciplines at the tertiary level.

(d) Teacher development policies have been transformed in the last 15 years. Singapore has created three tracks for the teaching service (Ministry of Education Singapore 2014). In addition to the leadership track, Master Teachers of Science are appointed in the Teaching Track to develop innovations in teaching and learning pedagogies and take on mentoring roles across schools to spread the use of these new pedagogies. Senior Specialists on the Specialist Track are given training to develop expertise that are essential for breaking new grounds in curriculum and resource development. Professional development opportunities for teachers, including science teachers, have also been enhanced to help teachers grow professionally throughout their career, for example, through professional development leave and work attachment for teachers. In 2010, the Singapore Ministry of Education also set up the academies, which includes the Science Subject Chapters (Academy of Singapore Teachers 2012), to support more teacher-led professional development efforts.

(e) The accessibility, plausibility and feasibility of science education research (Tan and Gilbert 2014), conducted in Singapore and elsewhere, to teachers and policymakers are important considerations for research to have impact on practice and policy. Research findings have to be translated into forms which are easily available, understood and used by teachers and policymakers. Some encouraging trends which have emerged in recent years: (i) more teachers pursuing a degree in Masters of Education and hence, leading to an increase in the number of practitioners with knowledge about research and heightening of chances that research findings may be utilised in classroom practice; (ii) more science education faculty members being invited to schools to discuss research design, implementation and findings; and (iii) more researchers actively inviting policy makers and teachers to come on-board research projects as collaborators so that there is greater alignment between the research project goals and policy and practice.

Even as we are writing this chapter to describe what we know about science education in Singapore in the last 50 years, the new chapter of science education in Singapore is unfolding and as science educators in Singapore, we look forward to contributing to this new narrative.

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Chapter 10
Opportunities and Challenges for Science Education in Asia: Perspectives Based on the Taiwan Experience

Chorng-Jee Guo and Mei-Hung Chiu

Abstract Although the opportunities and challenges facing each country may differ regarding science education research and practice, there are certainly commonalities, shared interests, and so on that suggest it would be of mutual benefit for different countries to exchange and share their experiences. Toward this end, a recently published book edited by Chiu (2015a, b) not only reports the successes and achievements, but also examines and articulates the existing and emerging opportunities and challenges for science education in Taiwan. While each chapter of the edited volume presents the progress of science education in Taiwan from a different perspective, a closer examination and reflection of these collective efforts and activities point to the emergence of a set of experiences that worthwhile to share with science education scholars, researchers, and policymakers from other Asian countries and the rest of the world. Based on the "Taiwan Experience," it appears that in spite of the complexity of the political and socioeconomic backdrop in Asia, promising opportunities exist at the individual, regional, and global levels for science educators to improve the quality of science education research, to increase the effectiveness of science teaching and learning at school, and to reach out and educate a wider audience in a range of informal settings. The edited volume by Chiu (2015b) documents the emergence of the "Taiwan Experience" and lays the groundwork for a similar phenomenon happening in other fields and in other regions of the world. The implications for science education in Asia and beyond are discussed in detail.

While there are a few articles describing science education research and practice in Taiwan (Chiu 2007; Chiu and Chen 2012; Tsai and Wu 2010), a recent book edited by the second author of this chapter provides a more comprehensive review of the

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development of science education in Taiwan in the past and discusses in detail the challenges and opportunities faced today (Chiu 2016a, b). The book edited by Chiu (2016a, b) does not simply present a historical overview of the development of science education in Taiwan over the past few decades, but also provides a comprehensive review of research studies focusing on both local and international issues in science education. It also discusses the impact of this research on practices in science education in Taiwan, including teaching and learning of science, development of curriculum materials and assessment, teacher education and professional development, and use of information and communication technology in science and mathematics education. The chapters by domestic authors and their accompanying commentary by well-known international science educators and researchers include immensely rich descriptions of local experiences that will be of particular significance for countries in Asia and other regions undergoing similar changes in social, political, and economic development.

The first section of this article provides an overall description of the "Taiwan Experience" and discusses its main implications in terms of opportunities and challenges in science education in Asia. In doing so, the authors hope to highlight answers to questions such as the following: What are the most important factors contributing to the apparent success of science education in Taiwan? What lessons can be learned? What kinds of challenges and problems still lie ahead? What are their implications for the future development and implementation of science education in Asian countries? Since each chapter in the book edited by Chiu (2016a, b) answers the questions above from a different perspective and involves different aspects of science education, the following section of this article presents the main message of each chapter as it relates to the different areas of science education and includes supporting evidence from the volume.

10.1 The Taiwan Experience and Its Implications for Science Education in Asia

Based on a close examination and reflection of the complete volume edited by Chiu (2016a, b), in this section, we outline the "Taiwan Experience" and point out its relevance and implications for other Asian countries facing contemporary challenges in science education.

The relevance of the Taiwan Experience in science education for Asian countries is illustrated in the chapter by Yore et al. (2016):

> 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 (p. 419).

Guo and Chiu (2016) similarly highlight the steps that have led to the Taiwan Experience:

> The case story told 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” (p. 40).

For Duit (2016), what was most pivotal in developing science education in Taiwan was “deliberately establishing science education as a research field in Taiwan”, “international support”, and “becoming familiar with the international state of the art in science education” (pp. 81–82).

From the quotes above, it is clear that the most important factors contributing to the success of science education in Taiwan and that led to the “Taiwan Experience,” include the following:

(1) Strong government policy and financial support, including looking forward in terms of planning, sustaining funding, focusing on human resource development/deployment, evolving monitoring/evaluation/reward system, and supporting infrastructure.
(2) A well-coordinated science education community with effective leadership, wide participation from educators/researchers/teachers, sense of partnership, shared interests and common goals, willingness to help and learn from each other, and dedicated efforts.
(3) International support and cooperation of various forms, including consultants, conferences, workshops, and exchange visits.
(4) Keeping up with international trends and state-of-the-art advancements in science education, while at the same time attending to local contexts, needs, and problems.

In an era of rapid advances in science and technology, knowledge-based economies, and globalization, there are trends and challenges for science education that are of great concern to all countries, including the development of scientifically literate citizens in the twenty-first century, equal educational opportunities for all, and information technology education and use. Many of these trends and challenges are discussed at length in Abell and Lederman (2007); Fraser et al. (2012); Poisson (2001); Tan and Kim (2012). They are also discussed more specifically in Bencze et al. (2012); Ben and Alagumalai (2013); Chiu and Duit (2011); DeBoer (2011); Hodson (2011); McFarlane (2013); Yore (2012). There are a wide range of areas which encompass the major challenges and problems that emerge in an increasingly complex world where social scientific issues arise, and it is important for participating citizens to make informed decisions and take deliberate action. Rather than trying to enumerate the emerging challenges in science education, it is worthwhile pointing out that major opportunities and challenges for science education for Asian countries can be described as falling into the following three levels: global/international, regional, and local/individual.

First of all, regarding issues and challenges that are of global concern, since there has been great effort and rapid progress in the international science education community, it is a national and global challenge for science educators/researchers to keep up to date with the latest science developments, to take part in international activities, and to make effective contributions to these international trends and challenges. Meanwhile, more active participation by science educators/researchers from Asian countries in the international science education community would be of mutual benefit. In terms of the publication of research results in reputable international journals in science education, it is noted that Asian science educators contribute disproportionately (Bencze et al. 2012; Lee 2008; Martin and Siry 2011). Since Asia represents a large population with considerable cultural diversity, Lee (2010) and Martin and Siry (2011) advocate for more active contributions in terms of published work by Asian science educators in well-known international science education journals. They argue that including research participants who represent Asia's wide variation in demographic and cultural characteristics would improve our theoretical understanding of science teaching and learning. As such, great opportunities exist for Asian science educators to publish in international journals the results of their research studies focusing on local problems and participants using methodologies and theoretical frameworks that are comparable or complementary to the dominant Western ones. Of course, there are obstacles for non-English speakers to participate in international conferences and to publish their research results in international journals. Some practical means as well as wider structural changes to help reduce these obstacles were suggested by Lee (2008) and Martin and Siry (2011). In fact, the DES at the NSC in Taiwan has initiated a number of measures to encourage and help domestic researchers to more actively participate in the international science education community (Guo and Chiu 2016; Yore et al. 2016), such as offering financial support to attend international conferences, holding workshops on how to prepare and publish papers in international journals, and assigning higher credit in the award system to papers published in SSCI journals. The "Taiwan Experience" can be a useful model for policymakers and science education leaders in other Asian countries who want to provide learning opportunities, financial support, and leadership for their domestic researchers so they can advance science in their home country and become more involved at the international level.

Second, given the movement toward globalization in a knowledge-based economy, it has been increasingly realized that it is of little use to try to work in one country alone in order to change education's impact (Campbell et al. 2006). Countries in Asia need to contribute effectively to the development and transformation of common goals in maintaining a stable, sustainable, and prosperous Asia at the regional level. Since considerable inequality in the scale and pace of development exists at the regional level, there is concern for the codevelopment and improvement of science education across the Asian countries. Regional cooperation is important for the Asian countries to survive and prosper in the competitive global knowledge economy of the twenty-first century. In recent years, with the establishment of organizations such as the East-Asian Association for Science Education (EASE), there has been more cooperation and frequent dialog among science educators/researchers/societies in the Asian regions. The wide variation in language, culture, religious beliefs, ecological environments, and educational systems in the Asian countries provides great opportunities for science educators/researchers to do comparative studies in the areas of science teaching and learning, teacher education, use of information technology, assessment, and so on. Due to geographical proximity and the use of e-mail, Skype, and video-conferencing, it is now relatively easy to form international collaborative research teams with principal investigators from selected Asian countries working on problems of regional significance and common interest. According to the "Taiwan Experience," it is strongly suggested that governments and higher education institutions in Asian countries provide support and leadership roles in establishing and maintaining a kind of community of practice in science education at the regional level, which would also be active at the global/international level.

Third, considering the competitive nature of global knowledge economy in the twenty-first century, there is a challenge for science education at the individual and local levels in providing opportunities and learning environments that will help young people develop scientific literacy for the twenty-first century (Yore 2012) and empower them to live well both as individuals and as responsible participants in a society that is replete with complex social scientific issues (Christensen and Fensham 2012). Yore (2012) maintained that convergence of contemporary views of science, learning, and pedagogy has led to a vision of scientific literacy different from what is commonly held. In addition to the constructs of science as inquiry, argument, and constructing knowledge claims and explanations of patterns in nature and naturally occurring events, this vision emphasizes the essential role and function of language in doing science, in scientific discourse, and in teaching and learning science. It is noted that many contemporary social scientific issues occur in increasingly complex contexts involving dynamic, interactive, and recursive factors with consequences which may be risky, uncertain, or unpredictable (Christensen and Fensham 2012). The kinds of science teaching and learning that are in line with Vision III of scientific literacy and the complex social scientific issues described above present considerable challenges for the development of new science curriculum and pedagogy. In Taiwan, works in this direction began to take place in recent years, see for instance, the chapter by Liu in the edited book Chiu (2016a, b). The results from these studies highlight the difficulties that students encounter in the use of language at home, at school, in general, and at learning science especially. The essential role and function of language as part of Vision III of scientific literacy proposed by Yore (2012) is a major challenge facing science education in the Asian countries at the individual/local level, to which more science education activities in informal settings and collaborative efforts at the regional and global/international levels may be of help.

10.2 Overview of Science Education in Taiwan

A recent review of science education research and practice in Taiwan by Guo and Chiu (2016) reveals the three major findings from the literature. They will be elaborated in the following.

(1) Significant progress in science education

Yore et al. (2015) clearly outlined the central theme of their chapter in their opening paragraph:

> Science education in Taiwan has enjoyed an interesting and successful evolution over the last fifty 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 (p. 398).

Manifestations of the overall progress of science education in Taiwan in the areas mentioned above include students' performance on the TIMSS and PISA, evolution of teacher education systems, development of original curricula and implementation of these programs in schools, progress in science education research, and regional and international leadership roles played by science educators in Taiwan.

In contrast, the chapter by Guo and Chiu (2016) focused primarily on science education research funded by the Department of Science Education (DSE) at the National Science Council (NSC) from 1982 to 2012. They described the major themes and trends of the NSC funded research projects in science education, the growth of the resulting publications in domestic and international journals, and the general impact (e.g., raising the quality of science education research, improving K-12 science teaching and learning, and developing human resources). The number of sponsored projects started blooming during the period between 1996 and 2000 and then grew steadily from 2001 through today. As a result of the NSC funded projects, there has been a rapid increase in the number of papers from Taiwan appearing in international journals. An examination of the papers published in five influential international science education journals (i.e., *International Journal of Science Education, International Journal of Science and Mathematics Education, Journal of Research in Science Teaching, Research in Science Education, and Science Education*) from 1993 to 2012 indicated that there were only three publications by researchers from Taiwan during the first 5 years from 1993 to 1997, but that number increased steadily to 26, 76, and then 84 during the next three periods, 1998–2002, 2003–2007, and 2008–2012, respectively. Between 1993 and 2012, an average of 3.71 % of the publications in the five selected journals was from Taiwanese researchers. Compared to contributions from other countries, this is a record that stands only next to the USA, United Kingdom, and Australia, and is at the top among non-English-speaking countries. Among the Taiwanese papers published in the five journals, it was found that on average, 72.68 % of these papers received NSC support. Undoubtedly, the DSE at the NSC has played an influential role in promoting research that is carried out locally and recognized internationally.

Regarding the publication of results from NSC funded research in domestic journals, Chiu et al. (2016b) carried out a closer examination of the trends in science education research in Taiwan from 1993 to 2012, using a content analysis of the *Chinese Journal of Science Education* (CJSE), an official journal of the Chinese Association for Science Education in Taiwan. The results showed that *CJSE* published a very high percentage of empirical studies (93.3 %) over the past 20 years. The most common research area involved learning conceptions (27.4 %), followed by teacher professional development (13.2 %), and teaching (12.9 %). Other targets investigated included scientists, textbooks, curriculum, and authority persons, which accounted for 12.7 % of the publications, while there were very few studies on cultural/social/gender issues, history, philosophy, nature of science, informal learning, or textbook analysis. Meanwhile, they also pointed out that some science education researchers intended to publish their research in international journals rather than local journals. And some of them tended to publish their research in *CJSE* instead of the international journals. In both cases, very few science education researchers contributed to *CJSE* and the international journals equally. This phenomenon warrants extra attention and investigation because of its potential impact on research and practice in Taiwan.

Of course, the progress of science education in areas such as student achievement, teacher education, curriculum development, and research and leadership is interrelated. It is clear that the processes, findings, and results of the NSC funded research studies led not only to an increasing number of published papers in reputable local and international journals, but also to improvements in every domain of science education. This was supported by Guo and Chiu (2016) who used a survey questionnaire and by Yore et al. (2016) who used a survey questionnaire and interview format. Concerning the progress of science education in Taiwan during the past 50 years or so, there are additional aspects that the authors of both papers pointed out, including concurrent evolution of science education as a recognized discipline, master's and/or doctoral degrees in science education offered in a number of institutions, the establishment of a Chinese Association of Science Education with an official journal, the formation of a continuously growing learning community in science education, international cooperation and exchange, and the emergence of a group of science educators/researchers serving leadership roles in local, national, and international settings.

(2) Strong government policy and financial support

The development of an adequate supply of workforce and literate citizens in science and technology continues to be a major national concern in Taiwan, and development of science education is part of the entire design. Both the Ministry of Education (MOE) and the National Science Council are charged with special missions in this regard. The important roles that these two organizations played in the development of science education in Taiwan during the past few decades were described in detail by Yore et al. (2016). Each year, the MOE allocates a smaller amount of money to research studies related to the development of instructional materials and other practical sides of teaching and learning in science and mathematics. On the other hand, the DSC provides the NSC with an annual budget of more than US$20 million to support research in science education in a wide range of areas, from basic to applied research.

The historical background and funding policies and practices of the NSC and DSE are described in the chapters by Guo and Chiu (2016) and Yore et al. (2016). Guo and Chiu pointed out that through its funding policies and funding schemes, the DSE played a crucial role in providing, shaping, and improving a favorable environment for members of the entire science education research community in Taiwan to do research and to develop professionally. Yore et al. (2016) partitioned more than fifty years into more manageable periods (i.e., pre-1980, 1980–2010, and post-2010) and described the structure and functions of the DSE that influenced science education in Taiwan at the local, national, and international levels during the three periods.

Guo and Chiu (2016) mentioned that through the Call for Proposals, the DSE directs researchers' attention to selected research themes and topics that are of domestic relevance and in line with international trends, while allowing researchers to choose research topics of their own preference. Research proposals are granted financial support based on a well-developed evaluation system that takes into account not only the previous publication records but also the quality of the research proposal, including soundness of the theoretical framework, research methodology, significance of the research study, its potential impact, and so on. In addition to covering necessary expenses accrued while conducting the research, financial support, provided on a competitive basis, also covers attending international conferences and inviting international scholars to be key speakers at research workshops and seminars. The DSE has provided funds for various institutions and groups of research teams to organize seminars and workshops to inform faculty members of the latest research trends, to write research proposals, to carry out well-designed research studies, and to get their research results presented at international conferences and published in reputable journals. 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 doing research, especially by keeping outstanding publishing records and making significant contributions to the science education community (Guo and Chiu 2016).

In the chapter by Yore et al. (2016), the important role that the DSE at the National Science Council played in supporting and leading research in science education is outlined in the Contextual Overview and continues in the following sections. For instance, at the end of the section on Pre-1980: The Formative Years, the chapter authors pointed out the following two major themes in this period: (a) The MOE, NSC, universities, and science teachers cooperated to establish clear national priorities and patriotism and (b) the initial leadership, planned development, and evolution of the leadership laid the foundation for Taiwan's successes and were the basis from which the challenges of the 1980–2010 period were addressed. Also, the authors described the 1980–2010 periods as The Decades of Outreach and Expansion and pointed out how the continued effective leadership of established leaders, their contemporary replacements, and the NSC and MOE contributed to curriculum reform, international visitors, conferences, and education research. They also attributed the increased scholarship; the new generation of leaders; and the major shift in the direction of scholarship, research, and professional contributions as dividends produced by the investments in human resources. The authors described the activities, improvements, and challenges of science education in Taiwan during this period.

(3) Concerns for future development

With input from a group of new professors and PhD's, Yore et al. (2016) identified in the section on Post-2010: Second Decade of the Twenty-First Century and Beyond future promises and challenges in Taiwan as including the following: (a) As in the past and present, the future of Taiwan's science education depends on its people and leadership; (b) problems concerning science teacher education include demographic changes, teacher demand, university reorganization, and professional practice; (c) NSC and MOE policy changes; and (d) science education goals, curriculum, and instruction. The authors offered a number of suggestions, emphasizing that 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, Web sites, etc. In addition, they pointed out that 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, interpersonal relationships, and respect for others. The chapter suggests that effort must be exerted to align examinations with the new goals and teaching emphases. It also suggests that more attention be paid to the culture, language, and local context in Taiwan and the use of e-learning, technology-enhanced classrooms, and Web-based learning environments in addressing the public's understanding of science and technology.

Concerning the future development of science education research in Taiwan, Guo and Chiu (2016) noted that based on the results of their questionnaire, future research in science education needs to pay more attention to its impact on the teaching and learning of science and mathematics and on educational reforms in general. 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. It is time to carefully assess the outcomes and impact and to consider the possibility of scaling up such efforts. Chiu et al. (2016b) also suggested that detailed analysis should be made regarding questions such as the impact of research on theory and practice both locally and internationally, whether Taiwan had developed a unique theoretical framework for learning and teaching that reflected the country's cultural and demographic characteristics, and whether current research efforts sufficiently inform policymakers so that they can provide continuing policy support to promote quality research.

Before commenting on the first two chapters of the book (Chiu 2016a, b), Duit (2016) provided a brief overview of the development of science education research internationally and a general comment on the predominance of "Western" traditions and the role of English as lingua franca. He then proceeded to point out the rather impressive development of science education research in Taiwan between the early 1990s and 2013. He noted three issues that seem to have played a significant role in this process: (a) establishing science education as a research field in Taiwan, (b) receiving international support, and (c) becoming familiar with the international state of the art in science education. Regarding the science education research funded by the NSC and the papers published in *CJSE*, one of the critical points that Duit made was that although quality criteria of educational research were emphasized, most of the funded research and published papers were empirical in nature. Distinguishing *analytical* from *empirical* research, for instance, Duit pointed out that analytical research focuses on the aims of science instruction and on the structure of the content addressed in a study; while empirical research addresses various issues of teaching and learning science concepts, principles, and views of the nature of science. He noted also that it was not clear how design-based research would fit into the NSC position adopted for science education research in Taiwan and suggested that "it would be valuable to more fully clarify the conception of science education research adopted and to make the quality criteria used for 'good' research more explicit" (Duit 2016, p. 83).

10.3 Science Learning and Assessment

Research on science learning and assessment has been the central emphasis of research in Taiwan (Chiu et al. 2016a). In the early stage of science education research, several researchers adopted Piagetian theory to investigate how young students developed their conceptions about science (e.g., Guo 1992; Huang and Hwang 1992). Based upon a content analysis review of articles published during the period of 1976 through 1997, Liaw (2001) found that the main alternative conceptions students held were in the following topics: (a) light and shadow (e.g., Huang and Hwang 1990; Wang and Guo 1992), (b) heat, temperature, and energy (e.g., Hsien & Guo 1991, Guo 1992), (c) series of electrical circuits (e.g., Chen 1993; Chen and Chen 1992), (d) Newton's laws (e.g., Guo 1989; Young and Guo 1989), (e) changes of matter (e.g., Hwang and Chen 1993; Wang et al. 1992), (f) models of particles (e.g., Huang and Hwang 1985; Lin 1992), (g) acid/base and Redox, (h) chemical equilibrium (e.g., Chiu 1994; Lin et al. 1991), and buoyancy (e.g., Chiang, 1992). The target populations in these studies ranged from elementary to university students. In these studies, misconceptions or alternative conceptions were identified. For instance, some students considered that cats could radiate some light from their eyes in the dark but that humans could not (Huang and

Hwang 1989); students considered the final temperature of two solutions with different temperatures to be the average temperature of the two solutions (Hsieh and Guo 1991); students considered that electricity decreased when it passed through light bulbs (Chen and Chen 1992); students considered that evaporation only happened in water or solution with the solution not evaporating and particles only coming out of the solution and not returning back to the solution. There were no equilibrium conceptions held by the secondary school students (Huang and Hwang 1990), and mass was considered to decrease when matter became solid (Wang et al. 1992). In addition, the students had difficulty understanding chemical equilibrium (Chiu 1994). These misconceptions were not unique from the misconceptions held by other students in Western countries. Some possible explanations included that the scientific concepts were abstract and complicated and that they were mainly influenced by personal interaction with the phenomenon and intuition.

As for studies in the area of process skills during the period of 1976–1997, Liao (2001) found that some researchers developed process skill assessment tools to identify the developmental stages for physical sciences. For instance, in a series of research studies conducted by Hsu (1989, 1992), he found that eighth and ninth graders did not improve their laboratory skills over time after instruction. He also used TIPS (II) to test middle school students and found that the students improved their data processing and conclusion drawing as their grade increased. However, if the teaching materials were investigated, most of their structure was closed-ended. Very few laboratory activities provided opportunities for students to form and test hypotheses in practice.

However, the phenomenon described above changed gradually after 2000. Although there were still quite a number of interesting studies on investigating students' alternative conceptions about science, research into students' learning tended to move from investigating students' conceptions of science to promoting conceptual change in science-teaching practice via different channels, such as alternative assessment and teaching strategies. Later, scientific argumentation and socioscientific issues gained attention from researchers in science education. For instance, the National Science Council initiated an integrated project on diagnosing students' alternative conceptions of science starting from 2000 and lasting for 4 years. Over 100 science education researchers and school teachers were involved in the project to develop, test, and analyze the data of two-tier test items for physics, chemistry, and biology collected from over 10,000 students across different grades from elementary to senior high school. The outcomes of the project appeared in the *International Journal of Science Education* as a special issue (2007, Issue 4) and was titled, *Taiwan's National Science Concept Learning Study: A Large Scale Assessment Project Using a Two-Tier Diagnostic Test*. Chiu et al. (2007) found how the National Science Concept Learning (NSCL) study identified some similar alternative conceptions in biology, chemistry, and physics (such as photosynthesis, nature of particles, and electricity) to those obtained from students in other countries. Also, students in Taiwan were found to come to school with preheld misconceptions about natural phenomenon that remained even after formal school instruction.

Moreover, students' misconceptions were often associated with the structure and meaning of Chinese words used in textbooks and daily life. Chiu (2007) found that students held various types of conceptions of chemical concepts. For instance, 27 % of the elementary school students in the sample thought that all acids/bases were toxic; 56 % of the junior high and 43 % of the senior high school students failed to consider chemical equilibrium when a sugar crystal was added to a saturated sugar solution and the shape of the sugar did not change. Chang et al. (2007) found that some physics concepts made it difficult for students to develop a coherent and correct repertoire for linking conceptions together, such as image formed by lenses and mirrors and force and motion. In addition, the difficulty of learning about electricity was evident in Lee's (2007) findings of elementary school students' conceptions of electricity, which were consistent with studies conducted in the Western countries, namely 71 % thought that the battery was like a water reservoir that stored electricity and allowed it to flow when in use. Wang et al. (2007) analyzed the relationships between students' background information and performance on a diagnostic test of biological concepts and found several factors influenced students' performance in science learning, such as environmental aspects (e.g., urban–rural locations and various types of media) and self-efficacy. However, their results indicated that gender was not a significant indicator for biology education in Taiwan.

Based upon several studies using content analysis and survey methods to investigate science education research trends in Taiwan, there were some findings revealing the current status of science education in comparison with international trends. First, Chiu et al. (2016a) conducted a content analysis on 394 articles published in the *CJSE* in Taiwan from 1993 to 2012. They found that a very high percentage (93 %) of the published studies over the past 20 years were empirical, which was consistent with the international trend of science education research. Also, close to 30 % of the articles dealt with science learning, followed by teacher professional development, and teaching. Among the 394 articles, 63 % of the studies used students as their participants.

Second, Chiu et al. (2016a) reviewed the current research on conceptual change in science education and found that Taiwan ranked third in terms of publishing in international journals from 1982 to 2012. Among the articles published in these international journals, the authors found that about 70 % of the studies from Taiwan tended to relate to the instructional perspective and about one-third of the articles were related to the epistemological perspective. These results differed from the studies conducted outside of Taiwan. However, the authors found that both scholars from Taiwan and international scholars tended to use physics as the main science subject to be investigated compared to chemistry or other scientific subjects. Third, Yang (2016) commented that learners from Taiwan, 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. This was in contrast to countries (such as China and Turkey) which were recognized as having high-context cultures and tended to believe more in authoritative knowledge while relying more on the value of effort.

Finally, Lu and Lien (2016) compared the results of elementary school students (fourth graders) from Korea, Japan, Singapore, USA, and the Russian Federation on the TIMSS. They found that from the questionnaires to the parents, in general, Taiwanese parents' support for educational development was higher than the parental support found in the other countries. Also, Grade 4 students in Taiwan received about 2.08 h of science classes weekly which was less than Korea, Japan, Singapore, and USA. However, there was a low correlation between curriculum and performance on the TIMSS, which held true for Korea, Japan, Singapore, and Taiwan.

Besides the changes of emphasis in science learning from identifying alternative conceptions to conceptual change, other issues began to also develop, such as inquiry-based instruction and e-learning, which were blooming to cultivate students' scientific literacy in a broader manner.

10.4 Innovative Technology for Science Learning and Instruction in Taiwan

The development of research in innovative technology in Taiwan has been dramatically blooming during the past 2 decades. For instance, Hsu et al. (2008) developed an online course for teaching students about the seasons. They found that the correct explanations for the phenomenon increased. Hsu and Wu (2016) further reported a series of studies on technology-infused learning environments for promoting science education and found the use of innovative technology with a student-centered approach elicited students' metacognition. In particular, the students with lower metacognition competence improved significantly in inquiry ability. They further provide evidence of developing students making scientific decisions for complex socioscientific issues. Apart from the Web-based instructional environment, several researchers also developed online assessment systems to assess students' performance in various domains. For instance, Wang (2011) developed a Web-based dynamic assessment system (graduated prompting assessment module of the WATA system, GPAM-WATA) to assist students in understanding key concepts with the use of prompting questions and guided self-assessment. He found that GPAM-WATA was effective in facilitating students' science learning, in particular with low-level prior knowledge. Wang et al. (2013) further developed a Web-based diagnostic system for diagnosing mental models that allows educators to investigate mental models in a systematic way, eliminating the time-consuming impact and poor reliability of categorizing students' mental models via traditional methods. Lin and Tsai (2016) analyzed studies published in international journals on topics related to technology-assisted science learning by researchers from Taiwan from 2003 to 2012. They found more emphasis on mobile technologies than in the past. Meanwhile, a gradual increase in the use of educational games, augmented reality, and audience response systems was found in the publications by scholars from Taiwan. Moreover, the research topics chosen to be investigated were related to the learning environment and students' motivation for science learning. Finally, Wang and Yang (2016) also reviewed the existing articles published by scholars in Taiwan and suggested three key elements for the implementation of all emerging learning technology in education: nature of ICT, mediation model, and transforming model to understand how to make learning technology pedagogically and practically effective in improving teaching effectiveness and student learning effectiveness (p. xx).

Taking a different angle to investigate the impact of media and e-learning, Huang (2016) commented that the difficulties and challenges of science communication are primarily coming from the transformation between "public communication of science" and "communicating science to the public." So, he proposed three steps, namely to be correct, to be popular, and to be reflective, to advance our understanding of the power of science media in science education.

Science education scholars in Taiwan extended their research from traditional science education paradigms to integrate other disciplines (such as neuroscience, eye tracking, and facial expression) in order to capture a bigger picture of science learning. For instance, Yen and Yang (2016) analyzed 15 empirical journal articles related to eye-tracking techniques in Taiwan. They pinpointed several important findings. First, a general text-oriented comprehension strategy in processing material with text and illustration was found. Second, they found that participants with higher-level prior knowledge tended to make transitions among (critical) areas of interest (p. 24), and the participants with higher-level prior knowledge tended to fixate on the relevant parts of the material longer and more often than those with lower-level prior knowledge. Third, they found that some results were not consistent with prior research. She and Chen (2009) found that the inspection time in the pictorial areas increased when the combination of interaction and sensory modality modes were suitable for learning. In another area of neuroscience, Liu and Huang (2016) advocated that neuroscience can be a link to bridge the gaps among research trends, methodologies, and applications among different disciplines. Huang and Liu (2012, 2013) analyzed students' performance on mental rotation of chemical compounds via the use of ERPs with university students. They found that both high- and low-achieving students used similar strategies of mental rotation in identifying 3D chemical structural formulae and even found chemical element symbols to be meaningless for low-achieving students. Away from these eye tracking and neuroscience studies, Chiu and her colleagues (Chiu et al. 2014, Liaw et al. 2014) adopted the FaceReader System to investigate how students responded to counter-intuitive scientific phenomenon via their online microexpressions. They found that although the students' facial microexpressions changed, this did not guarantee that they understood the concepts presented to them.

The use of advanced technology to uncover learning processes and outcomes became one of the important research interests in Taiwan, and this trend of research can provide inspiring thinking and direction for facilitating school learning in the sciences.

10.5 Curriculum and Teacher Professional Development

Aside from the studies in the area of learning in science, there was a great amount of research dealing with teacher professional development in Taiwan, especially involving the development of science curriculum and instructional modules as a strategy to enhance teachers' professional proficiencies.

With the enactment of the Teacher Education Act in 1994, and the accompanying educational reform measures initiated by the MOE, the themes and topics of NSC funded research projects in science teacher education were strongly affected over the next two decades. Major changes in teacher education policy and practices included, for instance, a shift from a centralized system to a decentralized system, allowing qualified teacher education programs in colleges and universities to prepare preservice science teachers. There were quality control mechanisms built into this new teacher education system, including the kinds and quality of education courses required, quality internships with proper supervision, primary and secondary certification systems prior to and after the internship, and so on. Beside general educational theories and practical wisdoms, much more research-supported evidence was needed to help the policymakers and education administrators make decisions and take action, and the NSC and science education researchers have been quick to respond to many important issues and research problems that have arisen ever since. Research topics along this line included, for instance, the standards of science teaching among preservice teachers, the effectiveness of standards-based teacher education programs, the impact of mentoring on internship science teachers, and so on.

Since there are different subject matter areas at both the elementary and the secondary school levels and there are different theoretical perspectives, instructional goals, and instructional strategies in approaching problems, the DSE at the NSC encouraged researchers to form research teams to jointly study problems in a more coordinated effort. It is noted that while it is central to consider local contexts and to meet local needs in approaching these problems, the researchers were well-informed of the latest progress in the international science education community and adopted/adapted various theoretical frameworks and research methods available from the international literature.

As mentioned above, many NSC funded research projects in the past were directed at helping teachers to implement new science curriculum and reaching the goals of educational reform. A good example to illustrate the successful and mutually beneficial relationship between research and practice in these research studies is the introduction and use of action research in long-term in-service teacher professional development programs, typically lasting 2 years or four summer sessions. The participating teachers were required not only to take a number of courses but also to write a master's thesis. Many action research theses have been generated through this kind of program, and the teachers had the opportunity to put the knowledge they learned in their professional development programs into practice while engaged in reflective thinking that helped them change their beliefs and improve their teaching methods and strategies. Some of them have become master teachers in their own schools, while others have continued to earn PhD degrees in the science education field. As it turns out, long-term teacher education programs using action research not only help teachers develop professionally, but also cultivate leaders in science education to initiate school-based science curriculum reform.

In the most current review, Tuan et al. (2016) presented a comprehensive review of numerous local studies on science teacher education that they selected from a wide range of sources, mostly in Chinese, including National Science Council Monthly, NSC research reports, *Chinese Journal of Science Education* (CJSE), master's theses and doctoral dissertations in science education, and so on. A number of papers presented at international conferences, such as NARST, were also included. Their chapter begins with a brief description of the influence of the NSC and MOE on science teacher education research and policy, followed by separate reviews of studies on preservice science teacher education (including internships), and in-service science teacher education, and finally ends with some concluding remarks. They further pointed out that the NSC started to pay attention to preservice science teacher education research in 1990 by sponsoring researchers from three normal universities to establish microteaching laboratories for preparing secondary science/math teachers. In 1991, the NSC supported a series of case studies to uncover the characteristics of exemplary science teachers' teaching. At that time, interpretative research methods were new to most science education researchers in Taiwan. US science educators Dr. Ken Tobin and Dr. Jim Gallagher were among the leading foreign scholars initially invited to introduce interpretative research methods for exploring the features of classroom science teaching, leading to a series of subsequent research studies on science teacher education.

While Tuan et al. (2016) provided a comprehensive overview of the research studies on science teacher education in Taiwan since the early 1990s, Chaps. 16–18 in the book (Chui 2016b) serve to illustrate a few selected studies in this broad category. Drawing on a review of local research studies on strategies to improve science teachers' professional knowledge, skills, and beliefs in teacher professional development programs, and influenced by the ideas of situated cognition, teachers as active learners, social constructivism, and so on, Su et al. (2016) created a learning environment for participating in-service teachers in their study to form study groups aimed at developing science instructional modules with certain features implied by curriculum guidelines and general principles of science teaching and learning. Through teachers' participation in the development of curriculum modules in a collaborative learning environment with adequate supports, the researchers intended to explore the trajectories of teachers' 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. Results obtained from this study indicated that, in general, the professional development approaches were effective in enhancing teachers' understanding of curriculum designing principles. By developing curriculum modules through action research cycles, the case teachers practiced various teaching strategies in school contexts and to varying degrees developed better understanding of curriculum and the value of learner-centered approaches in science teaching and learning. In addition to better understanding of curriculum reform and science learning, they also identified some factors that affected the effectiveness of the professional development strategies in the study, including for instance teachers' belief and confidence in the instructional strategies and students' expectations of science teachers and science lessons.

In the study by Kao et al. (2016), the authors described in detail how to implement culturally responsive teaching in one indigenous school by beginning with the SWOT analysis of the school and by developing a curriculum for professional development of the school's teachers. By reviewing domestic and international literature, the authors took the contextual backgrounds and indigenous students' learning characteristics into account in their study. Based on the experiences documented in this study, the authors proposed a culturally responsive science-teaching model to help teachers render phenomena and activities related to both indigenous science and Western modern science; let students compare the differences between the two perspectives and propose a question for doing scientific inquiry. Although they found that culturally responsive teaching could help indigenous students become more interested and engaged in learning mathematics and science, they also pointed out one of the main problems for the indigenous students to learn laid in their lack of confidence and limited abilities in the use of official language at school, which was different from, and could be more complicated than, what they spoke at home.

The chapter by Liu (2016) highlights the importance of using environmental issues as a resource and a context for science education, as it has been suggested in the literature that such instruction effectively improves student decision-making and problem-solving abilities as well as civic participation. By analyzing relevant studies in this regard, Liu discussed the strength and obstacles of incorporating environmental issues into science curricula, noting especially that environmental issues are viewed as a "problematical situation" rather than "a scientific problem," because they are too complex, often lack conclusive information, and involve different aspects of thoughts and multiagent perspectives with various associated values and beliefs. Modifying an existing model, Liu proposed 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. In the ITLC model, students are required to develop solutions to environmental issues using the following processes: identify the issue(s), propose a focused model(s) of action, use this model(s) to examine real-life situations, and then verify the improvement of the status quo via the corresponding actions. Two teaching examples were included in order to illustrate the use of the ITLC model as an issue-based teaching approach. The author also recommended an agenda for future research, as she pointed out that there were only a few studies regarding instruction on controversial issues in Taiwan that had taken teacher perspectives into account and that examples of teacher education programs aimed at providing preservice teachers with experiences in exploring local environmental issues were still lacking.

Several common features were noted in the above four chapters, including (a) the importance of teacher PCK and teacher professional development in response to curriculum reforms in science, (b) the close interplay of local contexts and international theoretical and research efforts, (c) research results be included from other reliable sources (not just international journals), especially Chinese language sources, and (d) emphasis on the connection between research and practice.

Commenting on the above four chapters, De Jong (2016) noted several similarities and differences between science (teacher) education in Taiwan and Western countries regarding the following three topics:

(a) This book section clearly reports several Taiwanese curriculum innovations that bear strong influences from Western countries, including the growing demands from society to "*prepare students for a changing world,*" the psychological learning theory of "*social constructivism,*" and the ongoing requests from the science research community to *update* "*the curriculum content.*" However, according to De Jong's observation, Taiwan is now a very high-tech developed country and it is plausible that high-tech educational software and related technologies produced in Taiwan will be disseminated to Western countries and that the traditional route of impact on science curriculum reform from West to East might be reversed in the near future.
(b) Although Onno De Jong suggested similarities between Taiwanese and Western teachers' learning environments that include practice-oriented learning and action-reflection learning, he pointed out that the main difference between both groups of teachers is their culture-directed learning style. For him, teachers in Taiwan tend to have a stronger preference for courses that focus on the tradition of learning together in a group, pay attention to the traditional hierarchical order in the classroom in which the teacher plays a dominant role in the transmission of knowledge, and avoid or exclude the teaching of controversial socioscientific issues. He attributed the latter to the Confucian cultural roots of emphasizing harmony and avoidance of conflicts in discussions.
(c) De Jong (2016) noted that the contribution of teacher learning communities (TLCs) to curriculum reform included contributions to teachers' acceptation of new modules and teaching, to their adaptation of new modules and teaching for own practices, and to the development of modules and teaching for a new curriculum. He presented examples in the book (Chiu 2016b) that serve to illustrate the above contributions and strongly suggest that concerning science curriculum reform, both for Taiwan and the Western countries, the use of TLCs should be promoted more.

10.6 Concluding Remarks

An extensive review of the chapters contained in Chiu (2016b), as presented in Sects. 10.2–10.5, not only reveals the progress of science education research and practice in Taiwan in multiple domains, but also identifies the essential constituent parts of the “Taiwan Experience” outlined in the first section of this article.

The three levels of challenges and opportunities for science education, as mentioned in Sect. 10.1, are situated in a complex, dynamic, and interrelated web of relationships. Concerning reforms in science education, it is generally recognized that piecemeal efforts will be at best of limited value, and instead, more holistic and systematic approaches, such as suggested by the Carnegie Corporation of New York and Institute for Advanced Study (2009), will be necessary. As policymakers and leading science educators in the Asian countries are trying to improve the quality of science education research, to increase the effectiveness of science teaching and learning at school, and to reach out and educate a wider audience in a range of informal settings, deliberations on the “Taiwan Experience” mentioned in this article can be of great assistance.

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Chapter 11
Science Education in Thailand: Moving Through Crisis to Opportunity

Chatree Faikhamta and Luecha Ladachart

Abstract Both globalization and Westernization have influenced the Thai education system and have led to educational reforms. This chapter begins with a brief overview of the science educational reforms that have occurred in Thailand since 1868. Based on empirical research and our personal perspectives and experiences as Thai science educators, we go on to provide a synopsis of the status of the current educational context, including the aims of science education, student performance, and teacher preparation and development. In the main body of the chapter, we discuss the challenges and complexities of helping Thai students achieve scientific literacy and encouraging science teachers to shift their traditional teaching style to a constructivist-based approach. We then describe the process of moving Thai science education through crisis to opportunity and of creating a balance between sociocultural factors and the needs of today's knowledge-based society.

11.1 Science Education Reform

Thailand is situated in Southeast Asia and is bordered by Myanmar, Laos, Cambodia, and Malaysia. It has never been colonized by a European power. The main religion in Thailand is Buddhism, but there are also significant numbers of Muslims, Sikhs, Hindus, Christians, and other religions. Buddhism is a central part of community life and has had a strong influence on the culture and attitude of the Thai people. The general characteristics of Thai people are that they are peaceful, generous, concerned for others, adhere to the religious moral teachings, and uphold the institution of the monarchy. Despite the uniqueness of the Thai culture, however, modern advances and Western technologies and beliefs have affected the way that Thai people live and interact with each other. In particular, the rapid technology

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development over the past few decades has caused tremendous changes in the primary structure of Thai society, and the country is moving away from dependence on agriculture to become a semi-industrial and information-based economy (NESDB 2002).

The current education system in Thailand has been in a state of reform since 1999. Historically, there have been three main periods of reform. Roadrangka et al. (2010) have researched Thai science education for many decades; in their work, they clearly describe the history of Thai education reforms. The first reform occurred from 1868 to 1910, when King Chulalongkorn focused on modernization as a way of life and tried to overcome Western colonization by creating a modern and independent Thailand. The second reform (1973–1980) emphasized preparing the Thai people for a democratic society. The third reform (1990–1995) focused on helping the Thai people meet the new challenges of globalization. The purpose of the current fourth reform is to provide an education for all children and to encourage their learning potential and creativity in the context of the Asian economic crisis. It appears that all of the education reforms in Thailand, including the field of science, have been influenced by Westernization and globalization.

In 1997, Thailand and other Southeast Asian countries experienced a major economic crisis, which revealed that Thailand had deficiencies in many areas, including science and technology (ONEC 2001). All stakeholders were aware that the Thai education system needed to equip the next generation with the skills necessary to engage in an information-based society and to cope with the economic and technological aspects of globalization (ONEC 2001). Improving the education system was also a way to develop the country socio-economically, environmentally, and culturally. According to the 1997 Constitution, the State is required to provide an education that will help Thais attain knowledge and morality; to issue laws relating to national education; to improve the education system so that it is attuned to economic and social change; to create and strengthen students' knowledge and to instill in them a sound awareness of politics and a democratic system of government under a constitutional monarchy; to promote research in various disciplines; to accelerate the application of science and technology to national development; to promote the teaching profession; and to encourage a revival of the wisdom, art, and culture of the nation (ONEC 2001). Consequently, the 1999 National Education Act (ONEC 1999) was developed as a framework to provide principles and guidelines for the provision and development of Thai education, including science education. The Act suggested that the education system needed reform with respect to its approaches to learning, curriculum, assessment and evaluation methods, instructional media, and learning resources (Fry 2002; ONEC 1999; IPST 2002; Pillay 2002).

Learning reform—the heart of educational reform—was one of the many issues covered in this Act. Learning reform emphasizes the development and promotion of a learner-centered teaching approach that is based on a constructivist view of learning (e.g., Bell 1993; Tobin et al. 1994). It is suggested that students actively and purposefully construct their own knowledge to make sense of new information (such as scientific phenomena) by using and building on their existing knowledge and the new information (ONEC 2001). Therefore, the teaching and learning process should take an individual's interests, aptitudes, learning pace, and potential for learning into consideration. For science learning, the focus should be on encouraging all learners to develop the processes of thinking, inquiry, and problem-solving; increasing their learning ability and creativity; and instilling in them a desirable attitude of morality and a value for science, technology, society, and the environment. These learners will then be able to adjust to world trends and events, and they will develop desirable characteristics including virtue, competency, happiness, and self-reliance.

To provide students with opportunities and activities for learning science that are in line with these education reform guidelines, teachers need to use teaching methods that are associated with student-centered learning. Science teachers must shift their focus away from a teacher-centered director approach toward a more learner-centered facilitator approach (OEC 2004). As a facilitator, teacher provides students with activities that will turn their attention away from any alternative conceptions and toward scientific conceptions. A facilitator is also responsible for discovering what the students are thinking; helping students clarify and reflect on their own ideas; challenging students' ideas; helping students change their ideas; developing school-based science curricula, planning lessons, and instructional media; and assessing and evaluating student learning. From the constructivist-based teaching and learning perspective, the teacher as a facilitator who is using the learner-centered approach to teach is seen as one of many vehicles that will contribute to the success of learning reform in Thailand (OEC 2004).

11.2 Science Curriculum Standards

According the 1999 National Education Act and the 2001 Basic Education Core Curriculum, the Thai education system was revised to include four levels: preschool, primary, secondary, and higher education. The basic education curriculum has a 12-year core curriculum and a 9-year compulsory curriculum. Primary education is from Grades 1 to 6, and secondary education is from Grades 7 to 12. The final level is higher education. For primary and secondary education, each grade level has the same goals and objectives (but with different age-appropriate emphases) and the same "substance"; that is, the curriculum for each grade level consists of a body of knowledge, skills or learning processes, values or virtues, morality, and right behavior. This substance is disseminated through eight subject groups: Thai language, mathematics, science, social studies, religion and culture, health and physical education, art, career and technology, and foreign languages.

Science is seen as a crucial subject in the core curriculum. Science and technology skills are basic necessities for the advancement of high-technology and information-based industries and are a key catalyst in the development of the human resources of a country (NESDB 2002). The Thai science curriculum was initially developed to be a standard-based curriculum. Core content and indicators for each grade level were provided to help teachers easily convey this information through their teaching practices. These standards were developed by the Promotion of Teaching Science and Technology (IPST) in 1999 to meet national needs and help Thailand cope with modern advances and globalization. These standards provide very brief objectives, curricular strands, indicators for curricular contents and learning outcomes, and assessment and evaluation methods for teaching and learning science subjects. Scientific literacy is regarded as an ultimate goal of science learning (IPST 2002). All learners are expected to be scientifically literate. They should be able to:

- understand the principles and theories of basic science;
- understand the boundaries, nature and limitations of science and use skills to inquire about and explore science and technology;
- develop thinking processes and imagination and the ability to solve problems, as well as management, communication, and decision-making skills;
- realize the influence and effects of the relationships between science, technology, people, and the environment;
- use their knowledge of science and technology to advance society and everyday life; and
- have scientific minds, morality, and values for using science and technology creatively.

The science curriculum standards are comprised of eight strands over the 12 years of basic education: (1) living things and living processes; (2) life and the environment; (3) substances and their properties; (4) force and motion; (5) energy; (6) changing process of the earth; (7) astronomy and space; and (8) the nature of science. Students at all grade levels are required to learn the content in all eight strands. Interestingly, strands 6, 7, and 8 are very new for Thai science education. These three strands are apparently omitted from the previous science curriculum. In particular, the term *nature of science* is unfamiliar to most teachers and has been received with skepticism. According to the standards, however, the nature of science should be integrated in all other strands.

Because of an attempt to decentralize education as stated in the National Education Act, each school needs to develop their own school-based curriculum according to the national science standards by taking into consideration the learning needs of society, local wisdom, and desirable attributes of members of families, communities, society, and the nation. Therefore, schools are responsible for coordinating and cooperating with individuals, families, communities, community organizations, local administration organizations, private persons, private organizations, professional bodies, religious institutions, enterprises, and other social institutions. The idea is that a school-based curriculum is flexible and more related to a local community. However, the idea of developing a curriculum is very new for most teachers, students, and local communities.

11.3 Student Performance in Science

Despite serious attempts to reform science education in Thailand, student performance had not significantly improved since 2008. This has become evident through the results of the Ordinary National Educational Test (ONET), which is administered by a public organization, the National Institute of Educational Testing Service. ONET assesses student performance in all eight subject areas (Thai language, mathematics, science, social studies, religion and culture, health and physical education, art, career and technology, and foreign languages) at the end of each semester. ONET is not designed for year-by-year comparisons, but rather focuses on monitoring whether students achieve the national curriculum standards at the end of each basic education level in each year. However, regarding the science content area, ONET has shown that in 2008, the average score of sixth-grade students was not satisfied because it was lower than 50 %.

When considering each grade year by year, it appears that after 2008, even the sixth-grade students' performance in science decreased, while the ninth-grade students' performance gradually increased. For the twelfth-grade students, their performance in science fluctuated between 28 and 34 %. When considering each grade in the same year, it is clear that the sixth-grade students performed considerably better than the ninth- and twelfth-grade students. Therefore, it can be assumed that the students' performance in science tends to decrease in the higher grade levels. However, it should be noted that this tendency in students' performance in science could be affected by the test's increasing difficulty and score ratio for each year (Fig. 11.1 and Table 11.1).

Since ONET was designed to assess students' performance in science based on indicators from the national science curriculum standards, it is valuable to consider their performance in each strand (living things and living processes, life and the environment, substances and their properties, force and motion, energy, changing process of the earth, astronomy and space, and the nature of science). However, these data are only available for 2008 and 2009. During these 2 years, students at all grade levels performed on par with or lower than the average for all strands (Fig. 11.2 and Table 11.2).

Since ONET was administered to all students around the country, it is also valuable to consider students' performance in science in different areas of Thailand. In the figure above, the green bars refer to areas whose students performed in rank of different areas of Thailand from 1 to 15 out of a total of 76 areas, the yellow bars refer to areas whose students performed in rank of 16–61, and the red bars refer to areas whose students performed in rank of 62–76. In this figure, 11 of the 15 red areas are located near a border, while 9 of the 15 green areas are central or industrial areas. This shows that there is inequality in the caliber of education provided across the country.

In addition, the ONET results agree with the international test, PISA, which assesses international students' scientific literacy. From 2006 until 2012, the PISA results have indicated that Thai students perform lower than the average when

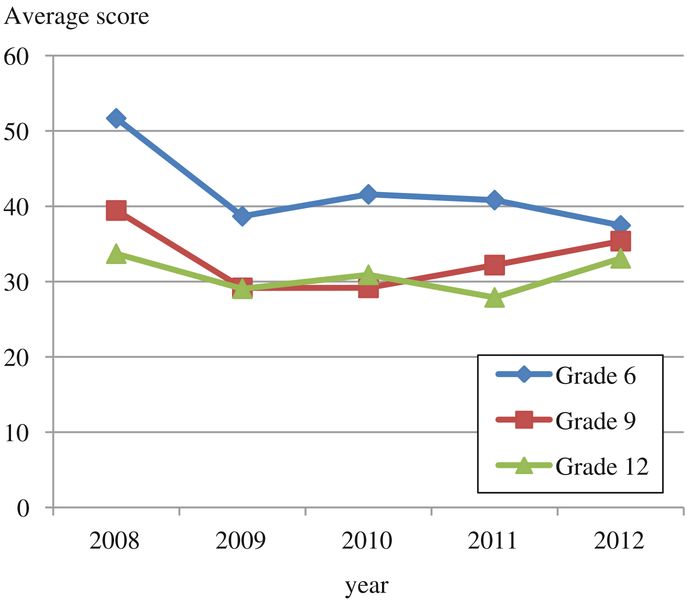

Fig. 11.1 Tendency in students' performance in science for each year

Table 11.1 Students' performance in science from Ordinary National Educational Test (ONET) (NIETS 2012)

Grades	Years (%)				
	2008	2009	2010	2011	2012
6	51.68 (17.28)	38.67 (14.72)	41.58 (16.86)	40.82 (13.79)	37.46 (12.68)
9	39.44 (14.13)	29.16 (11.70)	29.17 (13.33)	32.19 (11.63)	35.37 (11.70)
12	33.71 (10.55)	29.05 (9.09)	30.90 (9.30)	27.90 (8.59)	33.09 (10.37)

compared to students from around the world. In the 2012 PISA results (OECD 2014), for example, Thai students received an average score of 444 in science, while the international average score was 501. The Thai score is lower than the scores of Singaporean students and Vietnamese students but higher than the scores of Malaysian students and Indonesian students. It can also be seen that about 34 % of Thai students who took PISA in 2012 performed lower than Level 2, which is considered the basic level of scientific literacy. However, when compared with the previous years, Thai students' performance in science has slightly increased since 2009.

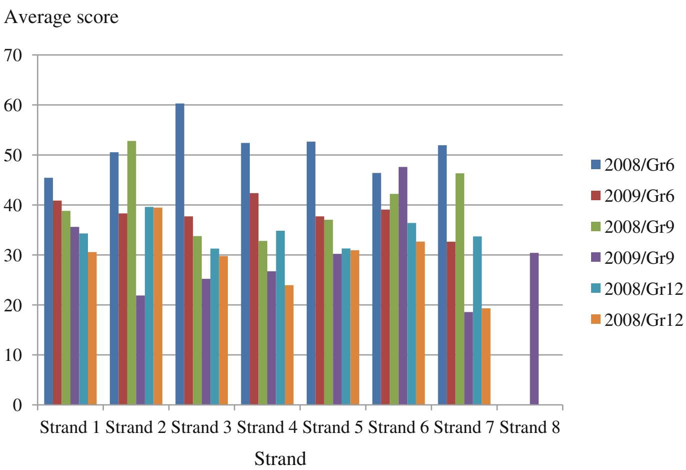

Fig. 11.2 Tendency of students' performance in science for each strand (NIETS 2012)

Table 11.2 Students' performance in science in each strand (NIETS 2012)

Strands	Students' performance in science[a] (%)					
	Grade 6		Grade 9		Grade 12	
	2008	2009	2008	2009	2008	2009
1: Living things and living processes	*45.43*	40.88	*38.80*	35.60	34.30	30.57
2: Life and the environment	50.53	38.31	52.80	*21.89*	39.60	39.47
3: Substances and their properties	60.30	*37.71*	*33.76*	*25.21*	*31.27*	29.77
4: Force and motion	52.40	42.36	*32.80*	*26.73*	34.83	*23.94*
5: Energy	52.67	*37.71*	*37.04*	30.21	*31.29*	30.93
6: Changing process of the earth	*46.40*	39.07	42.20	47.60	36.40	32.67
7: Astronomy and space	51.94	*32.64*	46.33	*18.57*	*33.70*	*19.31*
8: The nature of science	–	–	–	30.40	–	–
Average score	51.68	38.67	39.44	29.16	33.71	29.05

[a]*Italics* indicate scores that are lower than the average (NIETS 2012)

The lack of instruction time is considered to be a main factor for low assessment scores. Thailand is one of the lowest performance countries but has the maximum amount of educational instruction hours per day. However, instruction hours for science are less than the higher performing countries. When compared to other subjects, science is taught only about three hours per week. In addition, teachers may not be able to spend all two hours engaged in direct teaching of science content because of other schools activities and responsibilities.

11.4 Challenges Facing Science Education in Thailand

The developers of the new curriculum expected that new approaches to teaching science (e.g., constructivist-based teaching) could be implemented in the classroom. However, studies have shown that classroom events are more complex and teachers are less able to use the new ideas than what was expected. The challenges and dilemmas experienced with the curriculum implementation are described below.

11.4.1 Students' Understanding and Teachers' Teaching About the Nature of Science

Like other countries, understanding the nature of science has been a central goal of Thai science education programs. It is an important element of scientific literacy that students should be encouraged to develop through their schooling. As mentioned above, the term *nature of science* is firstly known in the Thai Science Curriculum Standards. Compared to international perspectives (e.g., the American Association for the Advancement of Science 1993; McComas et al. 1998), the Thai Science Education Standards broadly address the nature of science in terms of scientific worldviews, scientific inquiry, and scientific enterprise:

> The student should be able to use the scientific process and a scientific mind in investigation and to solve problems; they should know that most natural phenomena have definite patterns and are explainable and verifiable within limitations of data and instrumentation during the period of investigation; and they should understand that science, technology, and the environment are interrelated. (IPST 2008, p. 4)

Unfortunately, the meaning of the nature of science and its aspects are not described or explained in science curriculum standards. Even though the learning indicators in Strand 8 are addressed in each grade level, they focus on students gaining inquiry skills rather than understanding the nature of science. For example, the indicators for Grades 10–12 states that students should be able to do the following:

1. Pose questions, based on scientific knowledge and understanding, own interest, or current issues, that can be investigated comprehensively and reliably.
2. Construct hypotheses based on theories, put forward predictions, or propose models that lead to investigations.
3. Search and collect data, taking into consideration important factors or variables, including factors that may affect other factors, factors that are uncontrollable, and the number of repeats in an investigation, to ensure reliable and sufficient data (IPST 2008, p. 76).

The standards rarely emphasize what students should actually know about science, especially regarding aspects of scientific worldview and scientific inquiry. Most Thai science teachers do not understand nature of science and do not have any experience integrating into their teaching. Unsurprisingly, education research has found that both Thai teachers and students hold naïve views regarding this content (Buaraphan 2010; Ladachart and Suttakun 2012; Mahalee and Faikhamta 2010). Some of them view science as a product of knowledge for the purpose of explaining natural phenomena. In their view, science is a search for reality in the external world through the use of rigorous scientific methods. Consistent with other international studies, many Thai teachers and students believe that scientific knowledge is different from other disciplines because it involves step-by-step scientific processes and experimentation. They hold a naive belief that, unlike other disciplines, scientific knowledge is derived from a rigorous scientific method. When thinking of science, they consistently refer to scientific experimentation as a necessary prerequisite to claiming the validity of scientific knowledge. Almost all teachers and students believe that laws are mature theories, and they do not recognize that these constructs represent different types of knowledge and play different roles within the discipline of science. In their understandings, law is a reality and cannot be changed, while theory is a working hypothesis that can be changed.

The description of nature of science in the science curriculum may cause some science teachers to perceive that teaching the nature of science is to enhance students' science process skills (Ladachart et al. 2013). Hence, in teaching the nature of science, most teachers would think of helping students use scientific process skills in their investigation instead of giving them opportunities to reflect on what science is, how it works, and how it relates to other disciplines (Suttakun et al. 2011). The teachers rely heavily on project-based science, with the teaching of the nature of science designed to develop students' everyday problem-solving abilities and understandings of scientific methods. They believe that by providing situations to develop these abilities and understandings, they are asking students to carry out their own projects by observing everyday phenomena, formulating questions, and investigating these questions on their own. Therefore, the nature of science is taught in an implicit fashion. The teachers believe that the students can instinctively learn scientific process skills, scientific thinking, scientific methods, and the attributes of scientists when carrying out experiments (Faikhamta 2013).

11.4.2 The Inquiry Approach in the Classroom

Inquiry-based learning has been used in the Thai science classroom for many decades. IPST plays a crucial role in training teacher educators and science teachers to understand this approach and helping them to apply it in the classroom. IPST runs many projects. However, there are some difficulties in implementing the projects. Many teachers think that doing work in the laboratory is sufficient for illustrating facts and theories of science discovered by scientists (Ketsing and Roadrangka 2010). Students are provided with experiments or hands-on activities to verify the facts, not to acquire new knowledge. The teachers tend to encourage students to find the correct answer to a problem rather than helping them use the scientific process along with their own skills to investigate a problem or a natural phenomenon. Often, handouts and activity sheets are produced by the teachers and distributed to the students. The handouts contain a body of knowledge, terminology, and recall questions, and the activity sheets contain instructions for carrying out procedures in the laboratory. Some teachers ask students to copy information from the textbook, handouts, or activity sheets into their notebooks. The emphasis of the science lesson is on correct terminology and making sure that students have the approved definition in their notes.

A major difficulty is teachers' misconception of inquiry (e.g., Ketsing and Roadrangka 2010; Ladachart and Yuenyong 2015). They only hold a partial understanding of this concept and do not realize that inquiry is a method for investigating natural phenomena and that scientists use it to gain knowledge based on evidence.

Since in the national science curriculum, inquiry is simplified and broken down into a five-step learning model (5-E: Engagement, Exploration, Explanation, Elaboration, and Evaluation), instead of integrating scientific inquiry into their lessons, teachers just end up using the five steps without understanding them. For example, in the Engagement phase, many teachers engage students in the natural phenomena, but they rarely motivate them to ask scientific questions and use these questions in the next phase of Exploration. In addition, teachers do not connect the Exploration phase back to the Engagement phase. They mostly have students read laboratory directions and follow the steps of scientific methods rather than helping them plan investigations by themselves and use inquiry skills to investigate their problems or questions. In the third phase, Explanation, some teachers hold strong misconceptions that it means to have teachers explain to the students; and after completing an investigation, they do not use the data collected as the basis for their conclusion and discussion. A teacher plays a major role in introducing a new scientific concept, but they believe that coming up with the right answer is the most important aspect of a scientific approach to a problem. A large amount of body of knowledge is focused and teachers need to cover it. Discussions about the evidence and methods of investigation do not receive much attention in this phase. Students cannot draw conclusions from their laboratory work, as they do not appear to understand the point of the exercise. The key concepts and empirical evidence are not emphasized and/or discussed. In the Elaboration phase, teachers do not realize that the main purpose is to engage students in explaining the concepts or knowledge they have learned in other contexts, so they give them assignments or worksheets. Teachers have the students answer assigned questions. This approach is the opposite of the process of inquiry. In the last phase, Evaluation, teachers would give students homework rather than helping to evaluate their explanations for their investigations.

Some teachers are aware of the value and importance of inquiry, but they think that the purpose of inquiry is to develop their students' scientific process skills, not their conceptual understanding. They accept this approach in theory, but in practice, they reject it for a variety of reasons, such as time constraints, ineffective teacher science education, the current evaluation policies and values, and cultural and political influences.

11.4.3 Time Constraints

When teachers are asked to implement the inquiry approach in their classrooms, many of them believe that this is an idealized concept that is hard to realize. They cite time limitations as a major factor in this struggle (Chuleekan 2006). From their viewpoint, science curriculum standards require them to cover a large amount of content, which leaves little to no time for class discussions, laboratory and hands-on activities, and fieldwork (Kanklang 2005). They have found that their jobs as science teachers are not only about preparing lessons and materials and teaching their students, but also include other school-related responsibilities. In addition, there are many other activities during the school day, and they sometimes have to leave their classes to participate in meetings or conferences. Because of these other responsibilities and activities (Corcoran 2015), they end up focusing just on science content rather than using inquiry to obtain new knowledge. They believe that they have to cover all the science content addressed in the curriculum standards, and they do this through a variety of methods, such as thorough and accurate note-taking and copying information from activity sheets and the chalkboard (Boontim 2004; Dangyai 2004). When students do an experiment, the correct procedure is provided in the science textbook, and the students would record the correct information in their notebooks. Misbehaving students is another reason that they do not use inquiry-based teaching methods. When there are signs of misbehavior during hands-on activities or laboratory work, the teachers frequently just demonstrate the experiment for the class. From the teachers' viewpoints, their students are not easy to teach and classroom management is a big concern. They also think that it is hard for them to engage their students intellectually.

11.4.4 Teacher Science Education

During the science education reform movements, a science teacher preparation program was developed. Since 2004, there have been two main science teacher preparation systems. The first system, which is based on a 4-year teacher education program, requires preservice teachers to study at an education faculty. Preservice teachers would have 4 years of coursework followed by a year in the field. The second teacher preparation system is managed by the Project for the Promotion of Science and Mathematics Talented Teachers (PSMT), which is supported by IPST. The objectives of the project are to produce highly skilled science and mathematics teachers and to improve the teaching and learning of science in Thailand. These teachers are expected to be leaders in science and mathematics teaching and learning in high schools. Students with outstanding academic performance are recruited for this project. They would study science (majoring in chemistry, physics, biology, or computer science) for 4 years and then complete a 2-year graduate program in science education.

The goal of both science teacher preparation programs is to prepare prospective science teachers to use constructivist-based learning in classrooms. However, the programs seem to be more focused on theory than practice. Many studies have found that teachers who have completed these programs lack a good understanding of the concepts, principles, and processes involved in the new approaches to teaching and learning (Fry 2002; Pillay 2002; Silapabanleng et al. 2006) and that they have negative attitudes toward these new approaches (Narot 2004). In a study by Faikhamta and Roadrangka (2005), PSMT preservice teachers reported problems with the program regarding the professional experience training and the preparation. They also struggled with designing learning activities to fit both the science content and their students' abilities, creating instructional materials to suit the science content, using questioning techniques to elicit their students' prior knowledge, and concluding lessons by showing the interrelationships among the scientific concepts. Fry (2002) argues that some teachers do not understand that activity-based learning is only one of many methods that can be used to promote active and student-centered learning and that the teachers assume that learner-centered learning rejects all memorization. The reason behind this obstacle is that the curriculum and training provided at the teacher education institutions have not been attuned to actual practice and learning process reforms in schools, or to the concept of lifelong learning (Amornvivat 2002). Some educators (Amornvivat 2002; Fry 2002; Pillay 2002) have suggested that Thai teacher education institutions need to revise their curricula and teaching methods to better prepare effective science teachers participate in the educational reform movement.

11.4.5 Evaluation Policy and Values

Another reason that teachers do not focus more on inquiry during their lessons is because of the pressure of national tests and university entrance examinations. Since these examinations are comprised of content-oriented questions, the teachers think that they have to train their students to pass the exams. Particularly in physics and chemistry, teachers value quantitative problem-solving because it prepares students for the university entrance examination. From this perspective, science is viewed as a body of knowledge and as a source of mathematical formulations that can be used to describe the physical world. Biological science is seen as less precise, but it can still be organized in terms of taxonomies and terminology. Therefore, it is a waste of time to focus on the process of science, as this is not addressed on the examinations. This problem has been embedded in Thai science education system for many years. Unlike PISA, scientific literacy is rarely used as a framework for developing tests in Thailand. Achieving high marks and progressing through school to an outstanding university are seen as the most important reasons for learning science. Therefore, some parents views science as a superior subject. They believe that if their children learn science, they will have a higher chance of passing the university entrance exams and getting into the supposed good occupation fields like medicine or engineering.

11.4.6 Cultural and Political Influences

It is clear that culture can influence what happens in the science classroom. As the teachers and students embed themselves in a particular culture, they share a set of cultural beliefs and expectations. It has been instilled among Thai people that children and young adults should respect and obey their elders. In a Thai science classroom, therefore, students are expected to respect and obey the teacher. Thus, there is an expectation by the teacher and the students that the students will believe what the teacher says as well as follow the teacher's instructions. This shared expectation among the students and the teacher can shape the science classroom and limit students' opportunities to engage in scientific discussions and argumentation. In many Thai science classrooms, students are often reluctant to ask questions or express opinions if they do not agree with the teacher (Coll et al. 2010). If they do not understand what the teacher is saying, they may ask him or her to repeat the information, but no one will challenge the teacher. This reluctance to ask critical question reinforces the belief that the students should be receptive and passive. As a "good" student is expected to listen to the teacher, asking a critical question can be perceived by the teacher as threatening. As classroom activities progress, it is more likely that the teacher will become a lecturer and students will become his or her audience.

Such a compliant culture (Hallinger and Kantamara 2001) can go beyond a science classroom and play a role in the broader school context as well as the national context. As educational management in Thai schools still relies mainly on a top-down approach, science teachers can easily be influenced by their school principals. They are expected to comply with the principals' decisions without challenging them. As scores on ONET are used as an indicator of school achievement and education quality assurance, some school principals may ask their teachers to provide ONET tutoring for students, and students are asked by their teachers to just practice the ONET items. This may superficially look good, but the tutoring is often done through rote learning, and because the students are not learning science in a meaningful way, they do not perform well on the ONET. As a consequence, students lose out on the opportunity to learn science through inquiry as expected by policy documents. There is no short-cut for the deep learning of science.

Political influence is another factor. Since 2010, Thailand has had five prime ministers of education (MOEs). They have come from two main political parties whose educational policies are different. In late 2011, the MOE at that time announced that there would be a second-round educational reform that would focus on learning quality. However, before this announcement could have an impact on science instruction in the classroom, the government was dissolved. The subsequent MOE focused more on the use of ICT for learning. All first-grade students received tablets to be used for learning even though it was not clear how they could be used in a meaningful way. The MOE then introduced the idea of the flipped classroom. There was a slogan that encouraged teachers to have their students "study at home and do homework at school." However, this flipped classroom idea has yet to be implemented. STEM education is now a priority. Teachers and school principals seem to be excited about and responsive to all the new ideas. At this point, it can be said that Thailand's educational policies change at a rather fast rate, even though an old one—inquiry-based instruction—has never been implemented effectively.

11.5 Future Opportunities: The Way Out

As has been stated in this chapter, science education in Thailand is in a state of reform. Since there are many factors hindering the success of this reform, science educators and stakeholders need to reconsider how to best meet stated goals. Accordingly, as science educators, we would like to make some recommendations at both the policy level and the practice level. At the policy level, policy makers and curriculum developers should rethink common and sustainable goals in science education at the national level. It has been seen that science curriculum standards change frequently. This has brought confusion to science teachers and made it difficult for them to understand and implement these standards in their classrooms. In addition, even though science is emphasized as a very important subject in the national curriculum, many science educators, teachers, and others seem to view science as just a body of knowledge. From this viewpoint, the goal of science education is to help students master science content rather than engage them to act and think as scientists. Scientific literacy is not known or misunderstood by teacher educators. Science should be seen as a process of inquiry. Thus, science education standards should clearly address this and explain how to apply it in science classrooms. Additionally, since time constraints are a big factor hindering teachers' implementation of the new curriculum, education administrators need to help teachers cope with this issue. They should understand that some teachers are involved not only in teaching, but also in extra activities in their schools, and they should make adjustments accordingly. Reducing this extra work for the teachers and assigning teaching hours that are more appropriate to the available amount of time are needed.

In addition, effective science teacher education preparation programs are needed. One of obstacles that has hindered the success of Thai science education is that science teachers are not familiar with the new teaching methods used in a constructivist approach. The key questions that should be asked are, what must science teachers know and be able to do and what should science teacher education programs look like. We recommend that pedagogical content knowledge (PCK) (Shulman 1987; Abell et al. 2009) be made one of the ultimate goals of teacher education. PCK is an important teaching tool for defining what it means to be a good teacher, and it is reflected in teachers' understanding of what concepts are difficult for students to learn; their selection of appropriate instructional materials; and their pedagogies, such as the use of metaphor and analogy to help students make sense of their learning experiences (Coble and Koballa 1996). Therefore, institutions should use PCK as a framework to develop their teacher education programs. In the context of science education, PCK can be used to set goals, develop instructional strategies, and align assessments.

At the practice level, to help both preservice and inservice teachers develop their PCK for teaching science, they should be encouraged to learn and exchange existing knowledge for new knowledge using various methods (Bell 1993; Tobin et al. 1994). Within their particular social contexts, teachers should be provided with opportunities to construct and reconstruct their own knowledge and beliefs. Teacher educators should design subject-specific coursework to help science teachers apply their thinking about teaching to practice, help them cope with a wide range of student abilities and conceptions, and plan specific lessons that motivate student learning. This will help them learn various content-specific teaching strategies, such as the constructivist-based approach. Another key element in science teacher education is helping teachers become "reflective practitioners" (Schön 1983). Reflection is a way of developing science teachers' insights into their own beliefs and actions and enhancing their PCK development. Reflecting on their teaching can help teachers clarify their teaching and beliefs and guide them in improving their future planning and teaching. In these reflection methods, teachers are asked to reflect on their own and others' teaching via videotapes of their own classroom performance; others' teaching via classroom observation experiences; and themselves as science learners via participation in science learning activities.

Ongoing support by science teacher educators is important. Thai science teachers have clearly been struggling to apply the national curriculum to their classrooms. Therefore, they should be provided with direct experiences to transform their own understanding of teaching by planning, teaching, and reflecting on their lessons and teaching. They also should be provided with opportunities to test their personal understandings and to refine and reconstruct these theories with meaningful support and guidance.

Classroom action research is another way to sustain and develop science teachers' teaching and their PCK (Capobianco and Feldman 2010). In Thai education, action research is seen as a major tool for improving the quality of teaching skills. Classroom action research is expected to be an important driving force in improving the level of teaching and learning in Thai classrooms. The 1999 National Education Act states that action research is a compulsory activity and policy that inservice teachers involved in education reform need to carry out (ONEC 1999). In preservice teacher education, action research has been added as a compulsory course along with a full year of field experience, which is the highlight of the new 5-year teacher education program in Thailand. Preservice teachers are required to engage in action research to develop their professional knowledge base in real-life situations. Even though there are problems with action research, especially the misunderstandings of action research held by science teachers and teacher educators, we can use this policy and opportunity to enhance teachers' understanding of the ways to teach science. Therefore, undertaking action research is one of several strategies that can encourage teachers' understanding of constructivist-based teaching and learning science in both theory and actions.

Even though these recommendations are not the ultimate solutions, we hope that they will be regarded as one vehicle that will contribute to the success of science education reform in Thailand.

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Chapter 12
Commentary: What We Can Learn from Science Education in Asian Countries?

Opportunities and Challenges For: Perspectives Based on the Experience

Jari Lavonen

This book section consists of descriptions of science education research and practices in four different Asian countries: Singapore, Taiwan, Omen, and Thailand. Although the current state, the opportunities, and the challenges each country face are different, there are several commonalities and shared interests. Therefore, it will be valuable to learn and collect ideas from these example countries. This commentary aims to make a summary of each chapter and then conclude based on these summaries.

12.1 Science Education in Singapore

Singapore is a small city–country without natural resources. Therefore, Singapore has always focused on education and the progress of the students and whole country in order to meet the challenges of twenty-first century. Singapore has also been successful in the implementation of the policy and students have performed well in International comparative studies since 1990s.

Professors Kim Chwee Daniel Tan from the National Institute of Education, Tang Wee Teo from the Nanyang Technological University, and Chew-Leng Poon from the Singapore Ministry of Education analyze history, present, and future of science education and science education research in the context of Singapore. For example, the period 1959–1978 was called a survival-driven phase with a focus on "the development of a literate and technically trained workforce." Since late 1970, Singapore has emphasized English, mathematics, science and technical education in order to educate competent people who are able to meet a rapid globalization and

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knowledge-based economy. Late 1990 have been called as the ability-driven phase. The fourth and current phase is student-centric, values-driven phase and it was launched in 2011 with the aim to focus on the holistic development of the child "centred on values and character development."

In addition to historical analysis, the authors analyze in a versatile way national level science education policy and implementation of this policy through national science curriculum, assessment traditions, and the use of versatile teaching methods, including use of ICT, and, moreover, through the selection of core content from the primary to high school levels. The curriculum emphasizes science learning as an inquiry process and focusses on the knowledge, skills and processes, ethics and attitudes required in the practice of science, as well as the understanding of the impact of science in daily life, society, and the environment. The authors analyze in depth the implementation of science curriculum from primary to upper secondary level and use in this analysis outcomes of science education research from Singapore.

12.2 Thai Science Education Progress Through Crisis to Opportunities

Assistant professors Dr. Chatree Faikhamta from Kasetsart University and Dr. LuechaLadachart from the Thai Ministry of Education analyze Thai science education progress through crisis to opportunities. In the beginning of this chapter, the authors introduce (1) national-level education policy topics and its influence to globalization and "westernization." (2) Second, authors provide a synopsis of the status of the current educational context, including the aims of science education, student performance, and teacher preparation and development. Third, the authors offer a brief overview of the (3) science education reforms that have occurred in Thailand since 1868 and, moreover, (4) reflect on these reforms based on empirical research and on their personal views as Thai science educators.

The authors argue that science is one of the core subjects in the curriculum because science and technology skills are needed in the development of high-technology and information-based industries. The form of the curriculum support teachers to plan their teaching according to the description of learning outcomes as well as to assess the outcomes. The national curriculum state that all learners should become scientifically literate or use their science knowledge and thinking in different contexts. The curriculum emphasizes inquiry-based science teaching and learning the nature of science as a part of the literature. However, the authors argue that curriculum and school practice focus just on learning of inquiry skills rather than understanding the nature of science.

The analysis of student performance shows that despite the serious improvement of science education in Thailand, students' performance has not significantly improved. Thai science education research explains this by "traditional" teaching practices which have not developed although science teachers have been encouraged to shift their "traditional" teaching style. This research has shown that classroom events are more complex and teachers are less able to use the new ideas than what has been expected. Another outcome of the research on teachers' beliefs and practices is that although teachers are aiming to support students to understand the nature of science they are emphasizing the learning of science process skills or inquiry skills. Teachers believe that the students can instinctively learn scientific process skills, scientific thinking, scientific methods, and the attributes of scientists when carrying out experiments.

In the end of this chapter, the authors suggest recommendations to the policy and the practice level. First, at the policy level, the politicians change policy and science curriculum frequently and this makes it difficult to adopt new ideas at classroom level. Therefore, the policy makers and curriculum developers should rethink common long-term and sustainable goals for science education at the national level. Second, science education standards should clearly address inquiry orientation and explain how to apply it in science classrooms ion practice. Third, effective science teacher education preparation programs are needed in order to guarantee solid knowledge base, especially pedagogical content knowledge, and reflection skills for science teachers. However, science teachers might benefit on life-long learning skills which are needed in changing the working life. In many countries, research orientation as a part of the program is aiming to support this type of life-long learning skills.

12.3 Opportunities, Trends, and Challenges of the Science Education in Oman

Dr. Al-Balushi from the Sultan Qaboos University analyzes opportunities, trends, and challenges of science education and science education research in Oman. The author introduces the Oman educational context, where education system and science education are a part of it and the short history in science education research. An important reform in Oman educational system was the establishment of the Basic Education system in 1998. An emphasis in this reform was given to science, mathematics, foreign languages, technological, and life skills.

New national level science curriculum emphasizes inquiry-based and student-centered, education which supports learning of life skills, critical thinking, and the ability to understand and apply scientific and technological knowledge. Moreover, the curriculum emphasizes the use of modern educational technology and problem solving strategies. However, the authors argue based on the current research that teaching practice in science classrooms does not reflect the aims of science education and traditional teacher-centered methods that are still dominant in science education.

In general, research is understood as a tool for growth and productivity of society and economy in Oman. The research in science education has improved in 2000 because of the establishment of the first postgraduate program for science education research at Sultan Qaboos University (SQU). Moreover, funding for science education research was started to allocate by the Research Council (TRC). The author of the chapter gives interesting examples of science education research. The outcomes of this research have been published also in international journals. For example, the author introduces the research on teaching and assessment practices in Oman, outcomes of international comparative studies, research on sociocultural factors related to learning and research on teachers' beliefs and on students' common misconceptions in biology, chemistry, and physics. There are several examples of research in international level. One example is the research on visualization. The studies focus on: (1) learners' imagination of different submicroscopic scientific entities, and its relationship with their spatial ability; (2) their evaluation of the credibility of different scientific models, and its relationship with their spatial ability; (3) their visualization of different macroscopic and microscopic dynamic interactions; and (4) the presence of anthropomorphism and animism in learners' mental images in science. Finally, the authors introduce an interesting research on trends of science education research in Oman.

However, there are a number of challenges in education research in Oman. The main one is the limited number of science education researchers in the country. Especially, the number of female researchers is very low. The number of quantitative research studies is low compared to qualitative research and, moreover, there is limited attention to sociocultural issues. The author proposes that some of the pitfalls and challenges could be resolved by establishing a national science education research center that coordinates the research efforts and directs them toward the most pressing issues related to science teaching and learning. In addition, providing more scholarships to science education researchers to complete their Ph. Ds and founding a national professional science education research association could help in increasing the number of science education researchers and foster the research activities in the country.

The authors present a kind of consensus interpretation of the chemistry didactics in Russia and argue that the following domains of knowledge form the core of the chemistry didactics:

- general development of science,
- curricula for chemistry,
- allocation of chemistry lesson hours to grades (when and how much),
- learning materials for chemistry: textbooks, problem books, etc.
- journals, periodicals, conferences, and meetings for discussing didactical and pedagogical,
- collaboration and interaction between administration, teachers, and researchers,
- chemistry education research society for discussing on (research-based) improvement of chemistry education,
- pre-service and in-service teacher training,
- research in didactics of chemistry.

12.4 Opportunities and Challenges for Science Education in Asia: Perspectives Based on the Taiwan Experience

The Taiwanese professors Chorng-Jee Guo from the National Changhua University of Education and Mei-Hung Chiu from the National Taiwan Normal University analyze opportunities and challenges for science education in Taiwan and in Asia from the point of view of the experiences in Taiwan. These experiences have been published recently in an edited book by Chiu (2016). This book reports the successes and the achievements and, moreover, examines the existing and emerging opportunities and challenges for science education in Taiwan. The book consists of 22 chapters in which the international author team analyze and contrast wide range of topics on science education research and practice in Taiwan and all over the world.

The book chapter starts with an introduction to science education in Taiwan through four sub-chapters. The first chapter introduces a historical review of research projects on science education funded by the National Science Council. The second chapter analyzes the trends in science education research in Taiwan through a content analysis of the *Chinese Journal of Science Education* from 1993 to 2012, the next chapter is a commentary on the first two chapters by Reinders Duit, and finally the last chapter focus on the people and events shaping science education in Taiwan from an international perspective. In general, the sub-chapters offer very positive picture about the progress and development of science education and research in Taiwan.

Several research projects funded by the Department of Science Education (DSE) at the National Science Council (NSC) since 1980s have had a solid link to the science classrooms and raised the quality of science education research and, moreover, have had a general impact to K-12 science teaching and learning. The authors of the chapter introduced several key areas of research, like research on conceptual change and research on students' misconceptions; research on conceptual learning and learning of process skills and assessment of learning, including secondary analysis of the data of international comparative studies; research on scientific argumentation and socioscientific issues; research on use of educational technology in classroom and in distance learning and; moreover; research on teacher education. In addition to traditional qualitative and quantitative research methods, science education scholars in Taiwan have integrated new research methodologies, such as neuroscience methods, eye tracking, and FaceReader, in order to capture a deep picture of science learning and engagement. Because of solid funding, competent researchers and versatile research methodologies, there has been a rapid increase in the number of papers from Taiwan appearing in international high-quality journals. Between the years 1993 and 2012, an average of 3.7 % of the publications in the five top journals was from Taiwanese researchers. This is a top result among the non-English speaking countries. In addition to National Science Council (NSC) funding, science education researchers have been active in applying research resources from the Ministry of Education. Ministry allocates resources for research-based development of instructional materials and other practical sides of teaching and learning in science.

The analysis of research output and influence of the research to science education practices in Taiwan, and internationally, is without any doubt important. This was recognized also by Reinders Duit when he pointed out the impressive development of science education research in Taiwan between the early 1990s and 2013. He states that three issues seem to have played a significant role in this progress: (a) establishing science education as a research field in Taiwan, (b) receiving international support, and (c) becoming familiar with the international state of the art in science education and related research. Another interesting analysis is that the authors of the chapter present here are the influence of research projects to the science teachers' pre- and in-service education and to the adoption of new science curriculum. This is an excellent example how research and development/professional development go together. However, as authors of the sub-chapter state, it would be interesting to clarify in detail if Taiwan had developed a unique theoretical framework for learning and teaching that reflected the country's cultural and demographic characteristics, and whether current research efforts sufficiently inform policymakers so that they can provide continuing policy support to promote quality research.

The authors conclude that in spite of the complexity among the political and socioeconomic backgrounds in Taiwan as well as in many other Asian countries, promising opportunities exist at the individual, regional, and global levels for science educators to improve the quality of science education research, to increase the effectiveness of science teaching and learning at school, and to reach out and educate a wider audience in a range of informal settings.

12.5 Discussion

As it has been described in each summary above and original papers located after this introduction, Asian countries are aiming to improve the quality of science education and science education research, in order to increase the quality of science teaching and learning at Asian schools. Each paper presents a review on progress in science education, science education research and government policy and, moreover, challenges of future development. Therefore, the chapter is valuable and useful for science education researchers and developers of science education. However, there are differences in science education research among the five countries. For example, Taiwan, Singapore, and Oman are countries where the governments allocate resources for science education research. These resources have been used in a clever way and countries have increased the number of high-quality journal publications.

The four papers introduce several interesting science education research themes such as teaching and learning of science, the use of technology in education, motivation and affects, professional development of teachers, and teacher education. Moreover, there is a lot of research in all countries focusing on the outcomes of science education policy like secondary analysis of international comparative studies data. The research have been organized in research groups and it is interesting to read from the papers how the research activities are organized in different countries. Especially, it is interesting to become familiar how

- the research activities are organized in research teams and how research is split into concrete research projects with clear aims and external funding,
- the research outcomes are communicated in international conferences and international journals,
- the groups promote national and international collaboration in the research projects,
- Ph.D. students are recruited to the research projects and research is conducted with Ph.D. students.

However, it would be interesting to know how science education research is coordinated with effective leadership. For example, how senior and young researchers are collaborating and how Ph.D. education is organized on the international level.

Reference

Chiu, M.-H. (Eds.). (2016) *Science Education Research and Practices in Taiwan: Challenges and Opportunities*. New York: Springer.

Part II
Content Analysis of Science Education Research

Chapter 13
Impacts of Citations on Conceptual Change Articles Between 1982 and 2011: From International and Regional Perspectives

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

Abstract The purpose of this book chapter is to investigate the impacts of research articles on conceptual change field via the analysis of citations listed in a set of selected journal articles. According to our screening processes, we found 365 articles in the selected science education journals (*Journal of Research in Science Teaching, Science Education, International Journal of Science Education, Research in Science Education, International Journal of Mathematics and Science Education*) and 17,919 citations were included in the articles. Out of 365, there were 78 articles that had Asian scholars as either the first author or the corresponding persons. Among them, there were 3710 citations in these Asian studies. From the analyses, we found that Posner et al. (Sci Educ 66(2): 211–227, 1982) was the most cited article across the world, followed by Strike and Posner (Cognitive structure and conceptualchange. Academic Press, New York, pp. 211–231, 1992) and Pintrich et al. (RevEduc Res 63(2): 167–199, 1993). However, there were some differences of the orderings of the cited research articles in Asia except the first one, Posner et al. (SciEduc 66(2): 211–227, 1982). In terms of the authors, we found Driver as the most influential researcher in the area of conceptual change compared to others across the world. This holds true in Asia as well. However, the orderings of the cited authors were quite different between global and regional aspects. These findings might show specific preferences or impacts of research directions globally and locally. Detailed analyses and implications will be discussed.

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13.1 Introduction

There is quite a developed literature on conceptual change over the past 40 years. For this development, we can trace back to Kuhn's (1962) "normal science" or Lakatos's (1970) "theoretical hard core" that are considered as the central commitments for knowledge use on the one hand. On the other hand, conceptual change occurs when these central commitments require modifications and replacement. Kuhn terms this kind of conceptual change a "scientific revolution" whereas Lakatos called it research programs. Posner et al. (1982) believe there are analogous patterns of conceptual change in learning. Taking Piagetian terminologies, assimilation, and accommodation, as analogies, assimilation refers to the use of existing knowledge to cope with new knowledge, whereas accommodation refers to the replacement or reorganization of one's knowledge structure accordingly (Posner et al. 1982) which is considered as radical conceptual change. In addition to these scholars and theories, different researchers in the fields of cognitive science, cognitive psychology, or social psychology also developed important theories to describe the nature of conceptual change and what attributes to conceptual change. For instance, Stella Vosniadou, as a cognitive psychologist, considered conceptual change as related to learners' ontological and epistemological presupposition of a phenomenon that shapes one's conceptual understanding and internal representations (e.g., Vosniadou and Brewer 1994; Vosniadou et al. 2008). Micki Chi, as a cognitive scientist, proposed that conceptual change refers to moving one ontological concept from an ontological tree to the other (e.g., from Matter to Process categorical tree) (e.g., Chi et al. 1994; Chi 2008). She categorized conceptual change into three types, namely belief revision, mental model transformation, and categorical shift. All are dealt with the ontological categories of a concept. In science education, Posner et al. (1982) identified four conditions for conceptual change, namely, dissatisfaction, intelligibility, plausibility, and fruitfulness. Driver et al. (1994) defined learning as involving a process of conceptual change. Linn (2008) defined conceptual change as "the individual's lifelong trajectory of understanding of a given topic or discipline" (p. 694). Pintrich et al. (1993), Sinatra and Pintrich (2003) advocated contextualized learning and motivation factor that play influential roles in science learning. Even though different authors do not seem to share similar ideas or theories about what the nature and representation of knowledge is and how knowledge is constructed and reconstructed, the importance of understanding the theories and mechanism of conceptual change inform the use of the term within science education.

Chiu et al. (2016) investigated 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. A total of 383 articles in the international journals (including 26 English papers from researchers in Taiwan) were investigated.

The authors used an approach titled RAINBOW (Research and Instructional Based/Oriented Work, Chiu and Lin 2008) with six perspectives, namely, development, epistemology, ontology, evolution, affection/social, and instruction, to analyze the types of the articles. They found that there were more empirical studies than nonempirical studies (82.5 % vs. 17.5 %). Among the empirical studies, 66.1 % of the articles adopted the epistemological approach and 61.1 % of the articles were based upon instructional perspective. Very limited percentages of articles were from the ontological perspective (6.0 %) and evolutionary approaches (0.5 %). Affective and developmental perspectives had about 8.6 %. It was understandable that there were more articles coming from the epistemological perspective because researchers in science education tend to understand how to help students learn scientific knowledge and phenomenon. From the analysis, the authors also found that the numbers of articles published in epistemological and ontological perspectives started to increase in 1993 while the number of affective perspective articles started to increase in 1998 for five years after Pintrich et al. (1993) published their influential article on "hot" conceptual change (Chiu et al. 2016). The authors also noticed that in addition to Posner, et al.'s articles on the conditions of conceptual change, some influential research articles were also published during the years between 1991 and 2000. Therefore, we intended to put one more step further to analyze the frequencies of citations in the selected five journals that Chiu et al. used in their study for investigating the impacts of the articles on conceptual change.

13.2 Research Questions

There are three research questions to be answered in this chapter.

Question 1: Which articles were ranked on the top of 25 most citable papers across the world during 1982–2011?

Question 2: Which articles were ranked on the top of 25 most citable papers in Asia during 1982–2011?

Question 3: Who were ranked on the top of 25 most citable researchers across the world during 1982–2011?

Question 4: Who were ranked on the top of 25 most citable researchers in Asia during 1982–2011?

13.3 Method

13.3.1 Identifying Papers for This Review

Journal articles published from 1982 to 2011 in the top five international science education journals [i.e., *Journal of Research in Science Teaching, Science Education, International Journal of Science Education (formerly entitled as European Journal of Science Education)*, *Research in Science Education,* and

International Journal of Science and Mathematics Education] were searched with the keywords of "conceptual change." This process yielded 365 articles and 17,919 citations. Among them, there were 78 articles whose first author or corresponding author was Asian. There were 3710 citations from these Asian studies.

13.3.2 Data Analysis

For the international highest impact citations, we identified the most cited references among the 365 articles, and selected the top 25 articles. If the citation number was equal, we compared the published year of these articles or books and selected the newer ones for our list. For the highest impact citations in Asia, we looked for the most cited studies among the 78 Asian articles, and selected the top 25 citations as well.

Since a single author might have several important studies, we have also ranked the number of citation for each scholar to better reflect his/her contribution. For the highest impact international scholars, we counted the first author who was the most cited in the 365 articles, and selected the top 25 scholars. For the highest impact Asian scholars, our scope was changed to the 78 Asian articles, and the top 25 high-impact scholars in Asia were also selected.

13.3.2.1 Formation of an Analytical Framework

In this chapter, we used content analysis method to analyze the journal articles mentioned above. Figure 13.1 shows the dimensions of the framework for content analysis of this study.

13.3.3 Reliability of Data Source

The difficulty of this study was the accuracy of authors' citations. The same work might be cited as different information by different authors. For examples, Strauss's work (1998) might be cited as "Basics of qualitative research: Techniques and procedures for developing grounded theory" or "Basics of qualitative research:

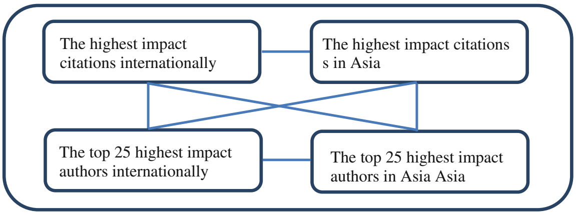

Fig. 13.1 The framework for content analysis of this study

Techniques and procedures for developing ground theory". These inconsistent citations might lead to different codings; therefore, the authors of the current study spent much effort to correct the information to enhance the reliability of this study. Once the data were verified and then the computer software would analyze them accordingly.

13.4 Results and Discussions

13.4.1 The Top 25 International Highest Impact Articles

To answer the first research question of this study, some descriptive statistics were conducted. Our analysis results are shown in Table 13.1. During 1982–2011, the top 25 articles that have major international impact on science education were published between 1962 and 1996 and the Time Cited count was ranged from 29 to 199. The top three influential articles are Posner et al. (1982), Strike and Posner's (1992), and Pintrich et al. (1993). Posner et al. were the first group that proposed the conceptual change model (CCM). They claimed four necessary conditions for students' conceptual change: dissatisfaction, intelligibility, plausibility, and fruitfulness. The second influential one, Strike and Posner's study, expanded the explanatory power of the CCM and used "conceptual ecology" to interpret student's science learning. Pintrich et al. reminded that the previous studies of conceptual change was too rational and highlighted the significance of students' motivational dimension (goals, values, self-efficacy, and control beliefs).

The rank 5 article, National Science Education Standards (NSES, National Research Council 1996) and the rank 18 article, Benchmarks for science literacy (American Association for the Advancement of Science 1993) are the most influential education documents. NSES are a set of guidelines for science education in primary and secondary schools in the United States. It is based heavily on constructivism, and emphasized scientific literacy (i.e., inquiry, history, and nature of science, personal and social perspectives of science, science, and technology). Programs that were defined according to these standards should be developmentally appropriate, interesting, and relevant to students' lives. As for Benchmarks for Science Literacy, it is not a curriculum framework or a curriculum plan. It simply provides educators with sequences of specific learning goals, and states what all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12.

The rank 6 (Pfundt and Duit 1994), rank 13 (Driver and Easley 1978), rank 14 (Osborne and Freyberg 1985), rank 17 (Wandersee et al. 1994), rank 18 (Driver et al. 1994), and rank 22 (Osborne and Wittrock 1983) citations included a bibliography, three books and two review articles, which delicately collected and categorized various students' or teachers' alternative conceptions. It is worth mentioning that number six on the ranking was a bibliography by Pfundt and Duit. This bibliography was revised several times to reflect the rapid developments of science education

Table 13.1 The rank of the top 25 international highest impact citations (N = 365)

No.	Rank. Authors	Title	*n*	%
1	1. Posner et al. (1982)	Accommodation of a scientific conception: toward a theory of conceptual change	199	54.5
2	2. Strike and Posner (1992)	A revisionist theory of conceptual change	88	24.1
3	3. Pintrich et al. (1993)	Beyond cold conceptual change: the role of motivation beliefs and classroom contextual factors in the process of conceptual change	78	21.4
4	4. Carey (1985)	Conceptual change in childhood	54	14.8
5	5. NRC (1996)	National Science Education Standards	52	14.2
6	6. Pfundt and Duit (1994)	Bibliography of every day conceptions and science education	50	13.7
7	7. Hewson and Thorley (1989)	The conditions of conceptual change in the classroom	49	13.4
8	7. Kuhn (1962)	The structure of scientific revolutions	49	13.4
9	9. Chi et al. (1994)	From things to processes: a theory of conceptual change for learning science concepts	46	12.6
10	10. Chinn and Brewer (1993)	The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science instruction	44	12.1
11	11. Vosniadou (1994)	Capturing and modeling the process of conceptual change	42	11.5
12	12. Hewson (1981)	A conceptual change approach to learning science	40	11.0
13	13. Driver and Easley (1978)	Pupils and paradigms: a review of literature related to concept development in adolescent science students	39	10.7
14	14. Osborne and Freyberg (1985)	Learning in science: the implications of children's science	37	10.1
15	15. Vosniadou and Brewer (1992)	Mental models of the earth: a study of conceptual change in childhood	34	9.3
16	15. Nussbaum and Novick (1982)	Alternative frameworks, conceptual conflict and accommodation: toward a principled teaching strategy	34	9.3
17	17. Wandersee et al. (1994)	Research on alternative conceptions in science	33	9.0
18	18. AAAS (1993)	Benchmarks for science literacy: a project 2061 report	32	8.8
19	18. Driver et al. (1994)	Constructing scientific knowledge in the classroom	32	8.8
20	20. Duschl and Gitomer (1991)	Epistemological perspectives on conceptual change—implications for educational practice	31	8.5
21	21. Strike and Posner (1985)	A conceptual change view of learning and understanding	30	8.2
22	22. diSessa (1993)	Toward an epistemology of physics	29	7.9
23	22. Osborne and Wittrock (1983)	Learning science: a generative process	29	7.9
24	22. Tyson et al. (1997)	A multidimensional framework for interpreting conceptual change events in the classroom	29	7.9
25	22. White and Gunstone (1989)	Metalearning and conceptual change	29	7.9

research. We counted them as the same literature despite the revisions. Its final version was named "Students' and Teachers' Conceptions and Science Education". However, its author, Duit (2009), decided to stop revising the bibliography since new powerful search means have become available. In summary, this bibliography was helpful for teaching and learning science from a constructivist perspective.

The fourth (Carey 1985), seventh (Hewson and Thorley 1989), 9th to 12th [Chi et al. (1994) followed by Chinn and Brewer (1993), Vosniadou (1994), Hewson (1981)], and 15th to 22nd [Vosniadou and Brewer 1992 followed by Duschl and Gitomer (1991), Strike and Posner (1985), Tyson et al. (1997), diSessa (1993) and White and Gunstone (1989)] dealt with theories of conceptual change. It seems that there are two peaks among these fundamental theories.

The first peak, Carey's work on children's understanding, was a coherent and consistent account for biology. It finally enabled us to understand the classical Piagetian work on animism and how it fitted with the later work on children's concepts of living things. She also differentiated degrees of conceptual change into weak and strong. The former only dealt with addition and/or deletion while the latter dealt with the restructuring of knowledge. Hewson's study could be seen as the pioneering work for CCM. It investigated how a student holding a set of conceptions of natural phenomena would respond when confronted by new experiences. Hewson and Thorley further showed that the four conditions for conceptual change have been used to analyze interview data and plan instruction but not to interpret interactions in the classroom via literature review. Their analysis of the ways in which students can and do produce evidence of meeting conditions shows that this only happens when they are able to monitor and comment on the scientific content of their conceptions. Chi et al. interpreted students' learning difficulties in science from the ontological perspective. She argued that students tended to use matter ontology rather than emergent process ontology to explain complex natural phenomenon due to their lack of the emergent process schema. The contribution of Chinn and Brewer is to propose students' seven responses to anomalous data. "Peripheral theory change" and "theory change" are the only two responses from the seven that could reach conceptual change. Vosniadou (1994), Vosniadou and Brewer (1992) proposed the "framework theory" and explained that all kinds of students' mental models are limited by "specific theories" from different cultures and nature observations. Furthermore, these specific theories are constrained by ontology and epistemology.

For the second peak of these important theories, there were Duschl and Gitomer who used "portfolio culture" to advance a piecemeal model of the character and mechanism of restructuring. The essential characteristic of this culture is that it creates opportunities for students to develop their scientific understanding and equip them with the tools necessary to take responsibility for their own restructuring. Strike and Posner (1985) examined the criticisms of the original CCM and provided empirical evidences to revise it. Tyson et al. (1997) analyzed the various usages of "conceptual change," and developed a multidimensional framework (i.e., epistemological, ontological, and social/affective perspectives) for conceptual changes in the classroom. They asserted that effective changes in students' knowledge structures should be considered from this multidimensional framework.

In contrast to Vosniadou's framework theory (Vosniadou 1994), diSessa (1993) investigated the intuitive sense of mechanism and proposed a p-prim theory and coordination theory to explain how intuitive ideas influence school physics learning. He claimed that the intuitive sense of mechanism contains various simple elements (p-prim), which were originally relatively problematic, and the system is weakly organized. White and Gunstone (1989) claimed the promotion of a new belief is relatively easy, but it is difficult to get students to abandon their former beliefs. They argued that the resolution of conflicting beliefs requires elements of metalearning (i.e., conscious control over one's learning). These theoretical articles and the top 3 highest impact studies possess 2.26 times cited more than the other studies, and displayed various vital perspectives explaining students' conceptual change.

The publication of Kuhn's work (ranked 7) was a landmark event in the history, philosophy, and sociology of scientific knowledge and triggered the development of CCM. "The structure of scientific revolutions" was also the only publication from science philosopher's perspective. Nussbaum and Novick's study (rank 15) presented a case study on a sequence of two lessons about the particle model and provided an analysis of the phases of the instructional strategy (alternative frameworks-conceptual conflict-accommodation) employed for cognitive accommodation. This study only focused on particle model unlike other books or review articles on our high-impact list, which documented various students' alternative conceptions.

13.4.2 The Top 25 Highest Impact Articles in Asia

To answer the second research question of this study, some descriptive statistics were conducted. The top 25 highest impact articles in Asia are shown in Table 13.2. During 1982–2011, the top 25 articles which have major impact on science education were published between 1962 and 2003 and the Time Cited count was ranged from 7 to 37. The top three influential articles are Posner et al. (1982), Pintrich et al. (1993) studies and Chi et al.'s (1994) ontology theory. The comparison of the high-impact articles between the Asia and International lists showed the studies of Chinn and Brewer (1998), White and Gunstone (1992), Chi (1992), Dreyfus et al. (1990), and Shepardson and Moje (1999), She (2004), Pintrich (1999) and Clement (1982) were only on the Asia list. Conversely, the studies of Hewson and Thorley (1989), Hewson (1981), Vosniadou and Brewer (1992), Benchmarks for science literacy (AAAS 1993), Duschl and Gitomer (1991), Strike and Posner (1985), diSessa (1993), White and Gunstone (1989), and Osborne and Wittrock (1983) were only on the International list.

The following studies are related to teaching strategies or teaching models. Chinn and Brewer (1993) first proposed a taxonomy of seven responses to anomalous data (ranked 7). In 1998, they revised the taxonomy and added the

Table 13.2 The rank of the top 25 highest impact articles in Asia (N = 78)

No.	Rank. Authors	Title	n	%
1	1. Posner et al. (1982)	Accommodation of a scientific conception: toward a theory of conceptual change	37	47.4
2	2. Pintrich et al. (1993)	Beyond cold conceptual change: the role of motivation beliefs and classroom contextual factors in the process of conceptual change	22	28.2
3	3. Chi et al. (1994)	From things to processes: a theory of conceptual change for learning science concepts	18	23.1
4	4. Strike and Posner (1992)	A revisionist theory of conceptual change	15	19.2
5	5. Kuhn (1962)	The structure of scientific revolutions	14	17.9
6	6. Chinn and Brewer (1998)	An empirical test of a taxonomy of responses to anomalous data in science	12	15.4
7	7. Chinn and Brewer (1993)	The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science instruction	11	14.1
8	7. Vosniadou (1994)	Capturing and modeling the process of conceptual change	11	14.1
9	7. White and Gunstone (1992)	Probing understanding	11	14.1
10	10. Pfundt and Duit (1994)	Bibliography of every day conceptions and science education	10	12.8
11	10. Wandersee et al. (1994)	Research on alternative conceptions in science	10	12.8
12	12. Chi (1992)	Conceptual change within and across ontological categories: examples from learning and discovery in science	9	11.5
13	12. Driver et al. (1994)	Constructing scientific knowledge in the classroom	9	11.5
14	12. NRC (1996)	National Science Education Standards	9	11.5
15	12. Osborne and Freyberg (1985)	Learning in science: the implications of children's science	9	11.5
16	12. Tyson et al. (1997)	A multidimensional framework for interpreting conceptual change events in the classroom	9	11.5
17	17. Carey (1985)	Conceptual change in childhood	8	10.3
18	17. Dreyfus et al. (1990)	Applying the cognitive conflict strategy for conceptual change—some implications, difficulties and problems	8	10.3
19	17. Driver et al. (1985)	Children's ideas in science	8	10.3
20	17. Duit and Treagust (2003)	Conceptual change: a powerful framework for improving science teaching and learning	8	10.3
21	17. Shepardson and Moje (1999)	The role of anomalous data in restructuring fourth graders' frameworks for understanding electric circuits	8	10.3
22	23. Clement (1982)	Students' preconceptions in introductory mechanics	7	9.0
23	23. Gilbert et al. (1982)	Children's science and its consequence for teaching	7	9.0
24	23. Pintrich (1999)	Motivational beliefs as resources for and constraints on conceptual change	7	9.0
25	23. She (2004)	Fostering "radical" conceptual change through dual situated learning model	7	9.0

eighth response, “holding the data in abeyance” (Chinn and Brewer 1998, rank 6). They claimed that the taxonomy could help science teachers to anticipate students’ reactions to anomalous data and it could also be used to lead students’ discussion regarding the nature of scientific rationality. Shepardson and Moje’s (1999) study was also related to students’ response to anomalous data (rank 17). They studied the nature of fourth graders’ understandings of electric circuits and showed how they used it as frameworks for interpreting data derived from the observation and manipulation of electric circuits. In White and Gunstone’s (1992) study (rank 7), they attempted to provide several practical teaching methods for teachers to probe students’ understanding. In Dreyfus and his colleagues’ (1990) study (rank 17), researchers discussed how the three main stages of conceptual change (i.e., awareness, disequilibrium, and reformulating) influenced misconceptions of 10th graders. She (2004) developed the dual situated learning model to promote students’ radical conceptual change (rank 23). Summarizing these studies, it appears that the researchers in Asia (73.2 %) valued teaching methods or teaching models more than international scholars (12.1 %).

There were two studies about children’s ideas that were not on the international list. Clement’s (1982) study was focused on students’ alternative conceptions in force and acceleration. The source of this qualitative misunderstanding could be a result of a preconception that hinders the full understanding of Newton’s first and second laws. Clement proposed that new concepts must displace or be remolded from an existing concept. Gilbert et al. (1982) argued that what children bring with them to science lessons are logical and coherent to them, and that these views have considerable influence on how and what children learn from their classroom experiences.

Chi’s ontology theory was initially introduced in 1992. This chapter was also the study that was not on our analysis of the international list (Table 13.1). In this chapter, she firstly introduced the conceptual change that occurs within an ontological category and that necessitates a change between ontological categories to discriminate conceptual learning and development. It seems that researchers in Asia placed more emphasis on ontological perspective than international researchers (34.6 % vs. 12.6 %). The other significant perspective in Asia was Pintrich’s (Pintrich 1999; Pintrich et al. 1993) motivation in conceptual change theory (37.2 % vs. 21.4 %). Pintrich et al. (1993) have emphasized that the conceptual change processes are influenced by affective, motivational, and social factors. In Pintrich’s (1999) study, he further analyzed the impact of different goal orientations, epistemological beliefs, personal interests, self-efficacy, and the influence of control beliefs on conceptual change. He argued that intrinsically motivated learners with a mastery orientation, who focus on the understanding and mastering the subject matter, are more likely to be engaged in deeper cognitive processing and, thus, show more conceptual change than extrinsically motivated learners with a performance orientation, who focus on external rewards, good grades, and besting others.

13.4.3 The Top 25 Highest Impact Researchers Internationally

To answer the third research question of this study, we conducted some analysis and the results are shown in Table 13.3. Table 13.3 reveals the first authors who were ranked the top 25 highest influential researchers on conceptual change. During the period of 1982–2011, the most cited article was written by Rosaline Driver. In other words, all her publications during the period were cited more than once in all 365 articles. Following Driver, 85.8 % of the articles cited papers published by Stella Vosniadou and 83.3 % of the articles cited Peter W. Hewson's studies. Although George J. Posner's article on CCM published in 1982 was cited the most (Table 13.1), 60 % of his publications were cited and followed by Reinders Duit

Table 13.3 The rank of the top 25 highest impact authors internationally

Rank	Scholar	Country	Total	% (n = 365)	Aligned authors with publications in Table 13.1
1	Driver, R.	UK	366	100.3	13, 19
2	Vosniadou, S.	Greece	313	85.8	11, 15
3	Hewson, P.W.	USA	304	83.3	1, 7, 12
4	Posner, G.J.	USA	228	62.5	1, 2, 21
5	Duit, R.	USA	195	53.4	6
6	Osborne, R.J.	UK	171	46.8	14, 25
7	diSessa, A.A.	USA	161	44.1	22
8	Chi, M.T.H.	USA	153	41.9	9
9	Strike, K.A.	USA	142	38.9	1, 2, 21
10	Pintrich, P.R.	USA	135	37.0	3
11	Novak, J.D.	USA	134	36.7	x
12	Carey, S.	USA	126	34.5	4
13	Lawson, A.E.	USA	124	34.0	x
14	Clement, J.	USA	124	34.0	x
15	Piaget, J.	USA	117	32.1	x
16	Gilbert, J.K.	UK	109	29.9	x
17	Nussbaum, J.	UK	107	29.3	16
18	Roth, W.-M.	Canada	99	27.1	x
19	Chinn, C.A.	USA	98	26.8	10
20	White, R. T.	Australia	97	26.6	24
21	Gunstone, R.F.	Australia	92	25.2	x
22	Duschl, R.A.	USA	85	23.3	20
23	Tobin, K.G.	USA	77	21.1	x
24	Kuhn, T.S.	USA	72	19.7	8
25	Kuhn, D.	USA	72	19.7	x

Note x stands for not included in the internationally list with 50 % on his publications. In sum, nearly 20 % of the articles had cited works written by the top 25 researchers.

According to Tables 13.1 and 13.3, we found 16 out of 25 researchers in Table 13.3 had their publications listed on the top 25 most cited papers. Among them, Rosaline Driver had two influential articles (Driver and Easley 1978; Driver et al. 1994) ranked as 13 and 19 as shown in Table 13.1; Stella Vosniadou was ranked second and with two articles ranked as the 11th and 15th; (Vosniadou 1994; Vosniadou and Brewer 1992); Peter Hewson and Greg Posner were also recognized as the third and the fourth with three articles ranked highly in international community.

Finally, as shown in Table 13.3, we also found that about 70 % ($N = 17$) of the research was from the US, followed by 16 % ($N = 4$) from the UK, 8 % ($N = 2$) from Australia, and 4 % ($N = 1$) each from Canada and Greece, respectively.

13.4.4 The Top 25 Highest Impact Researchers in Asia

Table 13.4 revealed that the top 25 highest impact researchers in Asia on conceptual change were also cited the most in publications by Asian scholars. The first one was Rosaline Driver again as shown in Table 13.3. There were 82.1 % of the articles that cited her publications. Following Driver, there were 66.7 % of articles that cited Tsai's research work and then Vosniadou, Lawson, and Pintrich with more than 50 % of the articles citing them.

As compared to Table 13.2, we found that the works citing Driver's publications by Asian scholars were slightly different from non-Asian works that also cited Driver (such as Driver et al., 1985; Driver et al., 1994).

Finally, as shown in Table 13.4, we also found that about 60 % ($N = 15$) of the research was from the USA, followed by 12 % ($N = 3$) from Taiwan in Asia, 12 % ($N = 3$) from UK, 8 % ($N = 2$) from Australia, 4 % ($N = 1$) from Germany and Greece, respectively. The ones from Taiwan were works by Chiu et al. (2002), Chiu and Lin (2005), She (2002, 2004), and Tsai (1999, 2000, 2002, 2003), Tsai and Wen (2005), respectively.

13.4.4.1 Researchers Listed Among the Top 25 in the World and in Asia

We found that 20 out of 25 researchers were present in both of our analyses for international and Asian citations. Among them, Driver was ranked first either in the world ranking or in the Asian ranking. If we took the top 10 into consideration for both the international and the Asian rankings, we found that the frequencies of citations of works by several scholars (e.g., Chi, Duit, Osborne, Pintrich, Posner, and Vosniadou) were consistently high. In other words, Asian scholars were able to catch the main trend of research on conceptual change and cited relevant studies in the field.

Table 13.4 The ranking of the top 25 highest impact authors in Asia

Rank	Scholar	Country	Total	% (n = 78)	Aligned authors with publications in Table 13.2
1	Driver, R.	UK	64	82.1	13, 19
2	Tsai, C.C.	Taiwan	52	66.7	x
3	Vosniadou, S.	Greece	44	56.4	8
4	Lawson, A.	USA	42	53.8	x
5	Pintrich, P.	USA	41	52.6	23
6	Chi, M.T.H.	USA	38	48.7	3
7	Posner, G.	USA	37	47.4	1
8	Osborne, R.J.	UK	29	37.2	15
9	She, H.C.	Taiwan	29	37.2	22
10	Duit, R	Germany	29	37.2	20
11	Hewson, P.W	USA	25	32.1	1
12	Strike, K.	USA	25	32.1	1, 4
13	Chinn, C.A.	USA	23	29.5	6, 7
14	Nussbaum, J.	UK	23	29.5	x
15	White, R.T.	Australia	23	29.5	9
16	Clement, J.	USA	22	28.2	24
17	Novak, J.D	USA	21	26.9	x
18	Piaget, J.	USA	18	23.1	x
19	Chiu, M.H.	Taiwan	17	21.8	x
20	Carey, S.	USA	17	21.8	17
21	Tobin, K.	USA	16	20.5	x
22	Treagust, D	Australia	16	20.5	20
23	diSessa, A	USA	15	19.2	x
24	Kuhn, D.	USA	15	19.2	x
25	Linn, M.C.	USA	15	19.2	x

Note x standards for not included in the Asian list

However, we also noticed that there were some researchers who were listed in the top 25 persons internationally, but not in Asia (such as Duschl, Gilbert, Gunstone, Kuhn, T., and Roth). Similarly, there were some researchers listed as the top 25 scholars on conceptual change in Asia, but not listed on the international list (such as Chiu, Linn, She, Treagust, and Tsai). However, they did make their contribution on conceptual change research in Asia.

13.5 Conclusions and Implications

Based upon our analysis of the identified articles both from international scholars and Asian scholars, we have the following claims to make.

Claim 1: Both of the international and the Asian scholars valued conceptual change model and motivation most, but Asian scholars valued other theories more equally

This study found that the top three high-impact theoretical perspectives in international research were CCM (111.2 %) (i.e., Hewson 1981; Posner et al. 1982; Strike and Posner 1992), Pintrich's motivation beliefs (21.4 %), and Vosniadou's framework theory (20.8 %). On the other hand, the order in Asian research was CCM (66.6 %), Pintrich's motivation beliefs (37.2 %) and Chi's ontology theory (34.6 %). The focuses in common were the research of CCM and motivation beliefs. Although international studies respected the importance of theory, they put much attention on CCM, while the Asian studies valued various conceptual change theories more equally. Among these theories, Pintrich's motivation beliefs (Asian: 37.2 % vs. International 21.4 %), Chi's ontology theory (Asian: 34.6 % vs. International: 12.6 %), and multidimensional framework for interpreting conceptual change events (Asian: 21.8 % vs. 7.9 %) were some perspectives that caught more attention among Asian scholars than international scholars. Conversely, Vosniadou's framework theory got less attention in Asia (international: 20.8 % vs. 14.1: 0 %), and diSessa's (1993) p-prime (international: 7.9 % vs. Asian: 0 %) and White and Gunstone's (1989) metalearning element (international: 7.9 % vs. Asian: 0 %) were missing on the Asian list.

Claim 2: Reciprocal effects between international conceptual change research and educational policy

There were reciprocal effects between international conceptual change research and educational policy. On the one hand, the authors of the U.S. national standards documents (AAAS 1993; National Research Council 1996) consulted conceptual change research findings in writing content benchmarks (Anderson 2007). On the other hand, *National Science Education Standards* (NRC 1996) and *Benchmarks for Science Literacy: A project 2061 Report* (AAAS 1993) were also the fifth and the eighteenth high-impact document on the international list and guided several conceptual change researches. In addition, *National Science Education Standards* was also the fourteenth high-impact document on the Asia list.

Claim 3: The distributions of authors' countries were slightly different between the international and Asian citations

The analyses of citations in international and Asian studies were slightly different. For the international analysis, 96 % of the citations were from English speaking countries. Meanwhile, in Asia, there was relatively more diversity in terms of the countries that the authors are from, For example, while 80 % of the first authors of the citations in the Asian analysis were from English speaking countries, the percentage of the citations from Germany, Greece, and Taiwan was also relatively high (20 %).

Claim 4: Asian research focused more on teaching strategies

This study further categorized the top 25 international and Asian studies into theory (international: 226.2 % vs. Asian: 202.5 %), instruction (international: 12.1 % vs. Asian: 73.2 %), and the investigation of alternative conceptions (international: 69.5 % vs. Asian: 76.9 %), respectively, and found the Asian research more focused on conceptual change teaching strategies than international research. Among these studies, cognitive conflict was the most popular teaching strategy. This finding echoes Chiu et al.'s (2016) study that more studies were related to epistemology and instruction compared to other perspectives (e.g., ontology, motivation). Although their study compared International and Taiwanese studies, Taiwanese studies on conceptual change possess the largest part in Asia, their result could explain the similar situation in this study.

Suggestion 1: Strengthening the effort on developing theoretical frameworks for informing conceptual change research for local or global needs

Most Asian researchers were devoted to designing appropriate teaching strategies for promoting students' conceptual change in science. It might be a good approach for Asian researchers in the early stage of developing research in the area of conceptual change because it helps them understand different students' characteristics and effect of various teaching strategies from empirical studies in order to evolve new theories (or paradigm) on conceptual change. However, as the research has been investigated for more than 20 years, it is the time to reflect on what has been done and what has not been conducted and needed more knowledge and effort to be put in. Researchers in this field have accumulated considerable results from these empirical studies in Asia. The next step is to synthesize these results and increase the number of theoretical studies for renewing or reconstructing conceptual change theories for local or global needs.

Suggestion 2: Welcoming divergent research paradigms to shed light of cultural and societal impact on science learning

To expand impacts of research, to provide sustainable development of the research on conceptual change in science, and to influence school teaching and teachers' perceptions for conceptual change, we need to provide a wide range of instructional paradigms that are evidence based to support school teaching. Also, as science educators, we need to take individual differences (e.g., students' background, prior knowledge about science, gender) on understanding sciences into account and provide distinct and effective approaches that should be explored in research before implementing them in the school system. Therefore, research has to take cultural, societal, and students' characteristics into consideration for the sake of equality and quality science education. Although Asia started research on conceptual change later than other regions did, we believed researchers in Asia not only recognized the main research trend on conceptual change globally but also extended their research with contextualized elements in their studies. Researchers across the world should accept divergent research theories to shed light of cultural and societal impact on science learning is still the future work.

Suggestion 3: Outcomes of conceptual change research in Asia should inform education policies

The international conceptual change research had a substantial influence on educational policy. Many textbooks now include lists of common misconceptions in their teacher's editions (Anderson 2007). The conceptual change research in Asia was also influenced by ⟨National Science Education Standards⟩ (NRC 1996). However, the conceptual change research in Asia has accumulated considerable studies. In particular, teaching strategy was the major focus in Asian conceptual change research. There were more research results to inform local teaching practice and education policy.

Suggestion 4: Increasing the interaction between local scholars and international scholars to increase impacts of regional studies in Asia with its special characteristics on cultural and contextual aspects

Contextual and cultural factors have been investigated to show their impacts on students' learning in science. With some historical background and tradition of research on science education, some preferences of research topics might be influenced by specific needs or trends among the research communities in Asia or other areas. By comparing the local and international research results, the culture and society factors could be manifest. Based upon the results, linking local research with the international research community should be emphasized. We believe Asian researchers have expertise and experiences in conducting research locally and publishing in international journals. The interactions between different cultures and ideas could foster new ideas to enhance the impact of the theoretical and empirical research on conceptual change.

Suggestion 5: Identifying the most influential citations and authors for guiding research paradigm and even go beyond their territories

From the analysis shown in this chapter, several researchers and their work were highly cited which could shed some light of conducting research and even put more steps further to enrich in specific areas. However, we also need to broaden our view and then pay attention to other researchers or articles that have potential to lead insightful research topics, directions, or methodology that have not been well received and recognized by the research communities.

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Chapter 14
Overview of Science Education Research and Practice in Korea

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Abstract The aim of this chapter was to examine science education research trends that have been constructed in Korea. We were then interested in examining what impact these works have had on K-12 science teaching and learning. We conducted a content analysis of articles published in the *Journal of Korea Association for Science Education* with respect to research topics and contents. We also discussed the impacts of these research studies on science curriculum, science instruction, and science teacher education in Korea. Importantly, all of these particular foci provide an insight to the various applications of research and to ways how current research informs teaching practice, and thus raise questions of what needs to be done next.

14.1 Introduction

It has been 120 years since the modern science education in Korea has begun. The modern public school education started by laws in 1895 and since then the science subject has been taught at schools in Korea (Kim 1976). The importance of school science education has been recognized by the government since 1962. The government of the Republic of Korea released the national economic development plan and recognized the importance of science and technology development for the economic improvement. The government of the Republic of Korea emphasized the importance of science education with the slogan of 'Science Education for National Prosperity.'

School science education should be supported by research studies in science education. In other words, research in science education and school science education support each other. The master program in science education was begun at

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the graduate school of education at a few universities in Korea in 1964. And the science education curriculum projects developed in the United States were introduced to and conducted in Korea in the 1960s. These two historical events that occurred at the same time period were the foundation of science education research in Korea. In this chapter, we overviewed the trends of science education research in Korea for the past 40 years and examined what impacts these works have had on K-12 school science education.

14.2 Review of Science Education Research in Korea

Research on science education in Korea has begun since 1964 when master programs were available at a small number of graduate schools of education including the Seoul National University (Park 1984). The science education improvement project supported by the UNESCO/UNICEF in 1968 activated the research in science education at the 20 science education research centers at the college of education of the national university and teachers college (Jeong 1984). The strands of research studies were extended with the doctoral program available at the Seoul National University in 1984. The doctoral programs in science education are available at 20 institutions now.

Research studies in science education were published at journals issued by science education research centers at institutions and the "*Journal of Korean Chemical Education*" issued by the Korean Chemical Society, "*Biology Education*" issued by the Korean Society for Biotechnology and Bioengineering, and "*Physics Education*" issued by the Korean Physical Society. The science education community and the numbers of articles were small. The Korea Association for Science Education founded in 1976 has been a center of science education research in Korea. The first issue of the *Journal of Korea Association for Science Education* was published in 1978. The journal published an issue every two years at the beginning but now eight volumes a year.

This chapter was intended as an overview of research trends of science education in Korea since the 1960s. We also examined influences of science education research on teaching and learning in Korea school science classrooms. We classified the time from the 1960s to current into the four periods: Embryo, Infancy, Growth, and Maturity. The Embryo period was from the mid-1960s to 1977. The initiatives in Korea science education began in the mid-1960s by presentations of scholarly work in science education research. Since then, the development in science education research has been driven by the first issue of *Journal of the Korean Association for Science Education* in 1978. The Infancy period was from 1978 to 1991 wherein a few science educators published research studies in a small number of research areas. The Growth period from 1992 to 2003 was led by a number of science educators studied in both Korea and international institutions with increasing numbers of publications in the extended scope. The Maturity period from 2004 to 2013 meant a significant development both in the research fields and the numbers of publications. The international exchanges among science educators were active in the Maturity period. For research studies after the Infancy period, our examination have limited ones published at the *Journal of Korea Association for Science Education*.

14.2.1 Embryo Period (1965–1977)

According to the National Assembly Library of Korea, the first published science education research article in Korea was in 1965 (Kim et al. 1987). During the Embryo period in the history of Korea Science Education Research (1965–1977), research studies focused mostly on science education curriculum and science teaching. With support from the UNESCO/UNICEF (1968–1977), the science education curriculum projects such as ESS, IPS, PSSC, and CHEM Study were introduced to and conducted as pilot sessions in Korea. The related in-service teacher professional development programs were implemented at the college of education and teachers college (Kwon et al. 2003a, b). The researchers in science education were interested in the new curriculum movement by the United States and discussed about its influences and implications on Korea science education curriculum. Most graduate students in the master program of science education were in-service teachers. And the science educators at the college of education had doctoral degrees in natural science not in science education. As a consequence, the scope and fields in science education research in this period were limited. The scholarly works of science education were published at the academic journals issued by the science education research centers at institutions, *Biology Education* issued by the Korean Society for Biotechnology and Bioengineering, and the *Journal of Korean Chemical Education* issued by the Korean Chemical Society.

1. **Research on science curriculum**

Before the introduction of the post-Sputnik reform programs developed by the United States, Korea science education curriculum focused on science-in-everyday-life. The emphasis of the new science curriculum aiming both the science principles and scientific inquiry grasped attention of Korea science researchers and educators. The first implementation of the new science curriculum was in the PSSC physics laboratory class for Kyungbuk medical school students in 1961. A few science teachers in the Kyungbuk Province had research meeting and made experiment kits for the new science curriculum and they conducted a science teacher workshop on the PSSC physics in 1963 (Kwon et al. 2003b). Building upon the researchers' attention to the new science curriculum around the college of education at both primary and secondary levels, 10 year support from the UNESCO/UNICEF (1968–1977) disseminated the programs across the country. The institutions of training elementary teachers and secondary science teaches opened pilot courses and the professional development programs on new programs such as ESS, SAPA, SCIS, IPS, PSSC, CHEM Study, BSCS, and ESCP. Researches related to their applications into Korea science classrooms were also conducted (Kang 1968; Kim 1967; Kwon 1968; Han 1969; Park 1967) such as comparing the new science curriculum with Korea science curriculum (Joung et al. 1969) and suggesting implications of the new science curriculum on Korea science education curriculum reform (Chung and Row 1977; Lee 1974). Further, a framework of the new Korea science curriculum was suggested (Woo 1976).

2. **Research on science teaching**

There were marked changes in orientation between the new science curriculum and the science curriculum focused on the science-in-everyday-life. With comparisons between the new science curriculum and the previous science curriculum, research on goals, contents, instructional strategies, assessments, and teacher roles were conducted (Kim 1976; Han 1971; Oh et al. 1976; Park et al. 1974). As the new science curriculum emphasized scientific inquiry, the effective ways of guiding student engagement in science experiments, the requirements of laboratory classrooms, and the extent to which each school had experimental supplies and materials were investigated (Lim 1973; Moon et al. 1975).

14.2.2 Infancy Period (1978–1991)

There has been a significant development in science education researches in Korea since researchers with a doctoral degree from institutions in the United States joined Korea science education research community in the 1970s. Since then into the 1980s, researchers in science education from institutions in the United States or the Unites Kingdom have been teaching students in the undergraduate and graduate programs of science education and conducting researches in science education. Research studies conducted by those prominent science researchers were the foundations of the Korea science education research and published at the *Journal of the Korean Association for Science Education*. The main research agenda during the Infancy period (1978–1991) were as follows: teacher education, science education research based on Piaget cognitive theory, students' preconceptions/misconceptions, and school science teaching and learning. There were also a few research studies regarding integrated science curriculum, scientific inquiry and problem solving, and low achieving students.

1. **Foundation study on science teacher education**

While general education courses and science content courses were available in science teacher education programs, science education courses that were critical to educate professional science teachers were rarely open in the 1970s. As science educators recognized the problem, they developed science teacher education curriculum (Park 1978) and the running model for the curriculum (Cho et al. 1985).

Also, researches constructing instructional models and developing teaching materials were conducted to create courses such as 'Theoretical Foundations of Science Education' (Park 1984) and 'Research in Science Education (Park 1982).'

2. **Research on science instruction based on Piaget's theory**

Piaget's theory of cognitive development has provided important implications on school science education and research studies in science education. Kim (1978) examined the elementary students' concepts of 'movement and speed' and analyzed the science contents presented in the grade 4–6 science textbooks with respect to the stages of Piaget' cognitive development (Kim et al. 1986). Choi et al. (1985) examined cognitive levels of grade 7–12 students and Han (1986) analyzed cognitive levels of grade 7–12 students with respect to districts, grade levels, ages, sex, and social economic levels. Choi and Hur (1987) analyzed the relationships between students' cognitive levels and science contents presented in the science textbooks. They claimed that the cognitive levels required for science contents presented in textbooks were higher than student cognitive levels.

3. **Research on preconceptions in science instruction**

Researches on students' understanding of science concepts were led by Kim et al. (1978, 1980). They examined students' conceptions of 'movement and speed' with respect to sex and districts. Researches on students' preconceptions on various topics were activated since Cho (1984) presented the article of 'Relationships among philosophical foundations of students' preconceptions, misconceptions, and science learning.' During the Infancy period, research on students' preconceptions focused on physics and biology such as genetics, reproduction, fertilization, cell division, photosynthesis, force, and movement, Newton's third law, dynamics, temperature, electronic current, and changing states of water. There was little research on chemistry as chemistry deals with micro-level phenomenon.

4. **Research on school science education**

Identifying problems or difficulties in school science education needs to be done in order to improve school science education. Science educators examined how the science curriculum was conducted in schools (Kwon et al. 1987) and provided suggestions on the ways how to improve school science education (Cho et al. 1989; Park and Lee 1987; Park et al. 1988).

The college entrance examination has great influences on school education in Korea. With respect to this, in 1986 a special volume 6(1) of the *Journal of Korea Association for Science Education* was issued for the topics of the relationship between the college entrance examination and secondary school science education; relationships between college entrance examinations and school science education in the United States, England, German, China, and Japan; the new plan for the college entrance examination and assessment systems aiming for the proper school science education.

14.2.3 Growth Period (1992–2003)

14.2.3.1 Research in Science Education

Since 1979, the Korea government supported for the graduate student study abroad program contributed to bring up researchers and experts in science education. Since 1983, they come back from the United States and the United Kingdom and worked as professors at the college of education and then researches in science education were activated. Researchers with a doctoral degree from the Korea institutions also worked at the college of education and the universities of education, and also played a central role in Korea science education. There was significant progress in the researches of science education compared to the Infancy period. The research agenda were various and the numbers of research papers have increased. The *Journal of Korea Association for Science Education* was issued three times a year in the Growth period and six times a year in 2003. Table 14.1 indicates trends in the numbers of articles published in the *Journal of Korea Association for Science Education* during the Growth period.

14.2.3.2 Research in Each of the Main Research Agenda

Research topics such as preconceptions and conceptual change, scientific inquiry, teaching strategies, curriculum, problem solving, verbal interaction, teacher education and professional development, and educational technology were focused in the Growth period.

1. **Preconceptions and conceptual change**

Research on student preconceptions was conducted since the Infancy period. Results provided science teachers with information of what preconceptions students held on certain scientific concepts and helped them lead effective class discussions. Also, information on student misconceptions provided teachers with cues on how to generate conceptual conflicts in science instruction. Researches of student misconceptions on several topics such as light, gravity, free-fall, acid and base,

Table 14.1 Trends in the numbers of articles published in the *Journal of Korea Association for Science Education* during the Growth period

	Early-term				Medium-term				Late-term			
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Number of articles	28	34	36	49	46	48	55	61	58	75	88	57
Mean number of articles	36.8				52.5				69.5			

evaporation and condensation, acid rain, heredity and evolution, life, homeostasis, tide, and astronomy were conducted and used for developing textbooks.

Then, why do students hold their own preconceptions on scientific concepts? Research during the Growth period focused on what preconceptions or misconceptions students hold. However, there were few research studies looking for causes why students hold those misconceptions. It may be because the approach should be long-term and based on epistemology. There were a few studies investigating factors that influence the formation of student misconceptions. Kim and Chung (1997a) indicated that high school students held more misconceptions on 'diffusion and osmosis' and claimed that the science textbooks included unclear and brief descriptions on the scientific concept. Kim and Chung (1997b) also suggested that 38.3 % of teachers did not clearly understand 'homeostasis,' 'classification of animals and plants,' and 'formation of food in plants.' They indicated that teachers would play a role on the formation of student misconceptions. These findings provided important implications that school science classes would be a critical factor for the formation of student misconceptions.

Researchers recognized that it is hard to change student misconceptions into scientific concepts. With respect to this, Lee and Kwon (1993) identified factors impacting on the robustness of student misconceptions and developed a formula to generate index numbers indicating the robustness of student misconceptions. They expected that the formula would help design an instruction model to change student misconceptions into scientific concepts as they considered all factors impacting on the robustness of student misconceptions.

School science instruction tried to find ways how to change student misconceptions into scientific concepts and researchers suggested various instructional strategies and teaching methods for student conceptual change. Kwon and his fellows identified three factors impacting on cognitive conflicts such as factors of students, tasks, and instruction and investigated influences of the factors (Kim et al. 2001). The patterns of cognitive conflict and the characteristics of student responses with respect to the complexity of science contents were examined (Lee and Kwon 1999; Kim and Kwon 1995). They presented a model explaining the process of cognitive conflict and developed an assessment tool to evaluate the levels of cognitive conflict (Lee et al. 2003). Also, the effects of the teaching strategy using cognitive conflict on conceptual change were investigated (Kim and Kwon 1995; Kwon et al. 2003a, b).

While cognitive conflict was identified as an effective strategy for student conceptual change, other strategies such as evidence-based critique, deductive logic, history of science, interaction reinforcement, and multiple comparisons were used for student conceptual change.

2. **Scientific inquiry and inquiry ability**

Since scientific inquiry was identified as a major goal for science education in the third Korea national science curriculum in 1974 (Ministry of Education 2000), inquiry-based science teaching has been emphasized in school science instruction.

Hur's (1984) article on scientific inquiry model and assessment framework of scientific inquiry initiated researches on scientific inquiry in Korea. Cho (1992) identified the definitions of scientific inquiry, scientific research, scientific methods, scientific process skills and suggested science teaching methods for improving students' scientific process skills.

The college admission examination since 1994 (Korea Institution for Curriculum and Evaluation 2005) activated researches on scientific inquiry and scientific inquiry ability. The Ministry of Education in Korea implemented the college admission examination to evaluate the extent to which students are able to study in college. The parts of social studies and science focused on student inquiry ability. This approach reinforced inquiry-based science teaching in science classes and led a number of research studies on development of teaching materials and methods to improve student inquiry ability, multiple choice assessment method to evaluate student inquiry-based thinking, and assessment tools to evaluate scientific process skills. There have been also several research studies such as analyzing thinking process for each of the inquiry levels, identifying factors impacting on inquiry-based thinking, and developing the national level assessment of inquiry ability.

Choi and his fellows (Choi et al. 2002; Nam et al. 2002) recognized student scientific inquiry as a major goal of science education and investigated the effects of Thinking Science program on students' inquiry ability. They pointed out that cognitive conflict strategy using the Thinking Science program, verbal interactions during the process of resolving conflicts, and metacognition influenced the student inquiry ability such as compensation logic and variable control and resulted in student cognitive development (Lee et al. 2002).

3. **Teaching strategies**

In order to implement an effective science instruction, it is important to consider science contents, student understanding, learning goals, and proper teaching strategies. With respect to this, there have been several research studies investigating the relationships between instructional strategies and science contents. For instances, Kim et al. (1995) studied the use of metaphors for learning 'electricity.' Lee and Kim (1995) used the history of science to change student misconceptions on the concept of 'heat.' Noh and Jeon (1997) explored the effects of visual representations of molecules. And Jung et al. (1996) used a small group role-play for student understanding of astronomy.

A number of researches on the effects of cooperative learning were also conducted. The use of STAD or Jigsaw, relationship between cooperative learning and student characteristics, and grouping for effective cooperative learning were investigated. The use of concept map or Vee diagram, stimulation of student motivation, and questioning strategies were also explored.

4. **Curriculum**

Research on science curriculum centered on the integrated science curriculum and Science Technology and Society (STS). The integrated approach of science for grade 3–10 students had been accepted by the majority of the science researchers (Kwon and Park 1978). Then, there were needs to change the combined science curriculum into the integrated science curriculum. With respect to this, research studies such as theoretical reviews to develop the integrated science curriculum (Son and Lee 1999), development of the topics and contents for the integrated science curriculum (Choi and Choi 1999), and curriculum design for the integrated science education (Son et al. 2001) were conducted.

STS approach grasped researchers' attention since Kim (1988) reported the results of comparisons in elementary science contents between the United States and Korea. She indicated that the elementary school science emphasized student understanding of science concepts and scientific inquiry and insisted that the relationships among science, technology, and society should be included in elementary science curriculum to achieve goals of citizen education for students living in a society dependent on science, technology, and information. Kwon (1991) pointed out the problem of disciple-centered science education and claimed that there are needs to develop science textbooks including daily-life examples. Following his pioneer research, several research studies introducing STS programs (Cho 1991), investigating science teachers' perceptions on STS programs (Choi 1994), and identifying ways to apply STS approach (Chung et al. 1993) were presented. Researches of analyzing SATIS programs, exploring student attitudes to socio-scientific issues, examining the effects of STS programs on scientific attitudes and achievements, and professional development programs for STS approach were also conducted.

5. **Problem solving**

Since Kwon and Lee (1988) analyzed the process of students' problem solving, the majority of researches on problem solving focused on students' thinking processes for problem solving in physics (Bak and Kwon 1990; Bak and Lee 1993). Interactions between problem tasks and students are critical to problem solving. Then, researches centered on examining the relationship between problem solving and the characteristics of the problems such as problem context and the extent to which the problem requires students' attention (Ahn and Kwon 1995; Hong and Park 1995); the relationship between problem solving and the characteristics of students such as mental capacity, chunking level, recognition type, information process type, and visualization and organization ability.

6. **Verbal interaction**

While activity-centered scientific inquiry was emphasized, roles of verbal interactions in science classes did not attract researchers' attention much. Since 1980s, scientific literacy including communication skills and reasonable decision-making has been identified as an essential goal of science education.

A number of researches such as students' verbal interactions in cooperative learning, verbal interactions in group discussions, verbal communication-centered scientific inquiry, and learning environment for verbal communication were conducted. These research studies found that students' communications in science classes were inactive and superficial and there was little dialectic communication. They also implied that teachers should consider students' social and psychological aspects and utilize teaching strategies stimulating students' communications.

7. **Teacher education and professional development**

It would be in-service teachers that know what needs to be done for teacher education programs. With respect to this, Park's (1992) research grasped our attention. He examined 176 science teachers' perceptions on the teacher education programs and the requirements to be a good science teacher. Science teachers considered enthusiasm, science content knowledge, organization ability of teaching materials, instructional skills, and scientific philosophy. They also claimed that pre-service teachers should take more courses of 'science teaching methods.' This indicated that the portion of 'teaching methods' courses were relatively low compared to 'science content' courses in teacher education programs. Kwak and Kim (2003) observed and analyzed science classes by 10 science teachers who were recognized for the best science teaching in Korea. The good science teachers reorganized the science contents considering student level and learning context, used various teaching strategies, challenged students, stimulated students' cooperation, and used results of assessments of student learning for the next instruction. They were also joining the district science teacher association to become a better science teacher. They worked hard for good science teaching and loved to teach science and enjoyed to have 'highly engaged students.' These findings provided important implications on science teacher education and professional development programs.

8. **Educational technology**

While there were high expectations of using computers for science teaching with tremendous development of computers, the effects of the use of educational technology in science classes was not consistent. The early attempt of educational technology was simply using the functions of computers such as computer user interface or repetition learning. Research on educational technology extended to effectively connect the characteristics of science content with the strength of computers such as animations to show the movement of molecules and ions in dissolution, or simulation of chemical equilibrium and dynamics. Shim et al. (2003) investigated the effects of the '3D virtual reality technology' for the structure and function of eye.

14.2.4 Maturity Period (2004–2013)

14.2.4.1 Research in Science Education

In late 1990s, the Ministry of Education approved doctoral programs of science education at the major universities of education and the colleges of education. A number of science researchers from the institutions worked actively for research in science education across various research agenda. Table 14.2 indicates the trends in the number of articles published in the *Journal of Korea Association for Science Education* during the Maturity period.

There were significant increases in numbers of articles published in the *Journal of Korea Association for Science Education* during the Maturity period compared to the Growth period as shown in Tables 14.1 and 14.2. However, the increase of numbers of the articles during the Maturity period was not significant as the Growth period. It may be because of the high ratio of rejection for the manuscripts submitted to the *Journal of Korea Association for Science Education* during the Maturity period.

Research topics of the articles were more diverse compared to the Growth period. We analyzed articles published in the *Journal of Korea Association for Science Education* using the analysis framework by Tsai and Wen (2005). Table 14.3 shows frequencies and percentages of research topics of the articles published in the *Journal of Korea Association for Science Education* from 2004 to 2013 (Maturity period).

Table 14.3 indicates that researches on 'Teaching' and 'Learning-Context' have increased while ones on 'learning-conception' have decreased. Research on 'Teacher Education' and 'Gifted Education' increased over the years. There were a few researches on 'Culture, Social, and Gender' and 'Educational Technology.' Limitations of the results in Table 14.3 are that we analyzed only the articles published in the *Journal of Korea Association for Science Education*.

Lee et al. (2009) analyzed articles published in the *International Journal of Science Education* (IJSE), *Science Education* (SE), and the *Journal of Research in*

Table 14.2 Trends in the number of articles published in the *Journal of Korea Association for Science Education* during the Maturity period

	Early-term			Medium-term				Late-term		
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of articles	109	90	81	84	82	76	79	78	110	94
Mean of the number of articles	93.3			80.3				94.0		

Table 14.3 Frequencies and percentages of research topics of the articles published in the *Journal of Korea Association for Science Education* from 2004 to 2013

Research topic	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Teacher education	8 (7.4)	8	5	3	12	10	16	13	16	19	110 (12.5)
Teaching	18 (16.5)	18	18	25	21	20	20	22	23	20	205 (23.2)
Learning -conception	11 (10.1)	6	13	8	4	2	2	3	6	4	59 (6.7)
Learning -context	30 (27.5)	19	17	12	13	18	16	10	26	18	179 (20.3)
Goals, policy and curriculum	18 (16.5)	11	9	16	9	10	11	13	14	12	123 (13.9)
Culture, social and gender	3 (2.8)	0	1	2	1	0	1	0	0	2	10 (1.1)
Philosophy, history and NOS	7 (6.4)	10	7	4	7	5	6	3	7	8	64 (7.3)
Educational technology	2 (1.8)	5	1	2	2	0	0	0	0	0	12 (1.4)
Informal learning	7 (6.4)	4	2	6	0	2	3	1	3	2	30 (3.4)
Gifted education	3 (2.8)	6	5	4	12	6	4	12	11	7	70 (7.9)
Others	2 (1.8)	3	3	2	1	3	0	1	4	2	21 (2.4)
	109 (100)	90 (100)	81 (100)	84 (100)	82 (100)	76 (100)	79 (100)	78 (100)	110 (100)	94 (100)	883 (100)

Science Teaching (JRST) from 2003 to 2007. We compared the frequencies and percentages of research topics published in the *Journal of Korea Association for Science Education* with the results of Lee et al.'s (2009) analyses as shown in Table 14.4.

Table 14.4 indicates that the top one topic was 'Learning-Contexts' in both the JKASE and the three international journals. The next top topics were in the order of 'teaching,' 'goals, policy, and curriculum,' and 'learning-conception' in the JKASE while 'learning-conception,' 'teaching,' 'goals, policy, and curriculum' in the three international journals. There were more studies on 'teaching' in the JKASE compared to ones in the three international journals, while less studies on 'culture, social, and gender' and 'educational technology' in the JKASE compared to ones in the three international journals.

Table 14.4 Comparison of frequencies and percentages of research topics between the three international journals (IJSE, SE, and JRST) and the *Journal of Korea Association for Science Education* (*JKASE*)

	IJSE, SE, and JRST (*n* = 869)	KJSE (*n* = 408[a])
Teacher education	78(9.0)	30(7.2)
Teaching	121(13.9)	96(22.9)
Learning-conception	133(15.3)	48(11.4)
Learning-contexts	204(23.5)	101(24.0)
Goals, policy and curriculum	110(12.7)	68(16.2)
Culture, social and gender	59(6.8)	9(2.1)
Philosophy, history and NOS	71(8.2)	32(7.7)
Educational technology	47(5.4)	12(2.8)
Informal learning	46(5.3)	24(5.7)

[a]Double-counting for research topics

14.2.4.2 Research in Each of the Main Research Agenda

There have been increase in research topics compared to the Growth period. The number of research studies on ‘preconceptions and conceptual change’ and ‘scientific inquiry and inquiry ability’ have significantly decreased compared to the Growth period. Instead, a number of studies on ‘science education for gifted students,’ ‘argumentation and writing in science,’ ‘pedagogical content knowledge,’ and ‘informal science education’ were presented. The top topics during the Maturity period were ‘teaching strategy,’ ‘curriculum,’ ‘teacher education and professional development,’ ‘PCK,’ ‘argumentation and writing in science,’ ‘verbal interaction,’ and ‘informal science education.’

1. **Teaching strategy**

Research studies on teaching strategy during the Maturity period were conducted as much as the Growth period. More diverse teaching strategies were explored during the Maturity period compared to the Growth period. For instances, the effects of using concept map, metaphor, cognitive conflict, role-play, history of science, STS approach, daily-life examples were explored. Also, the effects of using drawing, writing, multiple modes, and models were investigated. Researches exploring the effects of reciprocal peer tutoring/cooperative mentoring, investigating the effects of argumentation-focused/question-generated science instruction, developing programs to improve core capacities, and examining the effects of the programs stimulating students’ reflection were conducted.

There were also a few studies on student self-regulated learning that focused on learners. These researches are meaningful in that there are many students who are not engaged in science classes and have difficulties in learning science. Student-centered learning has been emphasized in science education so these researches would provide important implications on science teaching and learning.

2. **Curriculum**

The majority of the research studies on curriculum during the early Maturity period focused on examining the extent to which the emphases of the 7th Korea national science curriculum were applied in the science textbooks and science classes. According to Kwak's (2004) study investigating the elementary school science, the 7th Korea national science curriculum assigned more authority to schools or teachers. However, the majority of the elementary school teachers just followed the directions provided by the teacher-guidebooks for goals, contents, teaching methods, and assessments and did not reorganize the teaching materials for a creative science class.

Kim et al. (2006) analyzed middle school science textbooks to examine the extent to which middle school science textbook embed the contents to achieve the goal of science education, 'scientific literacy.' They found that the science textbooks included scientific knowledge and scientific inquiry process but there were not enough descriptions for science as thinking process or STS. Another study (Hong and Jeong 2004) critiqued that the science textbooks included simple reading materials for the STS approach and implied more diverse STS topics and approaches needed. Research studies examining the extent to which science textbooks included the science contents targeting for ICT literacy and the history of science that stimulates student motivations and helps understand the nature of science and scientific inquiry were also conducted.

The 2009 science curriculum centered on 'Integrated Science' that aimed student interest and integrated understanding of nature. Kim et al. (2013) examining student interest in science reported that students' interest in science topics was medium level while their motivation was higher level. Also, students who aimed to major in science/engineering had high motivation but students who aimed to major in liberal arts had interest in hands-on activities. Ahn et al. (2013) claimed that several aspects such as leadership, teacher colleague cooperation, year-long plan, flexible time management, and using community resources are critical to the integration-based science education. This approach would reform school science education and keep science teachers informed.

3. **Teacher education and professional development**

The science teacher professional development is critical to the school science education reform. With respect to this, researches on in-service teacher education and professional development programs are very important. The main themes of the science teacher professional development were constructivism, student misconceptions, conceptual change strategy, learning theory and epistemology, verbal communication based on Vygotsky's social constructivism. Then, researches on teacher education focused on investigating pre-service teacher understanding of learning theory and developing and implementing instructional strategies, examining the effects of the mentoring programs, exploring the effects of teacher colleague collaboration or cooperative mentoring on the professional development.

Early research on teacher profession focused on examining the PCK of novice teachers, investigating the PCK components identified by science teachers, analyzing the PCK by observing science teaching, exploring relationships between the content knowledge and the PCK, and defining the PCK. Understanding the PCK as a profession index, researchers in science education made efforts to find ways to improve teacher profession by examining PCK development through CoRe (Content Representation) and investigating pre-service teachers' PCK development through mentoring before and after student teaching.

4. **Argumentation and writing in science**

As student argumentation and writing have been emphasized as critical components to student science learning, there have been a number of studies on argumentation and writing since 2000. The 2007 Korea national science curriculum indicated the importance of writing and discussion as teaching strategy, the 2009 Korea national science curriculum emphasized writing as a way to understand science concepts and develop scientific literacy (Ministry of Education and Human Resources Development 2007; Ministry of Education, Science, and Technology 2009). For the past 10 years there have been increase in research studies on argumentation and writing in science and significantly since 2008. The majority of the researches were on the development of teaching strategies using argumentation and writing, analysis of argumentation and writing, and examination of the effects of the developed programs. For instances, examination of the effects of argumentation (Lee et al. 2005), analysis of argumentation components and process (Kang et al. 2004), identification of the roles of writing in science education (Jeong et al. 2004), examination of the function of written arguments (Lee et al. 2009), analysis of scientific writing (Park et al. 2007), examination of the effects of writing in science instruction (Nam et al. 2008).

5. **Verbal interaction**

Cognitive constructivism based on Piaget's development theory emphasized student cognition and led researches on interactions between science contents and learners. As researchers identified social context as an impacting factor of learning process and understood that science knowledge can be developed through negotiation according to Vygotsky's social constructivism, they become more interested in teacher–student as well as student–student verbal interactions in science classes. While there were a number of researches analyzing verbal communications in the late Growth period, researches on the analysis of impacting factors on verbal communications were added in the Maturity period. For instances, verbal interactions between teacher and students in middle school science classes, teacher facilitation in student group work, communication levels in each of the scientific inquiry investigations, verbal interactions by the leadership type in a group work, cooperative collaboration for better verbal communication, supporting verbal communications using questioning and feedback strategy, interaction types in a heterogeneous group, and roles of leader in science laboratory classes.

6. **Informal science education**

The informal science education has been emphasized as a way to help students understand science better and keep motivated using various community resources (Osborne and Dillon 2007; Rennie et al. 2003). The 7th Korea national science curriculum recommended diverse filed trips), the 2009 Korea national science curriculum introduced various types of experience-education and emphasized the importance of the informal science education (Ministry of Education, Science, and Technology 2009). With the emphasis, researches on informal education have been increased. For examples, functions of natural history museums, natural history museums in Korea, natural history museum management, education programs provided by the natural history museums in several countries (Lee et al. 2004), perceptions by students, teachers, and parents on the natural history museums (Choi et al. 2004), informal science education and programs in Korea (Song et al. 2004), argument structure of learning materials provided by informal science education (Lee et al. 2005), verbal communications between parents and children in museums (Kim et al. 2007), and teachers' perceptions on using resources from museums (Han et al. 2010).

We have organized our review in terms of four phases that we believe to capture broadly the progress that has been made in science education research in Korea. As we have discussed in the previous section, there have been remarkable progress in both quality and quantity of science education research in Korea last 50 years. It is surely related with social and contextual background in the early period of science education research in Korea. As a result of the ambitious financial and systemic supports, there have been numbers of research in various topics in science education. The increase of research studies on professional development for science teachers and informal science education suggests desirable implications on the development of science education in Korea. To make more advances in science education research in Korea, investigations must carefully take into account of lack of research on diversity and equity in science learning, i.e., culture, race, socioeconomic, and gender differences on student learning science. In line with the results of the TIMSS 2011, attempts should be made to reduce gaps between high academic achievement level and low scientific attitude and understanding of science levels. Also, linking science education research to school science education should be essential to improve the quality of classroom science teaching and learning. With the careful identification of the issues and problems in school science education, advances can be made in science education in Korea, and in turn problems can be solved for reducing gaps between research and practice.

14.3 School Science Education in Korea

The science textbooks that are developed based on the Korea national science curriculum are important resources for science instruction. The national science curriculum, therefore, plays a critical role in school science education and how the rationale of science curriculum is represented in the science textbooks would be dependent on the textbook authors. Considering student levels and learning environment, science teachers are encouraged to reorganize the content presented in the science textbooks instead of simply delivering information as the way how they are presented in the science textbooks. Science teachers consider the aims, lesson goals, student level and characteristics, and plan and implement science lessons so that goals, instruction, and assessment are aligned to each other. Science teacher expertise, the extent to which science teachers are well prepared for effective science teaching would be dependent to the quality of teacher education.

This chapter reviews the changes in school science education with respect to science curriculum, science instruction and assessment, and teacher education for the past 50 years. We will discuss how much researches in science education have influenced on science curriculum, science instruction, and assessment; and science teachers played their roles and had difficulties in working as a profession.

14.3.1 Science Curriculum

The Korea science curriculum has been revised nine times for the past 70 years and there were critical changes for the four revisions. The first change was the 3rd science curriculum in 1974 that was influenced by the science education reforms according to the structure focused approach from the late 1950s to the early 1960s. While previous science curriculum focused on student daily-life experiences and motivation based on the life-adjustment education, the 3rd Korea science curriculum emphasized inquiry-based science learning that adopted the rationale of the knowledge structure and the spiral curriculum. Table 14.5 indicates the changes in the science contents of the middle school science between the 2nd and the 3rd Korea science curriculum (Ministry of Education 2000). The Korea researchers' attention to the national science education reforms such as ESS, SAPA, IPS, PSSC, CHEM Study, and BSCS influenced the revision into the 3rd science curriculum.

Second, the 6th science curriculum in 1992 adopted the trends in science education of the international community as well as the needs for a change. This was different from the change in the 4th and 5th science curriculum as they kept the frame based on the knowledge structure approach. In the late 1980s, the importance of 'Science for All' was emphasized with the Project Synthesis and the Project 2061 in the United States (AAAS 1989). The science education standards in the United Kingdom also suggested 17 achieving goals for 5–16 years old students (DES 1989) and the SATIS (Science and Technology in Society) program was released to emphasize the relationship among science, technology, and society (ASE 1990). In Korea, there were needs for revising the science curriculum to achieve the goals for creative, ethical, and independent citizens in the twenty-first century. With respect to this, the 6th science curriculum in 1992 described the characteristics of the 'science' subject, that is, 'help students to understand scientific concepts, principles, and laws through scientific inquiry investigating natural world and discuss and

Table 14.5 Science contents of the 2nd and the 3rd Korea science curriculum

Grade	The 2nd science curriculum	The 3rd science curriculum
1	Water, air, fire, earth surface, plants, animals	Property of matter, separation of substance, elements and compounds, earth materials and earth surface, types of plants
2	Weather, magnet and electricity, acid, base, salt, food and nutrition, human body, force and movement	Atom and molecule, heat energy, electric energy, solar energy and weather change, living things and environment, nature and human life
3	Light, energy, transportation and communication network, chemical change, hygiene, development and management of resources, evolution of living things, solar system and universe	Chemical change, force and movement, energy conversion, solar system and universe, change of earth surface and earth's history, continuity of life, metabolism

recognize the relationship between science and daily-life.' This statement emphasized the importance of student understanding of the relationship among science, technology, and society as well as inquiry-based science learning. The research studies by Kim (1988), Kwon (1991), and Cho (1991), that indicated the importance of student understanding of the relationship among science, technology, and society in the late 1980s influenced on the attempt of the curriculum revision. Also, research on the integrated science since the 1970s resulted in the introduction of the 'Integrated Science' for grade 10 students to help them develop problem-solving ability through doing research on daily-life and technology-related problems.

Third, the 7th science curriculum in 1997 established the core curriculum for grade 1 to grade 10 students and the selective curriculum for grade 11 and 12 students. While the goal of the core curriculum for all students was scientific literacy, students could take their preferred science subjects selected according to their aptitude and prospective careers in the selective curriculum. Also, the advanced curriculum and the supplementary curriculum were the important feature of the core curriculum. The low achieving students on the core courses took courses from the supplementary curriculum and the high achieving students took courses from the advanced curriculum. The curriculum recommended implementing of the advanced and supplementary curriculum in a class but there were difficulties in implementing both the curriculums in real science classrooms.

Last, there were changes in the recent 2009 revised science curriculum that reestablished the core curriculum for the grade 1–9 compulsory education and the selective curriculum for the grade 10–12. The 2009 revised science curriculum suggested the science content standard according to grade clusters such as grade 3–4, 5–6, and 7–9 instead of each grade level. The significant change in the 2009 revised science curriculum was the integrated approach of the selective 'Science' course for high school students. This approach was based on the need for people capable of creative and integrative thinking in the future of science and technology. Table 14.6 suggests contents of the 'Science' as a selective course.

Table 14.6 Science contents of the 'Science' as a selective course

Universe and living thing	Origin and evolution of universe	Origin of universe, big bang and particles, atom formation, star and galaxy
	Solar system and earth	Formation of solar system, dynamics of solar system, atmosphere of planet, earth
	Evolution of living thing	Birth of living things, evolution of living things, continuity of living things
Science and civilization	Information communication and new materials	Information development, information storage and management, semiconductor and new materials, mineral resources
	Human health and technology	Food resources, scientific health care, advanced science and disease treatment
	energy and environment	Energy and civilization, carbon cycle and weather change, energy issue and future

In summary, there have been continuous attempts of improving science education by revising the science curriculum in Korea. The approach targeted for inquiry-based science education, integrated science, scientific literacy, and selective science courses.

14.3.2 Science Instruction

In which ways has science instruction changed in Korea K-12 science classrooms and how does it look like now? What were the impacts of the research in science education on school science education? Unfortunately it is very difficult to get answers to the questions because there was few long-term and continuous monitoring on school science education. Then, we introduce some aspects of school science education according to the findings of research in science education.

Students and teachers use a selected textbook among several published textbooks although teachers refer to other textbooks. So, science textbooks play a critical role in science instruction in Korea. The extent and scope of motivation, content, assessment, and applications of researches are different across textbooks. For examples, researches on constructivist learning theory, misconceptions/ preconceptions, and conceptual change were applied in the science textbooks developed according to the 6th science curriculum. The science textbooks included a 'Think about' activity that stimulates uncovering student ideas, inducing cognitive conflicts, and identifying problems. However, there was only one textbook that suggested core concepts in each chapter, used an assessment requesting students to draw a concept map, and summarized each chapter using concept map. The science textbooks according to the 2009 revised science curriculum included activities of discussing on socio-scientific issues and arguing in verbal and written forms with claims and evidence. They were based on the researches of argumentation and writing in science. Taken as a whole, researches in science education have been applied in the majority of science textbooks although there were differences in the extent and scope. The description of goals, teaching and learning methods, and assessment in the Korea science curriculum required the authors of science textbooks for applying the results of recent research studies. In order to pass the textbook review, the authors of the science textbooks made efforts to apply the rationale and standards described in the science curriculum. It is promising that in-service science teachers join in writing science textbooks as they have years of teaching experiences and are qualified with master or doctoral degrees in science education.

Regardless of how much good science textbooks are, the quality of science instruction would be dependent to science teacher expertise due to the diversity of teacher background and characteristics. In this respect, it is important to observe and analyze science teaching. Park and Lee (1987) studied the characteristics of high school science instruction and indicated that 92 % of the science teachers used teacher-centered lecture and giving solutions to questions as their teaching methods while 76 % of the science teachers identified inquiry and scientific attitudes as the goals of science education. There was a conflict between teacher understanding of the goals for science education and their methods to achieve those goals. The majority (92 %) of the students wanted to do laboratory experiments in science classes but they (70 %) had opportunities of doing confirmation experiments only one or two times a semester. Cho et al. (1989) also pointed that it was problematic for secondary school students to do simply hands-on activities that led them to follow directions instead of designing experiments. This would be because the majority (70 %) of the science teachers believed that scientific experiments are not related to the college entrance examination. Recently, a study observing high school science classes reported that most class time were devoted for delivering scientific concepts and providing lecture and solutions to questions using summary sheets (KICE 2009). Also, the opportunities of experiments or discussions among students were provided with only one or two times a semester as a formative assessment. The development of assessment questions was for students to be prepared for the college entrance examination and focused on the understanding of advanced concepts as like the college entrance examination.

How do the science instructions in middle schools look like? According to the research comparing Korea middle school science instruction with ones in several other countries (Korea institute of curriculum and evaluation 2008), science teachers planned proper science instruction including diverse student-centered activities based on their understanding of student prior knowledge; and stimulated student interest and motivation to the lessons. Science teachers were provided diverse teaching materials by the local school districts or the science teacher associations and collaborated to reorganize them according to the lesson goal. Students perceived that they engaged in the activities in science classes, had a close relationship with their colleagues, and were treated fairly by their science teachers. According to the survey of class participation, however, only 20 % of the students answered that they participated in questioning, answering, proposing their ideas in science classes. Further, it seemed that there were a few teacher questionings that provoked student cognitive conflicts or high level thinking and the students rarely asked questions to the teachers or with curiosity. These findings were confirmed by a research observing science classes that rarely provided students with opportunities of brainstorming or problem solving. The science teachers were implementing teacher-centered and lecture-based science instruction instead of student-centered and inquiry-based one. According to the interview with the science teachers, they seemed to believe that school science practice should target for clear and accurate answers or conclusions although scientific inquiry is important. The science teachers understood that it is important to help and guide students to construct scientific knowledge through scientific inquiry. Due to the big class size, the amount of the tasks, teacher accountability, and the multiple choice college entrance examination, science teachers considered knowledge delivery important. Because of this complexity of reality in schools, Korea science teachers were not able to achieve good science teaching in a way how they believe for good science instruction.

Then, are these the only factors that lead science teachers to depend on lecture for knowledge delivery, use few provoking questions, and give few opportunities of constructing knowledge and solving problems? Korea science teachers who are well prepared for science instruction are not able to engage students in the lesson. What would be the reasons? Researches indicated that there was a difference in the PCK between what novice science teachers perceived and what they implemented in their science instruction (Ko et al. 2009; Min et al. 2009). The PCK of the science teachers, however, have improved through reflection writing, intensive professional development programs, and interviews to reflect their own experiences. Jang and Choi's (2010) research with experienced science teachers also reported similar findings. In summary, while the Korea science teachers learned knowledge for good science teaching in the teacher education programs, they were not good enough to implement in real science instruction.

The 'TIMSS 2011 report' also indicates the problem related to the science instruction (KICE, 2012). According to the TIMSS 2011, Korea grade 8 students achieved high levels in science. However, their interest to science, perception on science and science learning, and self-confidence were at a low level. This would be the problem that Korea science education needs to solve out. Recently, there was a movement to develop new school system, 'Innovation School' initiated by one school district. The innovation school practices the education of creativity and intelligence in a democratic and autonomous learning community. The innovation school pursues critical thinking instead of knowledge competition; essay writing or process assessment compared to fact memorization; and participation and collaboration with less than 25 students in a class; and democratic decision-making with teacher autonomy. With positive responses from teachers and students, we would expect solving our current problems regarding school science education by the alternative.

14.3.3 Science Teacher Education and Professional Development

Science teacher education includes both pre-service teacher education and in-service teacher professional development programs. The pre-service teacher education should be to guide pre-service teachers to establish the foundations to become good science teachers and the professional development programs for in-service teachers are to help them develop professionalism.

14.3.3.1 Pre-service Teacher Education

In Korea, elementary teachers are trained at university of education and secondary teachers at the college of education in a university. As the students graduate the college of education or university of education, they earn the teacher license and should pass the teacher appointment examination to work as a teacher at public schools. The programs of the pre-service science teacher education included courses of the liberal arts, general education, science education, science content, and student teaching.

The courses related to science education have been required for pre-service teachers since the Korea National University of Education reorganized the curriculum of pre-service teacher education into general education, subject education, subject content, and student teaching in 1985. In planning a new curriculum of pre-service teacher education, the courses of subject education that were not included in the previous one were added to train professional teachers. In this respect, researches developing the contents of science education courses were activated (Cho et al. 1985; Lee 1989; Ministry of Education 1996; Park 1984).

The courses related to science education in pre-service science education programs are comprehensive and diverse now. For instance, a chemistry education program in a university in Korea opens several courses such as theoretical foundations of science education, chemistry education curriculum and assessment, science teaching material development, chemistry teaching material development, student-centered chemistry teaching methods, and actual chemistry instruction, etc. The pre-service chemistry teachers experience a number of activities in each of the courses and are introduced to the recent research studies. Minimum requirements for the pre-service chemistry teachers are three science education courses. Researches on pre-service science teachers suggest several ways to develop pre-service teachers' professionalism (Jang and Choi 2014). However, the number of science education courses that pre-service teachers could take is limited due to time constraint. It would not be enough for pre-service science teachers to develop their professionalism during the pre-service teacher education. In this respect, the professional development programs for in-service science teachers would be essential for achieving excellence in science teaching.

14.3.3.2 Professional Development for in-Service Teachers

Taking a few courses of science education during the pre-service science education would not necessarily result in science teacher professionalism. Without teaching experiences, the pre-service teachers would not fully understand the rationale of the courses related to science education and the importance of science education compared to science content. Therefore, the professional development for in-service science teachers would be essential and effective. Especially the novice in-service teachers have strong desire to develop their professionalism as they recognize lack of pedagogical content knowledge through their teaching experiences.

The professional development programs for in-service science teachers included programs provided by local school districts, education of the master or doctoral programs, and teacher-organized seminars. Most programs by school districts are provided during summer or winter break and the online sessions during academic semesters. Some professional development programs such as science laboratory experiments are requirements for teachers to take as they are essential for teaching science. There are also a number of programs for developing teacher professionalism or teacher self-determined professional development. Teachers get financial support to take professional development programs and the course credit can be counted to get promoted or merits. In this respect, the majority of science teachers take courses as professional development programs for promotion, professionalism, and self-development

There are a number of in-service teachers who study in the graduate program. For instance, 40 % of secondary teachers have master or doctoral degree. In the master program in science education, science teachers study hard for better understanding of the alignment among goals, instruction, and assessment as well as science education curriculum. Further they aim for excellence in teaching practice. They conduct research on teaching and learning and earn master degree with confidence on theory and practice of science teaching and learning.

One of the critical characteristics related to teacher professionalism is enthusiasm. Science teachers who are enthusiastic for better science teaching join the local science teacher associations and have self-organized meetings or seminars. The science teacher associations collaborate to develop science teaching and experiment materials and share them with others through the website of the teacher association. Some science teacher associations open summer or winter sessions of science laboratory experiment for voluntary participant science teachers. According to the survey by the TIMSS 2011 (KICE 2012), Korea science teachers' participations in the professional development programs were relatively high compared to the international one. This indicates the Korea science teachers' active and passionate efforts for better science teaching.

14.4 Summary

Although the history of research in Korea science education was not long, there has been an expansion in the depth and width of research in science education. The field researches as well as the theoretical researches have been conducted for the last 20 years. Then, how much did the research in science education influence on school science education? We would argue that the impacts of research in science education on science curriculum and teacher education were immediate and significant. That was probably because researchers in science education participated in the curriculum development and teacher education. However, the research in science instruction would slowly influence on K-12 school science education then it would take quite a long time for significant differences. It is challenging for science teachers to make changes in school science education because of the complex social and cultural components such as accountability, parent perception, and social expectation.

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Chapter 15
Trends in Science Education Research in Turkey: A Content Analysis of Key International Journals from 1998–2012

Sibel Erduran and Ebru Zeynep Mugaloglu

Abstract Science education research in Turkey has grown at a rapid pace in the last decade. Increasingly, there is enhanced participation at key international conferences and publications by academics as well as junior researchers. The purpose of this chapter is to review recent trends in science education research in Turkey. The research literature reviewed includes some reference to local journals, dissertations and more widely, the national context of Turkey in terms of the higher education and research policies. The empirical aspect of the chapter is based on a study of trends in the coverage of research papers originating from Turkey in the top journals of *Journal of Research in Science Teaching, Science Education* and *International Journal of Science Education*. Trends from 1998 to 2012 will be presented in terms of authorship, institutional affiliation and topics researched among others. Results will be discussed and implications of contributions of science education research from Turkey to academic communities in Asia will be outlined.

15.1 Introduction

There is widespread observation that the science education research community has had much participation by scholars from Turkey in the past few decades (e.g. Lee et al. 2009). Take, for instance, Lee et al.'s (2009) observation that Turkey was one of the top 10 countries in terms of the number of papers published in top science education research journals from 2003 to 2007. Whilst only in the 1990s one could not find a Turkish name in a programme of an international conference or a journal,

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at the current time, there is an increasing presence of researchers at key events. Indeed, a similar observation can be stated about the fact that until fairly recently, it would have been difficult to locate an international conference in Turkey, which has now hosted some key conferences including the 2007 biannual conference of the *European Science Education Research Association* and the 2004 conference of the *International Conference of Chemical Education*, among others.

One might ask what has contributed to the emergence of science education researchers in Turkey in the world stage. This is a rather complicated question which would probably demand a book to be dedicated to a serious multifactorial analysis of the development of the science education field in Turkey. In this chapter, we will instead concern ourselves with a more confined question that elicits the nature of the participation in terms of research outputs. In other words, while it is now widely observed that there are academics from Turkey participating in key conferences and publications, the precise nature of these dimensions with respect to high quality publications remain unstudied. Our intention is to contribute to the literature through identification of the nature of the research outputs in top international science education research journals.

We will focus on the outputs of science education researchers in Turkey from 1998 to 2012 appearing in *International Journal of Science Education, Science Education and Journal of Research in Science Teaching*. Our choice of the timeframe as well as the journals is due to the existing studies that highlight trends in science education research more broadly in timeframes that overlap with our study (Erduran et al. 2015; Lee et al. 2009; Tsai and Wen 2005), giving us the opportunity to compare the observed trends in Turkey with the broader research community. Lee et al. (2009) examined trends in these journals from 2003 to 2007 as a follow up on the Tsai and Wen's (2005) earlier publication covering 1998–2002.

15.2 Theoretical Background

The Turkish education system has been undergoing reform efforts since the birth of the Republic in 1923. For instance, recent decades have witnessed considerable overhaul of curricular reform in part to align the Turkish education system with the European Union provision (Ayas 2012). Within higher education, Turkey's education policy has also coincided with the broader political will to join the European Union. On 3 October 2005, EU accession negotiations were opened with Turkey, which had been an associate member since 1963 and an official candidate since 1999. Turkey's progress in harmonising its laws with the European Union has been monitored. Education is one of the 35 distinct areas where discussions have been taking place. An EU report on Turkey has dedicated several chapters to education including research. Turkey has also been actively engaged in the Bologna initiative.

Despite the recent reforms in education, access to higher education remains a significant problem in Turkey:

> Turkey's participation rate in higher education is significantly below the enrollment rate in higher income countries, including North America and Western Europe (see Figure 5). Turkey's gross enrollment rate is about half the rate of most countries in Western Europe (generally in the 55-65 percent range) and less than half of the rate for Australia (72 percent), the United States (82 percent) and Korea (89 percent). (World Bank 2007, p. 12)

A *World Bank* report (2007) summarises some of the key strategies for higher education in Turkey in recent years. For instance, according to this report, *Higher Education Strategy for Turkey* was developed by the Higher Education Council (YÖK) in Turkey after "examining international experience in higher education across the globe and discussing and debating issues with stakeholders in Turkey" (p. 4). The higher education strategy identified increased expectations for higher education in a global, knowledge economy. The report also highlights *The Ninth Development Plan,* which provides "an overall strategy and direction for Turkey from 2007 to 2013… which emphasizes the need for a lifelong education strategy to ensure individuals have the skills needed for a changing and developing economy and labor market" (p. 5).

The key strategic directions for higher education as specified by the higher education strategy for Turkey developed by the Higher Education Council (YÖK) include statements that are mainly targeted for teaching, employability of graduates and institutional contexts as illustrated by the following key points from the strategy:

- increase access and participation in higher education;
- develop an appropriate financing strategy to provide sufficient resources and to realise strategic objectives;
- diversify education system in a flexible and open manner to allow institutions more autonomy and ability to adapt to changing conditions;
- increase the employability of graduates and contribute to regional and economic development
  (World Bank 2007, p. 5).

The *Ninth Development Plan* has specific priorities for higher education which also emphasise teaching, institutional contexts but also set out to define some principles of operation as well as goals for research:

- increase student contributions provided that grants and loans are available to help students meet the costs and to ensure ***equal opportunities***;
- permit private higher education if a system of quality assurance is set up and the entrance examination system is changed to increase the effectiveness of the system;
- restructure the role of the YOK to be responsible for setting standards, coordination and planning;
- provide administrative and financial autonomy to institutions along with ***transparency, accountability and mission diversification***;
- improve and ensure quality of higher education institutions and students;
- increase the number of graduate students and ***university research***
  (World Bank 2007, p. 5, emphasis is authors').

In the context of these recent developments in higher education sector, science education has seen growth. Apart from the YOK provision, TUBITAK, the Turkish Science and Technological Research Council of Turkey, has been an instrumental body funding a whole range of research projects in the physical sciences as well as science education. Both institutions have encouraged and funded participation at international conferences as well as short and long term sabbaticals in overseas institutions.

It is not surprising, then, that in the dynamic state of higher education and research funding, the science education research community in Turkey have grown in the past decade. Numerous reviews have been carried out to specify the nature of science education research in Turkey (e.g. Sozbilir et al. 2012; Sozbilir and Kutu 2007; Turkmen and Bonnstetter 2007) although numerous of such reviews are in Turkish (e.g. Bag et al. 2002; Sozbilir and Canbolat 2006). Sozbilir et al. (2012) has summarised the works of researchers in Turkey published in numerous international and national journals. Some of the recent trends in science education research in Turkey include the observation that there has been a major upsurge of work in this area. According to Lee et al. (2009), Turkey was not in the top 10 countries for 1998–2002 period but ranked 9th for the 2003–2007 time period in terms of the number of papers in top journals.

It is beyond the scope of this chapter to interrogate the various sources of publications that the science education research community functions in Turkey. Our primary intention is to explore the international dimension of such research, with an emphasis on mapping existing trends in the broader science education research literature globally. Towards this aim, we focus on some top science education journals that have, historically, had consistent high impact in the Social Sciences Citation Index. In a similar vein as Tsai and Wen (2005), Lee et al. (2009) and Erduran et al. (2015), we focus on the *International Journal of Science Education* (IJSE), *Science Education* (SE) and *Journal of Research in Science Teaching* (JRST) to investigate the trends in the work of science education researchers from Turkey between 1998 and 2012.

15.3 Methodology

The purpose of the study was to trace the trends in the publications that were produced by science education researchers in Turkey. The study was guided by the following overall question:

> What are the trends in the publications produced by science education researchers in Turkey between 1998-2012 in top science education journals SE, IJSE and JRST?

In order to address the question, we have carried out analyses of all issues of SE, IJSE and JRST from 1998 to 2012. content analysis of the mentioned journals have been previously conducted for other purposes (e.g. Erduran et al. 2015; Lee et al. 2009). Our analysis was guided by an initial selection of papers on the basis of the names of the authors in each paper that appeared in every issue. In other words, we traced the content of each issue and if there was a Turkish name in the authorship in any order, we selected the paper for inclusion in our data pool. Authors' affiliations and the abstracts were also noted. The purpose of the affiliation information was to determine the nature of research cultures and collaborations that publications originating from Turkey are contextualised in. We also wanted to distinguish authors with Turkish names who are based in universities in Turkey and those who are based elsewhere in the world to trace the trends in the Turkish diaspora in the science education research community (Appendix). Once the abstracts were noted, we have also traced the topics that were emphasised in the papers as well as the methodology followed. We have used a list of topics that Tsai and Wen (2005) generated and which was replicated by Lee et al. (2009) to analyse the trends in the science education research appearing in the same journals that overlaps with the timeframe that we investigated.

15.4 Results and Findings

Our analysis of SE, JRST and IJSE from 1998 to 2012 illustrates several overall trends. First, it is noteworthy to highlight that from 1998 to 2001 inclusive, there were no publications originating from Turkey in any of these journals (Table 15.1). There were only two publications in 2002 and 2003 in the three journals. The number of publications began to pick up from 2004, peaking in 2009.

A second trend is that if the data are organised around 5 year periods (see Fig. 15.1), there is considerable increase in the number of publications appearing in

Table 15.1 Number of publications in JRST, IJSE and SE originating from Turkey between 1998 and 2012

Year	JRST	IJSE	SE	Total/year
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0
2001	0	0	0	0
2002	1	0	0	1
2003	0	1	0	1
2004	3	2	2	7
2005	2	2	0	4
2006	0	5	2	7
2007	1	4	0	5
2008	3	4	0	7
2009	2	7	2	11
2010	2	5	0	7
2011	1	5	0	6
2012	0	4	0	4
Total/journal	15	39	6	60

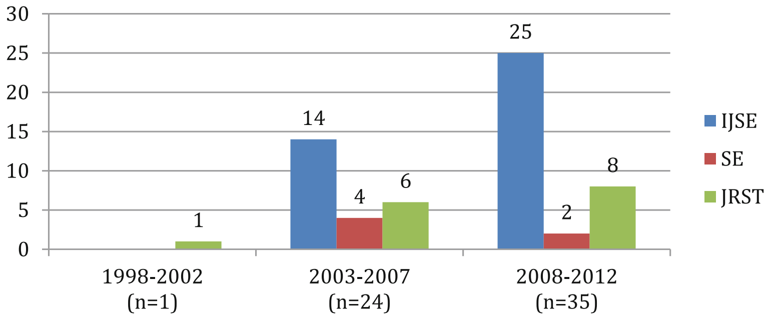

Fig. 15.1 Number of publications in each journal in 5 year periods

IJSE and JRST. There are a limited number of publications from Turkey appearing in SE, and most authors were publishing in IJST. For each trend, both are reported to illustrate the quantitative and the qualitative descriptions.

A third trend concerns the distribution of universities in Turkey where the authors are affiliated (see Fig. 15.2). Middle East Technical University (METU) in the capital Ankara leads by a great difference in the number of publications produced. Considering the historical context of this university as an English-medium, selective and Western-minded institution, this outcome is not surprising. Furthermore, in 2001, METU in cooperation with State Planning Organization established the Faculty Development Programme (ÖYP) to train academics for Turkish Universities. The ÖYP was run by METU until 2010 and since then has been run by Turkey's Higher Education Council (YOK). Within this project, many students have been enrolled in Master's and PhD programs at METU, and worked as research assistants during their education. As of 2013, 571 research assistants are in the process of doing their PhDs at METU within the framework of ÖYP. This provides METU with a substantial research capacity compared to other universities.

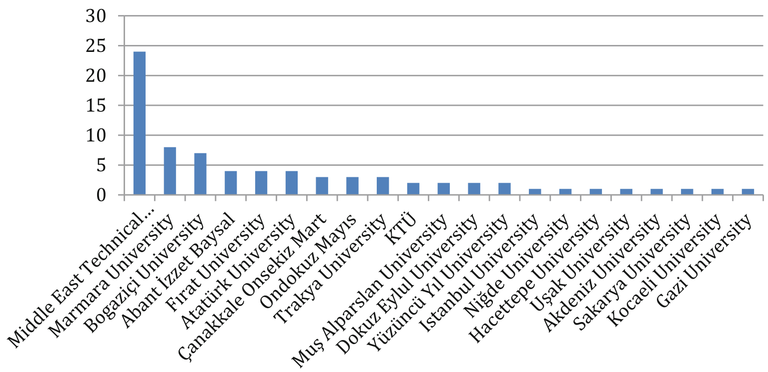

Fig. 15.2 Distribution of authorship in terms of number of publications across universities in Turkey

Take for instance the number of research assistants at the department of elementary education in the science education programme. As of 2013, there are 27 research assistants at METU Elementary science education programme while the number of research assistants at, for instance, Boğaziçi University, another english-medium university, primary science education programme is 2. It is also worthwhile to note that the frequency of contributions from METU could have been even higher considering that it is likely some of its research assistants indicated their subsequent university affiliation after graduation rather than METU where they conducted the research resulting in the publication. The comparatively higher number of publications emerging from Marmara University is interesting to note too, given that this university operates in Turkish.

A further observation in the data concerns the sequence of authorship in the publications originating from Turkish universities. In 60 publications, 86 Turkish names appeared in various rank of authorship. 52 of the total 60 publications were first authored with Turkish names. 22 authors with Turkish names were second and 11 of them were third authored in the papers. Regarding authorship, it should be noted that there were authors with Turkish names who have been employed in universities in the United States of America and United Kingdom whose publications were also traced. A total of 10 publications were identified with affiliations such as University of Georgia, Florida State University and University of Bristol.

In a further line of analysis, we were interested in tracing the topic of the publications that were generated by science educators in Turkey (see Fig. 15.3). Forty-five per cent of the papers concerned learning about students' conceptions and attitudes. This is followed by papers on teaching (15 %), policy and curriculum (10 %) and learning contexts (10 %). It is important to note that there were no publications that focused on informal learning and the coverage of teacher education (3 %), cultural, social and gender issues (3 %) was low. Our reference to the topics was guided by a categorisation scheme developed by Lee et al. (2009), who identified key trends in the same journals at overlapping timeframes. Both authors of the chapter read the abstracts of each publication and independently categorised the papers into the research topics. We had minimal disagreement which was resolved through discussion.

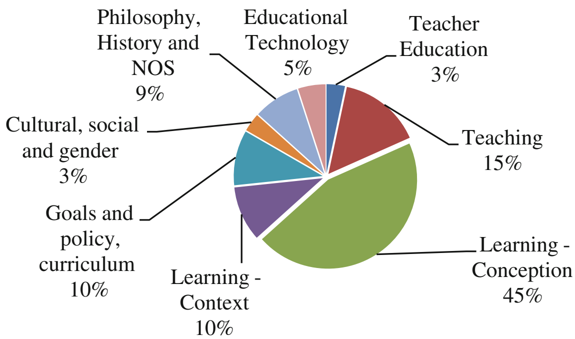

Fig. 15.3 Research topics studied by science educators in Turkey from 1998 to 2012 as published in SE, IJSE and JRST

Our analysis can be contrasted with the broader trends in the research literature as reported by Lee et al. (2009). For the timeframe 1998–2007, the most number of papers reported by Lee and colleagues were about learning contexts (20.8 %) whereas learning conceptions dominated the publications from Turkey (56 %). Overall there was not as much variety in the distribution of topics covered by researchers in Turkey as compared to the broader community. Although learning conceptions was studied to a similar extent as learning contexts in the broader literature (19.8 % vs. 20.8 %), the contrast in Turkey-based publications were quite strikingly different (56 % vs. 8 %). Similar trends can be seen for the topics of goals, policy, curriculum and cultural, social gender issue. Since Lee and colleagues' paper only covered years up to 2007, we do not have a way of comparing the subsequent trends we observed in our sample with the broader literature on these journals (Table 15.2).

We have also traced the methodological approaches reported in each paper. The majority of the papers used quantitative methodology followed by mixed quantitative and qualitative methodology. These results are consistent with a previous

Table 15.2 Comparison of frequencies and percentages of research topics between 1998 and 2007 for the three journals (IJSE, SE, and JRST)

	1998–2007 (*n* = 1671) all publications		1998–2007 (*n* = 25) publications from Turkey	
	n	%	*n*	%
Teacher Education	133	8.0	0	0.00
Teaching	174	10.4	5	20.0
Learning conception	331	19.8	14	56.00
Learning context	347	20.8	2	8.00
Goals and policy, curriculum	219	13.1	1	4.00
Cultural, social and gender	174	10.4	1	4.00
Philosophy, History and NOS	139	8.3	1	4.00
Educational Technology	74	4.4	1	4.00
Informal Learning	76	4.5	0	0.00

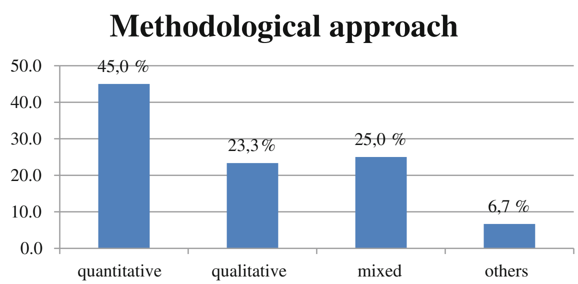

Fig. 15.4 Methodological approaches utilised by science educators in Turkey from 1998 to 2012 as published in SE, IJSE and JRST

study conducted by Sozbilir et al. (2012) where a more detailed profile of research methodology, particularly the types of quantitative methodology, was reported. In our analysis, all the studies were empirical in nature except for one which was a theoretical critique (Fig. 15.4).

15.5 Conclusions and Implications

The trends in the research literature on science education in Turkey illustrate that some of the key topics studied by science education researchers in Turkey are not in line with the broader community trends. For instance, the relatively strong emphasis on student conceptions and attitudes seems to be outdated considering the decline in this line of research in science education. There is also a limited number of papers published in *Science Education* among the three journals. Lee et al. (2009) had indicated that this journal published relatively more theoretical papers than IJSE and JRST. Our analysis has also indicated that the majority of the papers published in these journals were empirical in nature, with only one paper that was a theoretical critique.

According to Lee et al. (2009), Turkey was not in the top 10 countries for 1998–2002 period but ranked 9th for the 2003–2007 time period for coverage of papers in SE, IJSE and JRST. Our data illustrates that the growth has continued beyond this period to 2012. Our analysis, as well as the reviews conducted by other researchers (e.g. Sozbilir et al. 2012), demonstrates an inspiring story of the rise of the research culture in science education in Turkey in the last decade. This is particularly encouraging considering the constraints that remain on academics in Turkey. Consider the evaluation of the higher education sector in Turkey by a World Bank report which describes the rigidity of the sector:

> As a result of rigidities throughout the system in Turkey, little differentiation exists in the missions and purposes of institutions of higher education in Turkey. Ninety-five per cent of students attend public institutions, all of which operate on the same model. Most public institutions in Turkey have been developed as though they are or will be research universities even though the level of research is low at most institutions and the size of postgraduate education is small. Even for foundation (private) institutions, many of the requirements are set in the same model (World Bank 2007, p. 10).

A key factor in the diversification of the higher education sector will need to entail the formulation of communities of practice (Lave and Wenger 1991) whereby teams of science educators consisting of senior academics, early career researchers and postgraduate students work together in an apprenticeship model to develop respective expertise through collaborative learning. An example project that has taken on this mission was conducted by the lead author at Bogazici University during her fellowship funded by TUBITAK-EU Marie Curie Brain Circulation Scheme (Erduran 2013, 2014). Early career researchers from two other institutions (Ebru Kaya then at Selcuk University and Deniz Saribas from Istanbul Aydin

University) were invited to participate in the project along with the second author, Ebru Z. Mugaloglu and a senior American academic, Zoubeida Dagher, from University of Delaware (e.g. Erduran, Kaya & Dagher in press). Master's students were also occasionally at the meetings. The work of the team has been presented at the 2015 NARST conference in Chicago, and the junior researchers have already published an ethnographical account of their involvement (Saribas and Ceyhan 2015), itself involving a rather scarce methodological approach in the Turkish science education research context. The researchers had various strengths, for instance, in terms of teacher education and quantitative methodology. The meetings, documentation and correspondence operated with the principles of transparency and goal-oriented actions. The ownership of ideas and division of labour were negotiated within the team to ensure positive team spirit. Cross-institutional collaboration, international links and distributed expertise that operate with such values can, in unison, potentially contribute to the development of creative and inclusive research cultures in Turkey.

Our study is inherently limited in terms of the focus on the particular journals. As reported elsewhere (Sozbilir et al. 2012), there are countless other international, as well as Turkish, science education research journals. A main observation about the publication culture in Turkey is that many universities have their established journals, For instance, *Bogazici Journal of Education, Dokuz Eylul University Journal, Uludag University Faculty of Education Journal*. There is indeed a plethora of journals that have emerged in the past few decades both in Turkish (e.g. *Fen Egitimi ve Arastirmalari Dergisi*) and in English (e.g., *Eurasia Journal of Mathematics, Science and Technology Education* and *European Journal of Science and Mathematics Education*). As the culture of science education research is shaped towards a more collaborative version (for instance through more autonomous universities with more rewards for collaborative work), we anticipate that the journals, particularly the education faculty-based journals, will be streamlined to ensure quality and competitiveness of the manuscripts.

The future agendas for science education research in Turkey will need to acknowledge the requirements of funding agencies (e.g. She et al. 2009), in particular those of the international funders, if the research is to have international appeal. Recent trends in funding agencies' priorities, for instance the European Union's new Horizon 2020 scheme, illustrate the need to form closer links with industry partners. Conventionally the links with academia and industry have been limited in Turkey, according to the World Bank report:

> The survey also highlighted how little the private sector knows about higher education and likewise how little higher education knows about private firms. Interestingly, while firms were very critical of universities, a majority of firms—55 per cent—admitted that they had not attempted any relations or partnerships with higher education (see Table 4). In fact, neither side seemed to have a good idea of how the other party might help. As a result of poor information on both sides, partnerships between the private sector and higher education are indeed rare in Turkey. In addition, when mechanisms do exist for partnerships, they tend to exist more on paper than in practice and to have occurred as a result of personal relationships. (World Bank 2007, p. 20)

The prominence of Middle East Technical University in the contribution of the number of publications demonstrates the immediate impact of some national policies on research outputs. The case study of this university and its dealings with capacity building could provide a model for other universities both in Turkey and elsewhere.

In summary, the case of Turkey can set an example for the higher education sector in Asia, as this book aims to explore. As a country that spans both the European and the Asian continents, Turkey is well placed to problematise the tensions and opportunities in higher education in a global knowledge economy. If the future policies and funding priorities in Turkey address some of the current limitations of the system, there is likely to be even further growth in science education research with wider contributions to science education globally.

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Appendix

Summary of authorship and affiliation of papers published in SE, IJSE and JRST between 1998 and 2012 originating from Turkey and Turkish named authors working overseas.

Journal name	Year	Author	Affiliation
IJSE	2008	Ajda Kahveci	Marmara University
IJSE	2010	Ajda Kahveci	Çanakkale Onsekiz Mart University
IJSE	2011	Ahmet Ok	Middle East Technical University
IJSE	2008	Aytekin Cokelez	Ondokuz Mayıs University
IJSE	2007	Bugrahan Yalvac	Nortwestern University
IJSE	2007	Ceren Tekkaya	Middle East Technical University
IJSE	2011	Ceren Tekkaya	Middle East Technical University
IJSE	2012	Deniz Kahriman-Ozturk	Middle East Technical University, Mersin University
IJSE	2011	Diba yılmaz	Middle East Technical University
IJSE	2005	Dilek Ardaç	Bogazici University
IJSE	2007	Elvan Kahyaoglu	Middle East Technical University
IJSE	2009	Emine Adadan	Bogazici University

(continued)

(continued)

Journal name	Year	Author	Affiliation
IJSE	2012	Emine Adadan	Bogazici University
IJSE	2006	Esen Uzuntiryaki	Middle East Technical University
IJSE	2012	Eylem Bayır	Trakya University
IJSE	2012	Fatih Çağlayan Mercan	Bogazici University
IJSE	2007	Feral Ogan-Bekiroglu	Marmara University
IJSE	2009	Feral Ogan-Bekiroglu	Marmara University
IJSE	2011	Feyza T. Erden	Middle East Technical University
IJSE	2004	Filiz Kabapınar	Marmara University
IJSE	2012	Funda Savaşçı	İstanbul University
IJSE	2012	Gaye Tuncer	Middle East Technical University
IJSE	2009	Giray Berberoglu	Middle East Technical University
IJSE	2006	Gultekin Cakmakci	Hacettepe University
IJSE	2003	Gülşen Bağcı Kılıç	Abant İzzet Baysal University
IJSE	2008	Ibrahim Erdogan	Muş Alparslan University
IJSE	2011	Ibrahim Erdogan	Muş Alparslan University
IJSE	2009	Ilker Kalender	Middle East Technical University
IJSE	2007	İbrahim Erdogan	Fırat University
IJSE	2007	Jale Cakiroglu	Middle East Technical University
IJSE	2010	Lutfullah Türkmen	Uşak University
IJSE	2011	Mehmet Erdoğan	Akdeniz Üniversitesi
IJSE	2007	Murat Günel	Ataturk University
IJSE	2006	Murat Sağlam	Dokuz Eylül University
IJSE	2008	Mustafa Sami Topcu	Yüzüncü Yıl University
IJSE	2010	Mustafa Sami Topcu	Yüzüncü Yıl University
IJSE	2006	Nurtaç Canpolat	Atatürk University
IJSE	2009	Omer Faruk Ozdemir	Middle East Technical University
IJSE	2009	Osman N. Kaya	Fırat University
IJSE	2011	Osman Titrek	Sakarya University
IJSE	2008	Ozgul Yilmaz-Tuzun;	Middle East Technical University
IJSE	2010	Ozgul Yilmaz-Tuzun	Middle East Technical University
IJSE	2006	Ozgur Taskin	Ondokuz Mayıs University
IJSE	2009	Ozgur Taskin	Ondokuz Mayıs Üniversitesi
IJSE	2010	Ömer Acar	Kocaeli University
IJSE	2010	Özcan Gülacar	Southern Connecticut State University
IJSE	2004	Özgün Yılmaz	Middle East Technical University
IJSE	2007	Recai Akkuş	Abant İzzet Baysal University
IJSE	2012	Refika Olgan	Middle East Technical University
IJSE	2011	Sema Sönmez	Abant İzzet Baysal University

(continued)

(continued)

Journal name	Year	Author	Affiliation
IJSe	2011	Semra Sungur	Middle East Technical University
IJSE	2005	Sevil Akaygun	Bogazici University, İstanbul
IJSE	2010	Sibel Kaya	Florida State University
IJSE	2009	Şebnem Kandil İngeç	Gazi University
IJSE	2006	Yezdan Boz	Middle East Technical University
IJSE	2005	Yilmaz Cakici	Trakya University
IJSE	2012	Yilmaz Cakici	Trakya University
JRST	2010	Abdülkadir Demir	University of Georgia
JRST	2007	Ahmet Aypay	Çanakkale Onsekiz Mart University
JRST	2002	Ali Eryılmaz	Middle East Technical University
JRST	2004	Ali Eryılmaz	Middle East Technical University
JRST	2005	Alipaşa Ayas	Karadeniz Technical University
JRST	2009	Cuneyt Ulu	Marmara University
JRST	2004	Dilek Ardac;	Bogazici University
JRST	2009	Gokhan Ozdemir	Niğde University
JRST	2008	Hasan Deniz	University of Nevada
JRST	2008	Irfan Yilmaz	Dokuz Eylül University
JRST	2005	Muammer Çalık	Karadeniz Technical University
JRST	2007	Mehmet Erdoğan	Middle East Technical University
JRST	2007	Mehmet Sözer	Çanakkale Onsekiz Mart University
JRST	2009	Murat Gunel	Ataturk University
JRST	2008	Nihal Dogan	Abant Izzet Baysal University
JRST	2010	Osman N. Kaya	Fırat University
JRST	2011	Osman N. Kaya	Fırat University
JRST	2004	Selen Sencar	Middle East Technical University
JRST	2004	Sevil Akaygun	Bogazici University
JRST	2008	Sibel Erduran	University of Bristol
JRST	2004	Sibel Erduran	University of Delaware
JRST	2005	Yılmaz Sağlam	Purdue University
SE	2006	Murat Gunel	Ataturk University
SE	2004	Özgül yılmaz	Middle East Technical University
SE	2006	Serhat İrez	Marmara University
SE	2009	Serhat İrez	Marmara University
SE	2004	Sibel Erduran	University of Delaware
SE	2006	Şevket Gündüz	Marmara University
SE	2009	Yavuz Saka	Florida State University

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Chapter 16
Development of Chemistry Education Research (CER) in Turkey: A Comparison of CER Papers with International Research

Mustafa Sozbilir, Mustafa Akilli, M. Diyaddin Yasar and Hulya Dede

Abstract Chemistry education research (CER) ranges from understanding the history and philosophy of chemistry, which guides on us how chemistry knowledge was developed, to the developments and application of modern technologies and tools for a more effective teaching of chemistry. CER plays a mediator role in translating recent discoveries in the field of chemistry into content that can be understood by students. Like in many academic disciplines, it is necessary for chemistry educators to pause periodically and take stock of what kind of research we are doing and where chemistry education is going. A content analysis of research papers can guide scholars with a strong indication of the extent to which journal editors and scholars prioritize research in the chemistry education field and whether there have been changes in the subject matters studied and research methods employed over time. This chapter focuses on the development of research in chemistry education in Turkey through a content analysis of 1338 research papers published in peer-reviewed journals and compares it to international research published in high status journals that publish CER. It starts with a brief introduction to the Turkish education system and teaching chemistry as a discipline in Turkey. Attention then moves to the research in chemistry education in the world and Turkey. Content analyses of CER papers published by Turkish chemistry educators are compared with CER published by highly respected international journals. The results indicated that although CER has showed a visible increase in Turkey since

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2000 and the number of national and international publications is increased, there are still problems with publishing high quality research papers in respected international journals. The chapter concludes with a discussion on the status and future of CER in Turkey.

16.1 Introduction

Chemistry is a central part of science taught throughout the world from secondary to tertiary level as a separate subject, while it is also covered in science courses starting from the early years. Chemistry education (or chemical education) is concerned about teaching and learning of chemistry. As stated by Tsaparlis (2003), chemistry and chemistry education are closely related, and so is the research in the two fields. So it can be easily said that chemistry education lies somewhere in between chemistry as a science and educational sciences. Its research interests range from understanding the history and philosophy of chemistry, which guide us on how chemistry knowledge was developed to the developments and application of modern technologies and tools to teach chemistry effectively. It is a specific subdiscipline of chemistry that requires bringing elements of human learning theories together with the particular chemistry content to facilitate learning. Chemistry education as a science should be continuously developed based on research widely carried out. Teo et al. (2014) cited different ideas from Kornhauser (1979); Bunce and Robinson (1997); Herron and Nurrenbern (1999) and Bodner (2005) and emphasized that these ideas underscore the point that chemistry education research (CER) should be honored as a unique domain in its right. CER has to play a mediator role in translating recent discoveries in the field of chemistry into content that is easy to understand by young people at school.

One way to study the development of a discipline is through an analysis of papers in the field (Bodner and Towns 2010). So like in other many disciplines it is necessary for chemistry educators to pause periodically and take stock of what kind of research we are doing and where chemistry education is going. A content analysis of research papers guide scholars with a strong indication of the extent to which journal editors and scholars prioritize research in chemistry education field and whether there have been changes in the subject matters studied and research methods employed over time. Such information may serve to establish dominant research agendas or serve to motivate researchers to employ diverse needs and seek new ways of knowing. It may also increase dialog among researchers. A content analysis may serve to challenge the chemistry education field to reexamine subject matters studied and make decisions regarding the future of its position regarding publication of various research methods (Stead et al. 2012). This chapter focuses on the development of research in chemistry education in Turkey through a content analysis of research papers published in peer-reviewed journals and compares it to international research published in high status journals that publish CER. It starts with a brief introduction to the Turkish education system and teaching chemistry as a discipline in Turkey. Attention then moves to the research in chemistry education in the world and Turkey. Finally, content analyses of CER papers published by Turkish chemistry educators are compared with the CER published by the highly respected international journals.

16.1.1 Turkish Education System and Introduction of Modern Chemistry

Turkey, with a population over 76 million (Turkish Statistical Institute [TUİK] 2014), is a bridge between Europe and Asia. Following the collapse of Ottoman Empire after the First World War, the Republic of Turkey was established in 1923. Several reforms were taken in almost every area of the state. Educational development has been regarded as the most important factor for development since the foundation of the new state (Grossman et al. 2007). A state supervised system designed to produce a skillful professional class for the social and economic welfare of the nation has been established (Özelli 1974). Since then, several reforms in the education system have been introduced, including the acceptance of Latin characters instead of Arabic characters as the official script in 1928, expansion of secularism in the social, educational, and legal areas (Turkmen and Bonnstetter 2007), implementation of new curriculums (Ayas et al. 1993; Turkmen and Bonnstetter 2007). In addition, reforms in teacher training (Turkmen 2007), have been implemented and the results of these reforms have been impressive (Grossman et al. 2007). The current school system is consisted of four main components: primary schools (age 5–10; 5 years including one year optional preschool education), middle schools (age 11–14; 4 years), high schools (lycees or senior high schools including vocational and technical schools, age 14–18, 4 years); and higher education (universities). Since 2011, compulsory education has been 12 years.

Modern chemistry was not introduced until the nineteenth century, although the earliest teaching of chemistry probably occurred at the Imperial Military Engineering School, which opened in 1795 (Dölen 2013). It is argued by Dölen that the introduction of modern chemistry in Turkey can be traced back to the publication of the book *Usûl-i Kimya* [Elements of Chemistry], the first independent chemistry book written by Dr. Mehmed Emin Dervish Pasha in 1848. The book describes the content of chemistry of the period quite well. Initially chemistry was taught to medical, military, and pharmacy school students either as a separate discipline or as part of their science curriculum. During World War I in 1915, three chemistry professors among 20 Chemistry professors were brought in from Germany. They established the Institute of General and Industrial Chemistry in 1917, through which chemical education was independently organized and "Chemist" certificates were awarded. This movement is accepted as a milestone in the establishment of chemistry as a discipline in Turkey at the undergraduate level, although these professors left Turkey after the war. Chemistry education continued under the control of Turkish professors until the university reforms of 1933. In 1933, Istanbul University was reorganized and again numerous German refugee professors were hired. The influence of German professors in chemistry education continued until the 1950s. Following Istanbul University, the first university of Turkey, new universities were opened gradually. Currently, Turkey has over 170 state and private universities and over 80 of them provide chemistry or chemistry-related studies. Regarding chemistry teacher training, there are 13 different departments that provide five-year-long training for chemistry teachers. There is also a year-long certification program that provides a teaching certificate to those students who graduated from chemistry and/or chemistry-related departments.

Teaching chemistry in schools does not have as long a history as teaching chemistry in universities. After the foundation of Turkish Republic, several reforms were put in place, among them development of curricula for the new school system. In this new curriculum, chemistry was taught as part of general science. It was not until 1937 that chemistry began to be taught as a separate subject in schools as a result of European and American influence in education (Ayas 2013). During the Second World War and the years up to the 1960s there was little progress of teaching chemistry in schools. Together with the Cold War Era, US-based curricula and chemistry books were imported into Turkey; initially directly used, but later they were adapted to local conditions and used until the 1980s. A new curriculum development movement started in the 1980s and new programs were developed with local necessities in mind.

In the 1990s, a major effort to improve the educational system was made through a multi-phased comprehensive reform project titled the National Education Development Project (NEDP). The project was developed as another step to improve the quality of teacher education in Turkey. It was implemented under the loan agreement concluded between the Turkish government and the World Bank. NEDP, was funded by the World Bank and administered by Higher Education Council [YÖK] (Grossman et al. 2007). The objective was to contribute to the improvement of preservice teacher education. In 1997, as part of an effort to improve preservice teacher education, schools of education in universities were restructured to include more educational research components in the previously science dominated teacher training structure. The foci of the project were curriculum and instructional material development and material production, development of student teachers experiences in schools, establishment of a system of faculty-school partnerships, and development of a set of standards in teacher education. As a result of this project, schools curricula were redeveloped in order to transfer recent developments in educational sciences into practice. Through this movement, new chemistry curriculum has been in action since 2007 and it is revised after a five-year experimentation in 2013.

16.1.2 Development of Chemistry Education as a Research Area

It is a general view that chemistry existed as an adjunct to medicine until the eighteenth century (Johnstone 1993). Since then, chemistry has developed into a separate discipline and more attention had been paid to the improvement of chemistry through research. It is the Industrial Revolution that has propelled the development of new ways to teach chemistry since society needed more skillful workforce in industries. During this period, chemistry was taught mostly for practical reasons rather than developing a knowledge in chemistry. It was not until the beginning of the twentieth century that some chemistry appeared in the high school chemistry curriculum. The 1960s brought new developments in chemistry teaching. This improvement in science education can be traced to two main driving forces. First, there was new knowledge about the process of human learning following the research of Piaget, Gagne, Skinner, Bruner, and Ausubel. The second driver was the Sputnik effect, which was forcing America and its alliances to renew their curricula in order to bring more interest to science and help to train people equipped with knowledge and skills in chemistry to improve the science and technology that society needs. With these hopes, several large-scale curriculum development projects, such as *Chem Study* and *Chem Bond* in the U.S.A., and *Nuffield Chemistry* in the UK had initiated. Unfortunately, the outcomes of these new curriculum movements were disappointing. Not only did they not help in expanding our understanding in chemistry, declines in the enrolments in universities have been attributed to these programs. However, these curriculum movements did provide the impetus for the development of new research areas in science education, in general, and chemistry education in particular. The disappointing results with the first curriculum reforms caused chemists to think more about how to teach chemistry. They turned to psychology and tried to understand the process of human learning and to design teaching accordingly. This brought into reality chemistry education as a hybrid discipline (Kempa 1992, 2002).

Chemistry education is a comprehensive term that covers the study of the teaching and learning of chemistry at all levels. Chemistry education includes understanding how students learn chemistry and designing teaching in a way that results in improved learning outcomes. This requires a good knowledge of chemistry as well as knowledge of human learning. Doing research in chemistry education in addition necessitates knowledge and research skills in psychology and social sciences. Chemistry education is now a well-developed and accepted research discipline in developed countries, but still needs to be spread through the world.

The view about CER was articulated in the late 1970s by Kornhauser (1979). And it may be the first analysis study for CER papers in the field. She reviewed and evaluated CER papers published during 1975–1977. After these dates, the numbers of published CER papers have been increasing widely. For recently published papers, Teo et al. (2014) studied on content analysis of these papers between the dates 2004 and 2013 and presented trends in CER.

Contrary to the aforementioned international developments, research in chemistry education in Turkey hardly goes back to 1990 (Sözbilir 2013; Sözbilir et al. 2013). The first research papers in chemistry education appeared in national journals, and then increased dramatically on the national (Sözbilir et al. 2013) and international stage (Chang et al. 2010; Lee et al. 2009). As reported by the content analysis studies (Sözbilir 2013), although the number of papers published by Turkish chemistry educators in national and international papers has increased dramatically since 1999, the total number of papers are still quite low in relation to the number of people who are employed in chemistry education.

To date, the only comprehensive attempt at describing science education research in Turkey is a study by Sözbilir et al. (2012). There is another chapter devoted to account the development of science education research in Turkey in this book (see Chap. 15). However, there is no comprehensive study that has investigated the status of CER papers published by Turkish science educators. Therefore, the current study is aimed at identifying how the educational reform movement has affected the status of CER carried out in Turkey. This has been done by analyzing the papers published by Turkish chemistry educators and comparing it with papers published in international journals in English between the periods of 1997 and 2013. The analysis is restricted to journals that publish only in either English or Turkish.

With a particular emphasis on content analysis of the papers published by Turkish chemistry educators compared with international papers published in the main chemistry or science education journals, this study was designed to answer the following research questions:

- What are the trends in CER papers published by Turkish chemistry educators and international authors during the years 1997–2013?
- What subject matter areas and topics in CER are frequently investigated?
- What research methods/designs in CER are frequently used by Turkish and international chemistry educators?
- What data collection tools in CER are frequently used by Turkish and international chemistry educators researchers?
- What samples and sample sizes in CER are frequently used by Turkish and international chemistry educators researchers?
- What data analyses methods in CER are frequently used by Turkish and international chemistry educators researchers?

16.2 Method

16.2.1 Research Team and the Coding

The research team comprised four professors (one female, three male) who taught in science and chemistry education. All members of the research team have knowledge and experience in research methods and had previously carried out similar content analysis studies in science education. Before carrying out the study, all members of the team met together to discuss how to select papers, how to record them, and to develop the paper classification form. The paper classification form for this study was adapted from the authors' previous study (Sözbilir et al. 2012). This form is composed of seven sections ranging from descriptive information about a paper to subject matter areas and the titles studied, research methods employed, data collection tools, sampling and data analysis procedures employed in the paper.

A sample of 40 papers in both Turkish and English language was initially selected for the content analysis. Content analysis was done under the leadership of the first author and then the other team members carried out the content analysis on their respective duties. At all stages of the content analysis, inconsistencies and problems raised were discussed and resolved with agreement. Reliability of coding was initially established through a training period consisting of multiple passes of sample chemical education studies in which consensus was built around interpreting and applying the methods categories and their operational definitions. As the study progressed, coding uncertainties were brought to team meetings where the articles were reviewed, the operational definitions were considered, and consensus was reached as to how to code it.

Trustworthiness of content analysis was established in multiple ways. Internal validity was ascertained through the use of operational definitions by all researchers to consistently code a study. Furthermore, consistency in the quality of the selected journals and the examination of every article in the large number of issues across the time period ensured a valid data pool for our research purposes.

16.2.2 Collection of the Papers for the Analysis

The researchers applied a content analysis to CER articles from 1997 to 2013 published by Turkish and international researchers in 65 different journals. The list of journals surveyed is given in Appendix. Any national and international peer-reviewed journals that included a CER paper published by Turkish chemistry educators are included. However, for the international CER papers, only journals that indexed in Thomson Reuters Web of Science© were surveyed. Of the eight peer-reviewed English-language journals we included in this study, two focus exclusively on chemistry education; The *Journal of Chemical Education* (*JCE*) and *Chemistry Education Research and Practice* (CERP). The others are international science education journals that also publish CER papers, such as *Science Education (SE), Journal of Research in Science Teaching (JRST), International Journal of Science Education(IJSE), Research in Science Education (RiSE), Science & Education(S&E),* and *Studies in Science Education (SiSE).*

The criteria applied for the selection of papers published in these journals were that paper has to be featuring a CER title and it must report either theoretical or applied research in chemistry education. JCE publishes several different forms of research reports. We only included papers from JCE that were published in the

Table 16.1 Descriptive statistics for the papers subjected to content analysis (N = 1338)

	National		International	
	f	%	f	%
Language of the papers				
English	53	19.9	1068	99.6
Turkish	213	80.1	4	0.4
Total	266	100	1072	100
Nationality of the authors				
Other nationalities	8	3.0	866	80.8
Turkish	253	95.1	175	16.3
Joint authorship	5	1.9	31	2.9
Total	266	100	1072	100
Index of journal that papers published				
Thomson reuters web of science (SCI/SSCI)	22	8.3	857	79.9
Education indexes (ERIC, education index, etc.)	0	0	178	16.6
ULAKBİM SBVT[a]	201	75.6	9	0.8
Other indexes	31	11.7	23	2.1
No index	12	4.5	5	0.5
Total	266	100	1072	100

[a]ULAKBIM SBVT is a national index developed by Turkish Academic Network and Information Center for Social Sciences

category of *Articles* and directly related to chemistry education. Papers describing solely chemistry content were not included. Reports such as letters to the editors, short communications, editorials, classroom and laboratory activities, etc. are not included. As a result of the literature survey we have reached 1338 CER papers. Descriptive information about the surveyed papers is given in Tables 16.1 and 16.2.

16.3 Results

The data obtained from content analysis of chemistry education publications during the years 1997–2013 are presented, respectively, on the basis of research questions. As seen in Table 16.2, this covered 266 papers in national journals and 1072 in international journals.

Publication of CER papers by Turkish authors prior to 1999 is quite rare (Sözbilir et al. 2013), although the numbers increased from the early 2000s. This is the result of the policy taken by the government during 1990s in the context of reforming the teacher training system as part of NADP. As there were quite a few experts in this new research area, YÖK had provided international fellowships to those who wanted to do postgraduate education abroad as part of the aforementioned NEDP. Through this program several students went abroad mostly to the

Table 16.2 Number of CER papers surveyed across years

Years		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Naional	Turkish			3	1	10	11	15	19	25	20	23	17	19	21	20	34	15	253
	Other nationalities			0	0	0	0	0	0	0	0	1	2	0	2	2	1	0	8
	Joined authorship			0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	5
	Sub total			3	1	10	11	15	19	25	20	24	20	19	24	23	36	16	266
International	Other nationalities	21	20	33	38	49	32	52	43	54	62	75	71	53	41	72	63	87	866
	Turkish	0	0	0	0	1	3	9	6	10	22	13	19	15	23	10	15	29	175
	Joined authorship	0	0	0	0	0	0	0	1	3	2	6	4	5	3	0	3	4	31
	Sub total	21	20	33	38	50	35	61	50	67	86	94	94	73	67	82	81	120	1072
	Total	21	20	36	39	60	46	76	69	92	106	118	114	92	91	105	117	136	1338

Fig. 16.1 Contribution of Turkish chemistry educators to the international papers since 1997

USA, the UK and few to France and Germany. Many of those PhD candidates who completed their studies returned to Turkey. The impact of this is clearly seen on the Fig. 16.1; the number of papers published in international journals is increasing steadily since the 2000s.

16.3.1 Status and Trends in CER Papers

Tables 16.1 and 16.22 show that of the 1072 international papers 206 were published either by Turkish chemistry educators or through joint authorship. Of the 266 studies published in national journals, the majority (80.1 %) were published in Turkish. On the other hand, only four papers (out of 1072) were published in Turkish in international journals, with an extended summary in English. Only a few authors (3 %) published chemistry education papers in national journals, although Turkish chemistry educators contributed 16.3 % of the international CER papers. Additionally, Table 16.1 indicates that almost 80 % of the papers published in international journals were indexed in Thomson Reuters Web of Science (SCI/SSCI) while only 8.3 % of the national papers were indexed in SCI/SSCI journals.

Figure 16.1 shows the contribution of Turkish chemistry educators to the international CER in the past 16 years. Figure shows that the total number of papers published is increasing significantly since 2004. This increase can be attributed to the establishment of new international journals such as CERP, *EURASIA Journal of Mathematics*, *Science and Technology Education*, *Eurasian Journal of Physics* and *Chemistry Education*, *Journal of Turkish Science Education*, and *The International Journal of Environmental and Science Education.* However, a new national science journal (Turkish Journal of Science Education) has also been established in Turkey. Figure 16.1 indicates an interesting trend in the total number of chemistry education papers both at national and international level. The number of papers reached a peak around 2008 followed by a decrease which was reversed in 2011. This trend shift could perhaps be related to the international economic recession started in 2008. Together with the economic recession in the world, finance available for research projects decreased and this reflected a dramatic change in the number of papers published.

Figure 16.1 and Table 16.2 also show the effect of restructuring in the teacher training system in Turkey through the NEDP. This restructure initially caused some inconveniences, but after a couple of years many people chose to do educational research, thus helping in the establishment of chemistry education as a new research area in Turkey. Another reason for Turkish authors to publish in international journals is the state policy requires international publications for academic advancement. However, this policy brought together concerns about the quality of research studies carried out and published. Many researchers had experienced difficulties in conducting and publishing research in chemistry education as they moved from discipline-based research to chemistry education as a new research area. This difficulty is clearly seen in Fig. 16.2 in which the top ten nations' contributions to the CER literature in international journals that published in English are compared. The comparison is made in terms of journal types. The first group of papers represents all international journals while the second group only includes papers that were published in journals indexed by SCI/SSCI, while the third group only includes the major chemistry education journals such as JCE and CERP and science education journals such as SE, JRST, IJSE, and RiSE.

Figure 16.2 portrays two important findings in terms of Turkish chemistry educators. The first finding is that Turkey is the second in terms of contributing

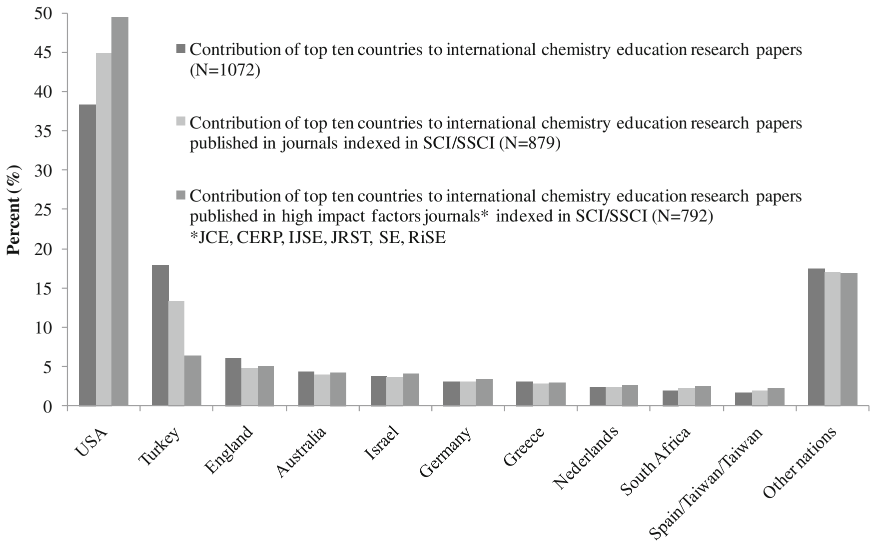


Fig. 16.2 Comparison of top ten nations' contributions to the international CER literature

CER publications after the USA, which produces almost half of the CER papers published in English language in international journals. The second finding is that Turkish chemistry educators have difficulty publishing in high quality journals. The state policy of "publish or perish" has led Turkish authors to target mostly low quality international journals. This policy brings both positive outcomes as well as negative results. The positive outcome is that Turkish researchers have to follow international trends and carry out research that complies with the trends. However, it also brings a negative outcome of carrying out research for the sake of international papers of which the quality is questioned, and which make no contribution to overcoming educational problems.

16.3.2 Frequently Studied Subject Matters and Topics in CER Papers

Concerning the topics frequently studied and the level of these topics in the education system in chemistry education there are similarities as well as differences between CER carried out in Turkey and internationally. It is clear from Fig. 16.3 that the majority of the CER is carried out at university level, and the second most common level is secondary school for Turkish researchers while there is a significant difference between the international and national research. However, there are a group of studies that carried out internationally are not counted as adjacent to any school level but rather related to general issues concerning chemistry such as philosophy of chemistry, psychology of learning in chemistry, chemistry teachers, assessment and evaluation etc. Therefore, they were classified as *others/unclassified*. These kinds of studies are prevalent at international studies while they were not evident in national papers.

Figure 16.3 indicates that studies mostly focus on school-level topics. This indicates that most studies in CER in Turkey focus on application studies, but lack research on theoretical and developmental aspects of teaching and learning chemistry. It is also clear that most of the CER is carried out at tertiary level. This is understandable as majority of the faculty employed by departments of chemistry in

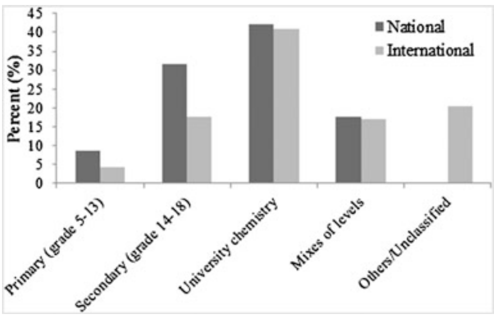


Fig. 16.3 Levels of schooling studied by chemistry education researchers

most of the places, they direct their research with the issues and topics covered at university.

The findings illustrated in Table 16.3 show that CER papers are focused on teaching and learning of chemistry. Among the top five topics studied are teaching (31.3 %), learning (28 %), measurement and evaluation (6.8 %), studies about affective dimensions/skills (6.7 %) and integration of ICT into chemistry teaching (6.5 %) respectively. The subject matter areas concerning laboratory activities,

Table 16.3 Frequently studied subjects areas in CER papers

	f	%
Teaching (total)	442	31.3
Effect of instruction on cognitive dimensions (academic achievement, problem-solving, conceptual change, subject knowledge etc.*)*	*231*	*16.4*
Effect of instruction on affective dimensions (motivation/attitude/interest/value etc.*) development*	*85*	*6.0*
Effect of instruction on skills (psychomotor, scientific process skills etc.*) development*	*32*	*2.3*
PCK	*9*	*0.6*
Others	*85*	*6.0*
Learning (total)	395	28.0
Misconceptions	*253*	*17.9*
Determination of school/academic achievement	*57*	*4.0*
Learning styles	*6*	*0.4*
Others	*79*	*5.6*
Measurement/evaluation (total)	96	6.8
Development or adaptation of instruments (such as test, questionnaires, scales etc.*)*	*57*	*4.0*
Development of a measurement and evaluation methods/techniques	*7*	*0.5*
Others	*32*	*2.3*
Studies about affective dimensions/skills	95	6.7
Integration of ICT into chemistry education	91	6.5
Design of laboratory activities/experiments	80	5.7
Curriculum studies	62	4.4
Concept analysis	61	4.3
Teacher training (total)	53	3.8
In-service training	*26*	*1.8*
Preservice training	*13*	*0.9*
Others	*14*	*1.0*
Instructional material design	48	3.4
Textbook analysis	26	1.8
Sociocultural/gender studies	20	1.4
Nature/history/philosophy of chemistry	19	1.3
Miscellaneous	64	4.5
Total	1410[a]	100

[a]Total number has been calculated according to the main categories. Total exceeds 1338 as some of the papers are categorized into two different groups. *Italics* stand for sub categories of a main category and did not count in overall total

curriculum studies, teacher training, material design, concept analysis, textbook analysis are also evident but their percentage is quite low. Sociocultural and gender studies and nature, history and philosophy of chemistry are quite low.

Research studies into teaching are dominated by investigations that aimed to identify the effect of instruction on cognitive dimensions (16.4 %) such as academic achievement, problem solving, conceptual change, and enhancement in subject knowledge. However, there are teaching studies that also investigated the effect of instruction on affective dimensions (6 %) and psychomotor and scientific process skills (2.3 %). On the other hand learning studies are dominated by documentation of misconceptions (17.9 %) which make up the highest proportion of studies in CER.

We have also investigated the commonly used instructional approaches/methods used in teaching studies. Findings are summarized in Table 16.4. As seen from the table, however, instructional approaches/methods used shows great variability. Among the most common approaches are cooperative learning, computer/web aided/based instructional designs, conceptual change-oriented teaching (see Chap. 13 for more detailed analysis in this area), problem/project-based teaching and inquiry-based teaching respectively.

There were hundreds of different topics identified in the published papers. The most common topics are listed in Table 16.5. Solutions and solubility, matter and related concepts, gases and related concepts, acid and bases are the most common.

Table 16.4 Frequently used instructional approaches/methods in chemistry education researches

	f	%
Cooperative learning	33	10.2
Computer/web-based instruction	27	8.3
Conceptual change-oriented teaching	27	8.3
Computer/web-aided instruction	25	7.7
Problem/project-based learning	20	6.2
Inquiry-based teaching	19	5.8
Constructivist approaches	17	5.2
Visualizations/simulations	17	5.2
Laboratory instruction	14	4.3
Writing/Heuristic writing	11	3.4
Peer instruction	9	2.8
Context-based teaching	8	2.5
Learning cycle	8	2.5
Analogy	7	2.2
Argumentation-based teaching	7	2.2
Case-based instruction	6	1.8
Active learning	5	1.5
Concept mapping	5	1.5
Demonstration	4	1.2
Miscellaneous	56	17.2
Total	325	100

Table 16.5 Frequently studied chemistry topics in chemistry education researches

	f	%
Solution/s, solubility and concentration	60	5.3
Matter and related titles such as physical and chemical states, changes of state, particulate nature of matter, etc.	54	4.8
Gases and related titles such as gas laws, gas properties, pressure, diffusion, etc.	53	4.7
Acid and bases	43	3.8
Laboratory and related titles	37	3.3
Chemical reaction/s	34	3.0
Molecules, molecular structure and related titles such as molecular geometry, symmetry, polarity, visualization, etc.	34	3.0
Structure of matter/atom/molecules	34	3.0
Chemical bonds/bonding	33	2.9
Thermochemistry related titles such as heat, temperature, energy, enthalpy, etc.	33	2.9
Organic chemistry	31	2.7
Chemical equilibrium	26	2.3
Atom and related titles (such as models, mass, size, etc.)	24	2.1
Chemical thermodynamics	20	1.8
Electrochemistry and related titles	20	1.8
Miscellaneous	596	52.7
Total	1132	100

A group of topics/titles that are listed in Table 16.5 as "Others" include hundreds of different titles composing almost half of those identified.

16.3.3 Frequently Used Research Designs/Methods in CER Papers

As CER is a hybrid area, it requires studying chemistry content with research methods of social sciences. This was a challenge for chemists initially to learn the research methods as well as theoretical framework of educational studies. Therefore, it is interesting to see which research methods are frequently used in CER papers. For this purpose research methods used in each study were analyzed. Table 16.6 and Fig. 16.4 show the frequently used research methods, while Fig. 16.5 compares the frequently used research designs in national and international papers.

As evident from Table 16.6 and Fig. 16.4, the five most common research methods are quasi-experimental researches, quantitative descriptive studies, descriptive qualitative studies, case studies and surveys, respectively, although there are quite significant differences between the national and international papers. The five most common research methods employed in national publications are quasi-experimental, case studies, surveys, quantitative descriptive studies and phenomenology, respectively, while studies published internationally most

Table 16.6 Comparison of frequently used research designs and methods in chemistry education researches

Research			Type of journal				Total
Approach	Design	Method	National		International		
			f	%	f	%	
Mixed	Mixed	Triangulation (Qual + Quan)	3	1.1	99	9.2	102
		Explanatory (Quan to Qual)	5	1.9	10	0.9	15
		Exploratory (Qual to Quan)	0	0.0	11	1.0	11
		Embedded	2	0.8	2	0.2	4
Quantitative	Experimental	Quasi-experimental	62	23.3	126	11.8	188
		Preexperimental	14	5.3	54	5.0	68
		True-experimental	0	0.0	3	0.3	3
		Single subject	0	0.0	0	0.0	0
	Non-experimental	Descriptive	18	6.8	100	9.3	118
		Descriptive—longitudinal	1	0.4	32	3.0	33
		Descriptive—cross age/section	11	4.1	15	1.4	26
		Survey	34	12.8	80	7.5	114
		Comparative	6	2.3	43	4.0	49
		Correlational	7	2.6	22	2.1	29
		Ex-post facto	0	0.0	3	0.3	3
		Secondary data analysis	0	0.0	2	0.2	2
		Meta-analysis	0	0.0	2	0.2	2
Qualitative	Analytic	Concept analysis	11	4.1	64	6.0	75
		Review	9	3.4	44	4.1	53
		Evaluation studies	3	1.1	18	1.7	21
		Content analysis	5	1.9	12	1.1	17
		Historical analysis	0	0.0	5	0.5	5
		Others	5	1.9	31	2.9	36
	Interactive	Qualitative descriptive	6	2.3	136	12.7	142
		Case study	35	13.2	106	9.9	141
		Phenomenology	23	8.6	20	1.9	43
		Grounded theory	3	1.1	8	0.7	11
		Ethnography	0	0.0	7	0.7	7
		Others	3	1.1	17	1.6	20
Total			266	100	1072	100	1338

commonly used quantitative descriptive studies, qualitative descriptive studies, quasi-experimental, case studies and triangulation (quan + qual) respectively. These figures indicate that the main difference in national and international CER in terms of research designs are seen in mixed and experimental designs. This difference is clearly seen in Fig. 16.5. Turkish researchers are inclined to engage mostly in quantitative studies such as experimental and nonexperimental designs together with interactive qualitative designs, while there is a more balanced distribution among the use of research designs and approaches in international

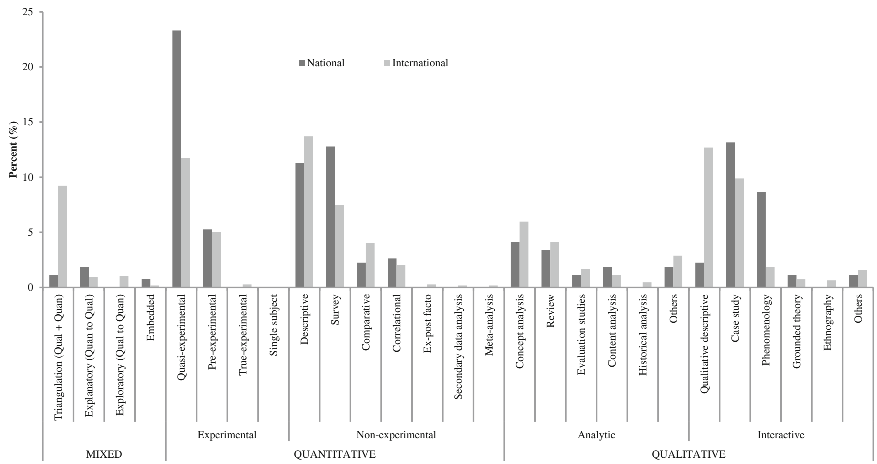


Fig. 16.4 Comparison of frequently used research designs and methods in chemistry education researches in national and international papers

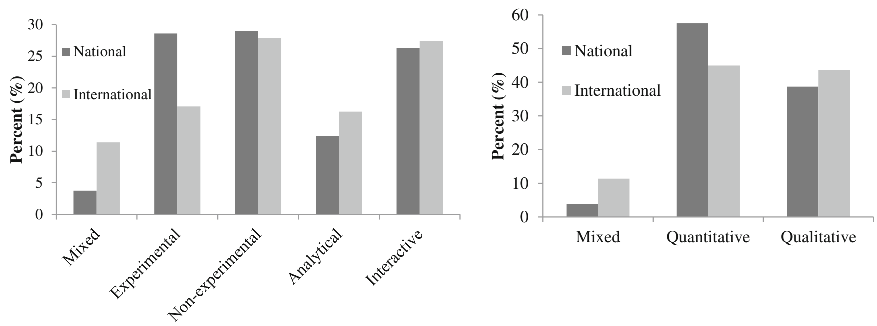


Fig. 16.5 Comparison of frequently used research designs and approaches in chemistry education researches in national and international papers

papers—although mixed methods are quite low compared to quantitative and qualitative studies.

Table 16.6 and Fig. 16.4 also show that some research methods, such as single subject and true-experimental research, causal comparative research, secondary data analysis, meta-analysis, ethnography and historical analysis, are not commonly practiced in the CER papers. Some of these methods, such as true-experimental, are not common due to their nature. However, the rarity of other methods is perhaps due to researchers' lack of interest in the subject or skills.

16.3.4 Frequently Used Research Data Collection Tools in CER Papers

The type and the number of data collection tools used in CER studies shows variability as seen from Table 16.7 and Fig. 16.6. Although achievement/concept tests, interviews, documents, scales/inventories and questionnaires, respectively, are the most commonly used data collection tools, chemistry educators used several different data collection tools such as alternative instruments, observations, reports,

Table 16.7 Frequently used data collection tools in CER papers

	f	%
Alternative data collection tools	123	5.2
Questionnaires	188	8.0
Likert type	*141*	6.0
Others	*47*	2.0
Achievement/concept tests	880	37.4
Open-ended	*378*	*16.1*
Multiple choice	*250*	*10.6*
Diagnostic	*112*	*4.8*
Exams	*27*	*1.1*
Not given/others	*113*	*4.8*
Documents	246	10.5
Scientific publications	*30*	*1.3*
Books	*52*	*2.2*
Multi media	*13*	*0.6*
Multi media-voices	*10*	*0.4*
Multi media-videos	*48*	*2.0*
Not given/others	*93*	*4.0*
Interviews	439	18.7
Focus group	*22*	*0.9*
Unstructured	*13*	*0.6*
Semi-structured	*239*	*10.2*
Structured	*7*	*0.3*
Not given/others	*158*	*6.7*
Observations	108	4.6
Participant	*16*	*0.7*
Nonparticipants	*22*	*0.9*
Not given/others	*70*	*3.0*
Scale/inventory	234	9.9
Reports/assignments/diaries	40	1.7
No data collection tool reported	62	2.6
Miscellaneous	32	1.4
Total	2352	100

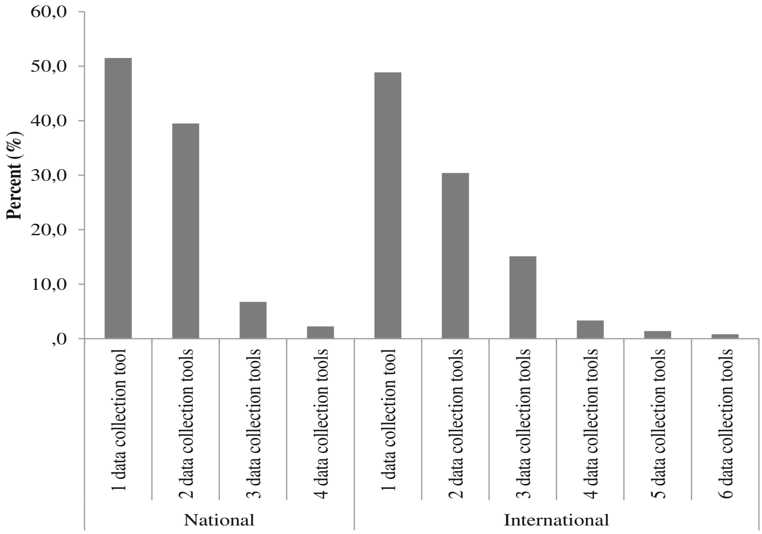


Fig. 16.6 Comparison of number of different data collection tools used

diaries, field notes, journals, assignments. It is also seen from Fig. 16.6 that there is little difference in terms of frequency of use of different data collection tools in national and international studies. Most of the studies rely on either one or two different data collection tools (90 % in national and 79 % in international studies), although few studies (10 % in national and 21 % in international papers) relied on multiple data collection tools. Use of multiple data collection tools in a study is concerned with the validity and the reliability of the data collected and results reached. Therefore, taking into account the fact that almost 50 % of the CER papers relied on single data collection tools, it could be argued that the validity and reliability of the conclusions reached are questionable.

16.3.5 Frequently Studied Samples and Sample Sizes in CER Papers

Chemistry education studies mostly reported on samples from the college/undergraduate and secondary levels. Trends illustrated in Figs. 16.7 and 16.8 show great similarity between national and international papers. This result is understandable: as chemistry is mostly taught at secondary and college/university level, studies are commonly done with these levels.

Figure 16.8 shows the sample sizes. The most common sample sizes range between 10 and 200 samples. Although most of the studies are done with these medium-sized samples, there are some large scale studies done with sample sizes

Fig. 16.7 Comparison of frequently studied samples in CER papers

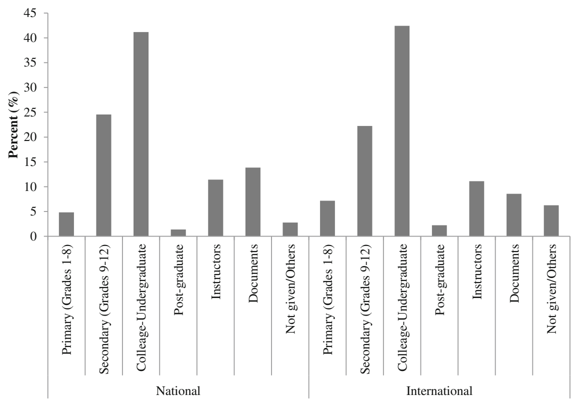
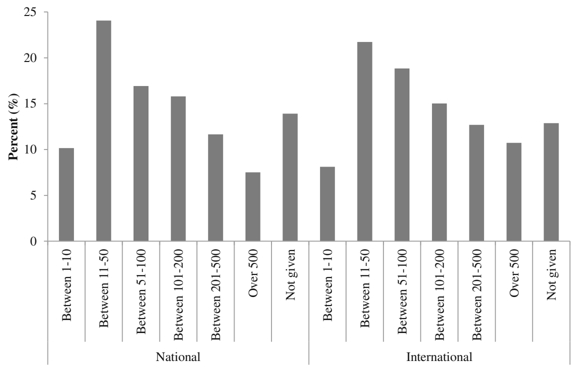


Fig. 16.8 Comparison of frequently studied sample sizes in CER papers



over 200, or even over 500 participants. There are a significant number of studies that were carried out without human subjects which were classified as "not given." The number of studies that were carried out with less than 10 participants is evidence of qualitative studies. These results regarding the sample sizes are in parallel with the distribution of research methods employed. One of the most commonly used research methods is quasi-experimental research. These studies are mostly performed with few control and comparison groups in which the number of students becomes less than 100, parallel to the finding seen in Fig. 16.8.

16.3.6 Frequently Used Data Analysis Methods in CER Papers

Results for the data analysis methods/techniques used in CER papers are summarized in Table 16.8 and compared in Fig. 16.9. Since many papers used more than one data analysis method/technique, the total numbers are larger than the total number of papers in Table 16.8.

Table 16.8 Frequently used data analysis methods/techniques in chemistry education researches

	National		International	
	f	%[a]	f	%[a]
Quantitative descriptive data analysis methods				
Descriptive statistics in tables	141	53.0	700	65.3
Descriptive statistics in figures/charts	33	12.4	86	8.0
Total	174	65	786	73
Quantitative inferential data analysis methods				
T-test	86	32.3	177	16.5
ANOVA/ANCOVA	48	18.0	151	14.1
Correlation	23	8.6	74	6.9
Nonparametric tests	15	5.6	69	6.4
Regression	6	2.3	34	3.2
Factor analysis	6	2.3	32	3.0
MANOVA/MANCOVA	4	1.5	28	2.6
Others	13	4.9	18	1.7
Total	201	75.6	583	54.4
Qualitative data analysis methods				
Content analysis	50	18.8	488	45.5
Qualitative descriptive analysis	54	20.3	120	11.2
Computer-assisted qualitative data analysis	1	0.4	6	0.6
Total	105	39.5	614	57.3
Total number of papers	266	100	1072	100

[a]Percentages are calculated according to the total number of papers analyzed

Both Table 16.8 and Fig. 16.9 show that the most commonly used data analysis methods are quantitative inferential and descriptive statistical techniques. Even in qualitative studies, descriptive statistics are used to summarize the results. Qualitative data analysis methods are also quite common as seen from the table.

Figure 16.9 compares the data analysis techniques both in national and international studies. It is evident from the figure that chemistry educators use a variety of data analysis techniques. The high frequency of descriptive statistics is understandable as they are used together with both inferential statistics and qualitative data analysis. However, most of the inferential statistical techniques used are rather simple techniques and they do not involve use of complicated statistical techniques. Among the most common inferential data analysis techniques used are t-test, variance analysis, and correlation analysis respectively. The commonality of use of t-test in national studies is in parallel with the research methods used. As can be seen from Fig. 16.4, the most common method used in national studies is quasi-experimental research. The results are analyzed by t-test in this method if there is one control and comparison group, or in the case of more than two groups variance analysis is used. That is why t-test is the most commonly used inferential statistical technique in national studies. Although there are some complex data analysis techniques used

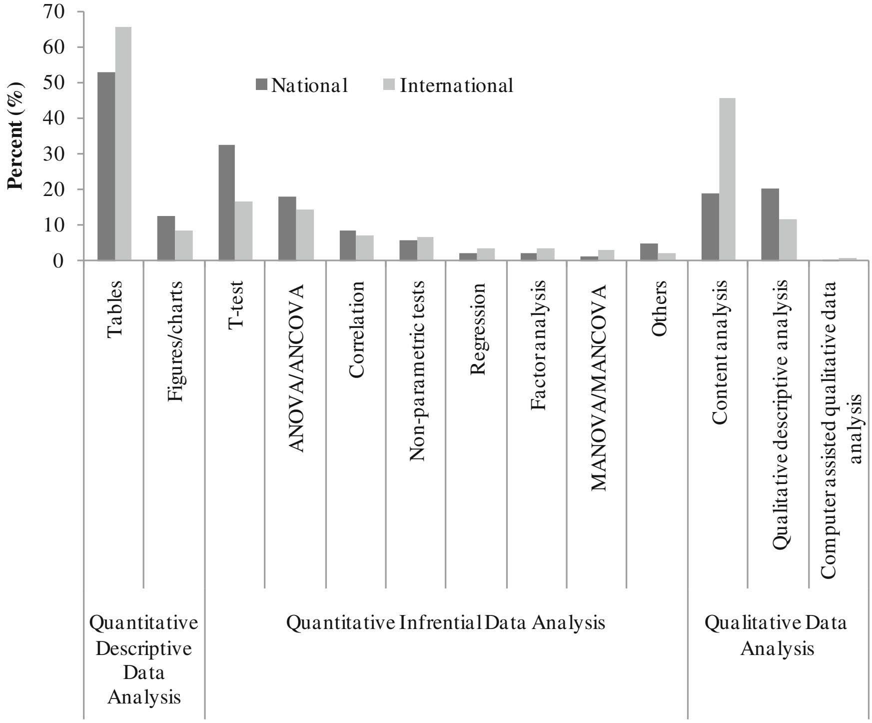


Fig. 16.9 Comparison of frequently used data analysis methods/techniques in Chemistry education researches

such as multivariate analysis, regression, factor analysis, they are not so common. It is also interesting to see that few studies used computer-assisted qualitative data analysis in chemistry education.

16.3.7 Discussions and Implications for Practice

This chapter provides a content analysis of the papers published in the field of chemistry education by Turkish chemistry educators at national and international journals, and also compares them with international papers published in main chemistry or science education journals. This provides insights concerning the development and status of CER in Turkey.

The results indicate that although chemistry education is a new research area for Turkish researchers, it has undergone significant development to the extent that Turkey has become the second largest contributor of CER literature internationally (see Fig. 16.2). This finding is also confirmed by the findings of Teo et al. (2014). Establishment of chemistry education as a new research area in Turkey is initiated by the help of NEDP project carried out in 1990s. Through this project, the teacher training system has been reformed and academic staff employed in teacher training encouraged carrying out more discipline-based educational research than discipline-based research which was previously the case. In addition, the researchers working in teacher training were also forced by the state to produce international, as well as national, publications in their research field. This state policy brought about a significant increase in the number of international publications although the quality of papers produced by Turkish chemistry educators is still under scrutiny. As seen in Fig. 16.2, Turkish chemistry educators are inclined to publish mostly in low quality international journals to overcome this state policy of 'publish or perish.' On the other hand, providing international postgraduate educational scholarships for young Turkish researchers who want to seek career in this new discipline-based educational research has brought positive outcomes such as integrating chemistry educational research in Turkey into the international research literature. The main barriers for Turkish researchers to publish internationally are two-folds: overcoming the language barrier and gaining the knowledge and skills required for CER. Chemistry education researchers in Turkey can be considered in three distinct groups. The first group of researchers comprises those who had a chance to take an international education scholarship and carry out their postgraduate education abroad. Generally speaking, these researchers are capable of publishing both in national and international journals. The second group is composed of those who were trained through discipline-based research such as doing pure chemistry research in different areas of chemistry. After the restructuring took place in 1997 some of those researchers opted to leave the teacher training sector, but a significant number decided to divert their studies into discipline-based educational research. This group of researchers had several difficulties in grasping the educational and methodological knowledge behind the discipline-based education research, although they have a strong background of chemistry knowledge. Therefore, they had several difficulties in learning how to do discipline-based education research, as well as publishing in national and international journals. The third group of researchers is composed of new-generation researchers that sought a career in discipline-based education research. Most of them carried out their postgraduate education under the guidance of supervisors from either the first or second group of researchers described above. Some of them have received adequate training while some of them were not able to receive proper training at this development stage of chemistry education in Turkey. Therefore, they have mixed abilities in terms of carrying out and publishing research in discipline-based education research. Whatever the difficulties Turkish researchers are facing, it is a fact that they are now ranked second in terms of contributions to the international CER literature. Overcoming the language barrier will always be a problem for those who have trained in their mother tongue. This is the case for researchers who came from those nations other than native English-speaking countries. The barriers concerning the knowledge and skills which are required to carry out educational research is improving in recent years although there are still problems, as seen from findings concerning research methods used.

CER in Turkey is limited to the replication studies focusing on subject matters such as learning and teaching. Research studies that concern evaluation of the current education practices with the purpose of development of policies for the improvement of education are not evident. At this developmental stage of CER in Turkey, the majority of the studies are replications of those published in international journals. This also brings another barrier for Turkish researcher to publish in high quality international journals. Therefore, the majority of Turkish chemistry educators are inclined to publish with new international journals, rather than the well-respected international journals. To overcome this problem, the state imposed a new policy of forcing the researchers to publish in SCI/SSCI journals for academic advancement. This also brought new challenges on top of the pervious difficulties for Turkish researchers in recent years.

The state policy of forcing researchers publishing internationally brought some positive outcomes as well as negative results. A positive outcome is that Turkish researchers have to follow international trends and carry out research that complies with the trends. However, it also brings negative outcomes of carrying out research for the sake of publishing internationally. A consequence is that the quality is questionable and also provides no contribution to overcome educational problems that society is facing such as establishing equality in education throughout the country, student selection and placement between the levels of schooling, improving preservice teacher training, keeping large number of in-service teachers with the current developments in education, updating curricula and evaluating the effect of reforms taking place in the educational system. While some of the schools provide really high quality education, this is not universal. However, all of the students are subjected to the same centralized exams. This inequality between the schools and regions creates significant pressure on the students and as well as parents. Therefore, they seek alternative support mechanisms such as private courses and tutorials. Arising out of this, in turn, is the issue of affording financial support needed for those private courses and lessons. So, whereas on one side we have researchers struggling to publish in high quality international journals without a focus on developing projects to overcome local educational problems, on the other side there are practitioners struggling to overcome problems they are facing day to day. The main challenge for Turkey is to establish a balance between this international publishing policy and directing research to solve local educational issues. One of the possible solutions to overcome this dilemma is to set up national research policies in all areas of education and direct funding available for the research into those areas. Another solution is to develop a new set of criteria for employment and advancement of academic staff in universities and research institutes. Currently, the major determinant criterion of employment and academic advancement is the number of papers published. Therefore, Turkish researchers are directing their efforts to publish internationally, but this policy does not help to overcome educational problems. However, there are several instruments that could be brought into practice for employment and academic advancement such as encouraging researchers to carry out national and international level large-scale projects toward addressing problematic areas. This policy may help researchers to work together and also produce valid and reliable data to better understand and produce solutions to educational problems. Encouraging training new researchers in chemistry education will also help current researchers to improve themselves. Efforts may be directed to encourage researchers to work on collaboratively either at national and international level to solve local and worldwide educational issues. Researchers need to be released from enforcement of researching for the sake of publishing. Instead papers published have to be the outcome of research that directed to overcome major educational problems. Although in general the aim of CER is to improve chemistry teaching, in Turkey this is vice versa, the main aim of research for researchers has become to publish. This misdirection is not helping to inform instruction. Therefore, an action needs to be taken against this trend in Turkey, not in chemistry education but in all fields of educational research.

As a conclusion, chemistry education is a hybrid research area. It requires knowledge of chemistry, educational sciences and research methods of social sciences in general. Therefore, to carry out high quality discipline-based educational research such as chemistry education, researchers have to be adequately trained in those three areas. This requires working together people from different disciplines. Most importantly, research in general needs to have good questions to investigate. If the questions investigated are not valid and important ones, then research reports as outcomes of research carried out would not be helping to improve practice. In this manner, action needs to be taken to direct research to important educational issues in Turkey and elsewhere. Forcing researchers to publish for the employment and academic advancement unfortunately does not help Turkey to improve chemistry education; although it looks Turkish chemistry educators are following the trends elsewhere in the world. The future of CER has to be strengthened by the policies of improving practice with large-scale nationwide and perhaps international projects firmly financed by state and international funding agencies.

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Appendix: List of Journals Surveyed for Papers in CER

N#	International journals	Type of journal	Number of papers (f)	Percentage within int. journals	Percentage within all journals
1	Journal of chemical education	International	302	28.2	22.6
2	Chemistry education research and practice	International	297	27.7	22.2
3	International journal of science education	International	130	12.1	9.7

(continued)

(continued)

N#	International journals	Type of journal	Number of papers (f)	Percentage within int. journals	Percentage within all journals
4	Journal of research in science teaching	International	72	6.7	5.4
5	Research in science education	International	46	4.3	3.4
6	Science and education	International	42	3.9	3.1
7	Science education	International	38	3.5	2,8
8	Asia-Pacific forum on science learning and teaching	International	20	1.9	1.5
9	Journal of science education and technology	International	19	1.8	1.4
10	Journal of baltic science education	International	18	1.7	1.3
11	Research in science and technological education	International	11	1.0	0.8
12	Eurasian journal of educational research	International	10	0.9	0.7
13	Eurasia journal of mathematics, science and technology education	International	10	0.9	0.7
14	International journal of science and mathematics education	International	9	0.8	0.7
15	International journal of environment and science education	International	8	0.7	0.6
16	Eurasian journal of physics and chemistry education	International	7	0.7	0.5
17	Turkish online journal of distance education	International	7	0.7	0.5
18	International journal of new trends in education	International	6	0.6	0.4
19	Turkish online journal of educational technology	International	6	0.6	0.4
20	Essays in education	International	4	0.4	0.3
21	Studies in science education	International	2	0.2	0.1
22	International journal of education in mathematics, science and technology	International	1	0.1	0.1
23	International science	International	1	0.1	0.1
24	Journal of science teacher education	International	1	0.1	0.1
25	Science education international	International	1	0.1	0.1
26	Didactica Slovenica Pedagoska Obzorja	International	1	0.1	0.1
27	European journal of teacher education	International	1	0.1	0.1
28	Instructional science	International	1	0.1	0.1

(continued)

(continued)

N#	International journals	Type of journal	Number of papers (f)	Percentage within int. journals	Percentage within all journals
29	The qualitative report	International	1	0.1	0.1
	Total number of chemistry education papers surveyed in international journals		1072	100.0	80.1
N#	National journals	Type of journal	Number of papers (f)	Percentage within nat. journals	Percentage within all journals
1	Turkish journal of science education	National	44	16.5	3.3
2	Hacettepe University journal of education	National	38	14.3	2.8
3	Kastamonu education journal	National	15	5.6	1.1
4	Ahi Evran University Kirşehir education faculty journal	National	14	5.3	1.0
5	Journal of national education	National	14	5.3	1.0
6	Necatibey education faculty electronic science and mathematics education journal	National	14	5.3	1.0
7	Gazi University Gazi education faculty journal	National	11	4.1	0.8
8	Turkish journal of educational science	National	11	4.1	0.8
9	Dokuz Eylül University Buca education faculty journal	National	9	3.4	0.7
10	Educational sciences: theory and practice	National	9	3.4	0.7
11	Journal of research in education and teaching	National	8	3.0	0.6
12	Erzincan University education faculty journal	National	8	3.0	0.6
13	Pamukkale University education faculty journal	National	8	3.0	0.6
14	Education and science	National	6	2.3	0.4
15	Electronik social sciences journal	National	6	2.3	0.4
16	Ondokuz Mayis University education faculty journal	National	6	2.3	0.4
17	İlköğretim online dergisi	National	5	1.9	0.4
18	Hasan Ali Yucel education faculty journal	National	5	1.9	0.4
19	Atatürk University Kâzim Karabekir education faculty journal	National	4	1.5	0.3
20	Çukurova University education faculty journal	National	4	1.5	0.3
21	Abant İzzst Baysal university education faculty journal	National	3	1.1	0.2

(continued)

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N#	International journals	Type of journal	Number of papers (f)	Percentage within int. journals	Percentage within all journals
22	Amasya University education faculty journal	National	3	1.1	0.2
23	Ankara University journal of faculty of educational sciences	National	3	1.1	0.2
24	Boğaziçi University education journal	National	3	1.1	0.2
25	Dicle University Ziya Gökalp education faculty journal	National	2	0.8	0.1
26	Ege journal of education	National	2	0.8	0.1
27	İnönü University education faculty journal	National	2	0.8	0.1
28	Anadolu University education faculty journal	National	1	0.4	0.1
29	Bati Anadolu Eğitim Bilimleri Dergisi	National	1	0.4	0.1
30	Burdur education faculty journal	National	1	0.4	0.1
31	Mersin University education faculty journal	National	1	0.4	0.1
32	MIJE-Mevlana international journal of educational	National	1	0.4	0.1
33	Pegem journal of education and teaching	National	1	0.4	0.1
34	Educational technology research journal	National	1	0.4	0.1
35	Sakarya University education faculty journal	National	1	0.4	0.1
36	Yuzuncu Yil university education faculty journal	National	1	0.4	0.1
Total number of chemistry education papers surveyed in national journals			266	100.0	19.9
		Total	1338		100

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Chapter 17
Commentary: Who Sets Trends in Science Education? I Comment on Four Exemplary Book Chapters

Ilka Parchmann

Abstract How does research develop in a certain area like science education? Who defines research areas? How does a country get on board by providing suitable environments and standards? How can researchers cooperate successfully to raise the quality and the variety of research approaches and research foci? These questions are raised and discussed in several chapters of this book. The explored developments in Asian countries could for sure raise similar questions also in other areas of the world, and might lead to a worldwide reflection of the state of research in our broad field of science education. They might also initiate some critical thinking about influences that might not always foster an enrichment of science education research, but perhaps, on the contrary, a narrowing mind by copying well-established approaches (only). How can research communities develop standards without taking the risk of developing monocultures predominantly?

How does research develop in a certain area like science education? Who defines research areas? How does a country get on board by providing suitable environments and standards? How can researchers cooperate successfully to raise the quality and the variety of research approaches and research foci?

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Four chapters have been a starting point for the following reflection, with all of them being highly interesting and informative. The chapter "Impacts of Citations on

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Conceptual Change Articles Between 1982 and 2011: From International and Regional Perspectives" by Chiu provides an overview about research areas in the Asian area and the international community. It raises questions about how research and educational policies are connected; and how broad perspectives of local research communities are and might be. The second chapter by Choi and Choi offers insights into one exemplary country: "Overview of Science Education Research and Practice in Korea." The stages described in this paper could probably be identified in other countries as well and help to understand in which way topics are generated from one to the next research emphasis.

The third and fourth papers investigate research trends for another exemplary country from different perspectives: the authors, the content areas, and methodological issues: "Trends in Science Education Research in Turkey: A Content Analysis of Key International Journals from 1998 to 2012" by Erduran and Mugaloglu, and "Development of Chemistry Education Research (CER) in Turkey: A Comparison of CER Papers with International Research" by Sozbilir and co-authors. Again, different influences, both with regard to policy measured and cooperation among research communities become obvious. Still, a comparison among the four papers does not seem to be valid and reliable, as the schemes of categorization have not been developed in a comparable approach, and in some chapters, it is not completely clear what had been counted and taken into consideration. This does in no way reduce the value of the chapters on their own, and might even initiate further investigations among countries and areas. I would like to thank all the authors for their interesting work and the insides they have provided!

Coming back to the questions raised at the beginning of this commentary, some aspect will be discussed in the following paragraphs with the aim of initiating further explorations and international discussions.

How do research emphases develop, how do we set standards without restricting the broadness of the research field in science education?

Authors of all four chapters had investigated and discussed the development of research topics and content areas. While the first sets the focus on papers specifically in the field of conceptual change and development, the other three try to cover the whole field of science education research categorized by leading perspectives, such as teaching, learning, or cultural and contextual influences. They explore changing emphases over time that might be found in other countries and areas as well. The "Report of Trends in Chemistry Education" in Germany (Becker et al. 2015) has almost identically shown shifts between research studies primarily investigating content and curriculum foci, teaching and teacher education, and/or learning and students conceptual, and affective developments. Also the curriculum foci have moved back and forth between daily-life contexts, basic principles of the discipline, and scientific practices like methods of inquiry. Why do we observe such changes, is it a matter of moving forward, or is it rather a cyclic and spiral movement of investigating and combining similar areas again on higher levels with more sophisticated methodologies and combining findings of the different perspectives? As nowadays topics had also been investigated in the past, we could argue for the latter. Take the example of research on teacher education that had been prominent some decades ago, then seemed to have lost interest in favor of investigations on students' learning, and now coming back fostered by famous books like the one by Hattie, pointing out the importance of the teacher for successful learning processes of students?

An important question for communities of researchers, especially developing countries in a certain research field, is whether to focus on established trends (that might be already decreasing again in other countries?) or on different and therefore individual areas. The extremely large number of several thousand studies on conceptual change and development around the world seems to indicate that countries do pick up well-established trends. The papers exploring exemplary countries undermine this hypothesis as well. With regard to the worldwide development of research knowledge, one could ask if again new studies on similar preconceptions do have a value if analogous studies had been carried out before? There might be two answers to this question: (1) For the research world, they might have a value if they point our cultural influences; this demands comparable methods, however. (2) For the development of young research communities and individual researchers, they might certainly have the value of developing and establishing methodological standards by applying methods and conclusions that are of high standards, accepted, and reliable. By that, new studies do raise the quality level in different areas and do enable new high-quality research in the future. However, just following trends that have been set by already existing and successful communities also involves a risk: Do we miss new promising ideas and approaches because we restrict research foci to some mainstream areas primarily? The development described in the paper by Sozbilir and co-authors highlights this dilemma of quality insurance on the one hand and a risk of narrowing the broadness of the field on the other: The guideline of publishing articles in SSI journals demands high quality especially with regard to methods, but does it also enrich or, on the contrary, narrow research foci? This of cause depends on the publishing and review procedures, and thereby leads to the next item of discussion.

How well do research communities cooperate and take each other's perspectives and findings into consideration, how can we avoid that "Davids" will get hidden under the influence of "Goliaths"?

A very interesting and worrying point is set in the chapter by Chiu: The Asian community refers to authors from different countries on a broader scale, while internationally, English speaking authors—probably mainly from the USA and the UK—were dominating. Three anecdotal observations without any empirical ground seem to confirm this very carefully raised criticism. (1) When reading US American papers and listening to talks by some outstanding researchers, one might miss references to analogous European trends, for example in the new trend area of learning progressions (that certainly have analogous foundations in European trends of spiral curricula and the educational transformation or reconstruction of learning opportunities). (2) European symposia, even invited, at US American conferences, like the well-known NARST conference, hardly show participants from the US research community in the audience. (3) Why do reviewers ask for the relevance of a study for the US education system when the journal especially invites international authors, when the same question is probably not stated for US studies with regard to the rest of the worlds' educational systems? Is it a "David against Goliath" development when smaller and perhaps less-established research communities from different countries get into the field, often with the extra difficulty of language issues in comparison to native speakers?

Books like this one should open the eyes of researchers around the world for findings and studies from all different parts, as the whole community can learn from each other and plan investigations of especially cultural influences in a more systematic way. Conferences, research visits, and exchanges of young researchers, as well as perhaps special issues of journals inviting different international perspectives on certain topics of interest are certainly promising approaches. The chapters describing trends in Turkey and Korea highlight especially the value of research visits. The chapter by Erduran and Mugaloglu additionally raises the question of where researchers carry out their research: do they develop new trends and quality measures when they return to their home countries? How do they make use of international cooperations starting from PostDoc internships? Do they adapt and further develop research approaches with regard to cultural specific demands and the worldwide development; or do they set up research cultures that might be outdated again in the country of origin, like cultures implemented and kept by emigrants that rather mirror cultures of old ages than nowadays? Again, a strong and dynamic international exchange and cooperation could probably support an international development with regard to specific cultural demands instead of "copy and paste"—cultures. This would certainly also strengthen the creativity and broadness of research and research-based developments in science education.

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Part III
Assessment and Curriculum

Chapter 18
School-Based Assessment of Science Students' Practical Skills in Hong Kong

Derek Cheung

Abstract Practical work is an important component of school science. However, over the past four decades there has been considerable debate about how assessment of science students' practical skills should be conducted as part of the public examination. In 1978, coursework assessment of practical skills was introduced to the Hong Kong Advanced Level chemistry examination and then extended to biology and physics examinations in 1995 and 2002, respectively. Recently, new chemistry, biology, and physics curricula for Hong Kong Secondary 4–6 students (aged about 16–18) were implemented in 2009 and a revised coursework assessment scheme called School-Based Assessment (SBA) was launched. To date, few published studies have investigated secondary school students' beliefs about SBA of science practical skills. This chapter reports on a study involving Hong Kong Secondary 6 chemistry students. Focus group interviews were organized for 36 students and a questionnaire was administered to 306 students drawn from ten schools. Both the interviews and questionnaire survey revealed that most students were skeptical about the worth of SBA and their beliefs about the value of SBA were affected by three major factors: the validity of SBA, formative functions of SBA, and effects of SBA on student motivation to learn chemistry. Multiple regression analysis of the questionnaire data indicated that the most powerful predictor of student beliefs about the value of SBA is the formative functions of SBA, followed by the effects of SBA on student motivation. The implications of these findings for implementation of SBA in school are discussed.

18.1 Introduction

Practical work is an essential ingredient of school science, but paper-and-pencil tests are invalid for assessing student performance when conducting science experiments in the laboratory (Gioka 2008). To assess science students' practical

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skills, some countries, such as England and Australia (Ofqual 2012), have incorporated school-based assessment (SBA) into public examinations. SBA has two important roles—as a complement to written papers in public examinations and as a catalyst for enriching the science curriculum in schools (Cheung and Yip 2004).

However, the involvement of students' own teachers in public examinations has been controversial (Crisp 2013; Harden 2005, 2007). For example, in the UK, Qualifications and Curriculum Authority (QCA 2005) reported that biology, chemistry, and physics teachers for both GCE and GCSE were not happy with SBA. Reiss et al. (2012) reviewed how practical work in school science was assessed in England by three awarding bodies. They found that there was limited amount of any direct assessment of practical skills by teachers. Many teachers relied on marking of student written reports, indicating that some assessments just focused on students' understanding of practical work rather than their performance in actually doing it. The unreliability and bias in teachers' assessment, additional workload for school teachers, and extra resources required for moderation procedures were also noted by researchers in the UK (Harden 2005; Parkes and Maughan 2009; Putwain 2009).

In 2009, secondary schooling in Hong Kong was shortened from seven to six years (referred to as Secondary 1–6). Secondary 6 students are required to take the new Hong Kong Diploma of Secondary Education Examination administered by the Hong Kong Examinations and Assessment Authority (HKEAA). Twelve school subjects have an SBA component, and this chapter focuses on the chemistry curriculum (CDC and HKEAA 2007) for Secondary 4–6 students (approximately 16–18 years of age). The external chemistry examination consists of two parts: theory papers (80 % weighting) and SBA (20 %). The SBA scheme requires chemistry teachers to assess their students' practical skills when conducting laboratory work in Secondary 5 and 6. The laboratory work includes volumetric analysis, identification of cations and anions, and experiments suggested in the chemistry curriculum (CDC and HKEAA 2007). A statistical moderation procedure is used by the HKEAA to adjust SBA marks against the theory marks. The characteristics of Hong Kong's SBA scheme are detailed in the next section.

There is little doubt that a chemistry teacher watching over and working with a student throughout a two-year period is better able to assess the student's practical skills than is a single external practical examination. However, owing to large class sizes, time constraints and other barriers to implementation of SBA, some Hong Kong teachers have complained about the need to implement SBA. Consequently, the HKEAA has made some changes in the SBA scheme to alleviate teacher concerns. The changes include a reduction in the number of assessments required and the use of investigative laboratory work as an optional assessment task. Do chemistry students in Hong Kong generally believe that SBA is good for them? Students' beliefs are critically important because they affect their interest in a school subject and classroom behaviors (Leder et al. 2002). For example, if a chemistry student does not believe that SBA is valuable, he or she will not be willing to actively participate in the assessment process; the effectiveness of the implementation SBA in school will be adversely influenced. Research has also indicated that students' beliefs influence their academic achievement (Cheung 2015) and attitudes toward a science discipline (Kapucu and Bahçivan 2015).

In Hong Kong, most previous research on SBA focused on teachers' views on internal assessment, typically finding that they were concerned about the dual roles of teacher and assessor (Yung 2001a), the fairness of SBA (Cheung 2001; Yung 2001b), and the additional workloads involved (Cheung an Yip 2003). For example, Yung (2001a) documented how three Hong Kong teachers performed the dual roles of teacher and assessor in the SBA scheme for Advanced Level biology. While one teacher was able to integrate the SBA assessments with normal teaching nicely, the other two teachers did not understand the rationale for SBA and thus created a very tense learning atmosphere in practical lessons. Cheung and Yip (2003) surveyed 372 Hong Kong chemistry teachers and found that they were most concerned about heavy workloads, resources and support, moderation mechanism, student workload, students' motivation, and teacher collaboration.

Although the importance of teacher assessment of practical skills has been highlighted by many researchers, few published studies have investigated students' beliefs about SBA. In the UK, QAC (2005) interviewed 460 students. Some students reported that they valued the coursework in those subjects they enjoyed. SBA not only helped them with planning and information technology skills, but also increased their knowledge of the subjects. However, the repetition of tasks was a tedious aspect of SBA for them, particularly in subjects they disliked. Fifty percent of students found SBA stressful at certain times of the year with the bunching of deadlines. Some students also admitted trying to download coursework from the Internet, using the coursework of friends or siblings as their own, or engaging in collusion with friends when working on coursework. In Singapore, a small number of students were interviewed, but no details are available in Hoe and Tiam (2010). Students preferred SBA to a one-off practical examination because SBA can assess their practical skills more accurately and provide them more opportunities to show their capabilities.

This chapter reports on my investigation of the major factors affecting Hong Kong students' beliefs about SBA, using secondary school chemistry as the context for research. I used a mixed-methods research design and aimed to answer two questions:

1. Do Hong Kong students believe that SBA is a good way to teach and learn chemistry in school?
2. What are the major factors affecting students' beliefs about the value of SBA?

18.2 Historical Development of School-Based Assessment in Hong Kong

Students in Hong Kong, as is the case in other Asian countries, are heavily influenced by external examinations. They have high stakes for students in relation to future education (e.g., for selection of students for entrance to university). Thus, competitive examination cultures are dominant in Hong Kong.

Science educators (e.g., Cheung and Yip 2004; Giddings and Hofstein 1980; Kempa 1986; Pang 1992) generally agree that school-based assessment of students' practical skills is better than external, time-limited written or practical examinations. Written practical tests cannot cover all the important experimental skills and processes. For example, they cannot validly assess whether a chemistry student can work safely in the laboratory, can assemble apparatus to carry out distillation, can observe the color changes during a titration, and can take accurate measurements using real apparatus. One-off, external practical examinations also cannot cover everything. They may confine the practical work done by students in school because teachers tend to limit their choice of experiment to those that resemble the type of experiment usually occurring in the external practical examination.

Secondary schooling in Hong Kong used to be seven years (referred to as Secondary 1–7). Students took the Hong Kong Certificate of Education Examination (HKCEE) at the end of Secondary 5. Those students with good HKCEE results continued their studies in Secondary 6 and 7 and took the very competitive Hong Kong Advanced Level Examination (HKALE). The results of HKALE were used to allocate a limited number of university places.

In 1978, a school-based assessment component called Teacher Assessment Scheme (TAS) was introduced by the Hong Kong Examinations Authority (later renamed as HKEAA) to the Advanced Level chemistry examination as an alternative to a 'one-shot' external practical examination. The ideas of TAS were imported from the UK (Cheung and Yip 2003). Before TAS was introduced to Hong Kong, Secondary 7 chemistry students were required to take an external practical examination, focusing on only two types of practical skills: volumetric analysis, and qualitative analysis of unknown compounds. The backwash effect of the external practical examination on teaching and learning of chemistry was that most teachers administered repeated volumetric analysis and qualitative analysis experiments to drill students' manipulative skills. The TAS scheme for practical chemistry was extended to the Advanced Level Biology and Physics examinations in 1995 and 2002, respectively. However, allocation of human and other resources were biased toward the development phase of the SBA schemes; few efforts were made by the HKEAA to monitor the degree of implementation of those schemes at the school level (Cheung et al. 1996).

Commencing from 1997, the TAS became a compulsory component of the Advanced Level chemistry examination. The HKEAA allocated 20 % of total marks to the TAS. Teachers had to assess students' manipulative skills, presentation of data, interpretation of results, planning of experiments, and attitudes toward practical chemistry continuously during the two-year advanced level chemistry course. Students were required to carry out a minimum of 18 experiments in Secondary 6 and 10 experiments in Secondary 7. Internal assessments should cover the following three ability areas:

- Ability area A (40 %)—manipulative skills, skill in observation, and general bench performance.
- Ability area B (40 %)—presentation of data, interpretation of results, and planning of experiments and project work.
- Ability area C (20 %)—attitude toward practical chemistry.

For illustrative purposes, the chemistry experiments performed by a class of students are shown in Tables 18.1 and 18.2. According to the TAS, each student should be assessed by the teacher on at least five occasions for ability A when conducting routine practical work, five occasions for ability B, and two occasions for ability C. It was not necessary for all students to be assessed on the same occasion or on the same practical. Ability areas A and B may be assessed together, but not every experiment need to produce assessments of both areas. In addition, the HKEAA suggested that the scope of chemistry experiments done by a class should cover four areas: changes in substances and patterns of these changes, equilibria, kinetics, and energetics. Three types of experimental work were also recommended: preparative, quantitative, and qualitative. The TAS provided teachers with great flexibility. They were free to select their methods of assessment, decide the number of students to be assessed in a practical session and the types of practical skills to be assessed, but assessments should not be done under examination conditions. In other words, during TAS practical work, teachers should not deny help to students; they should treat a TAS practical first as a teaching situation and second as an assessment occasion. For example, teachers may unobtrusively observe students during normal laboratory activities to make assessments in ability area A. Students' performance in ability area B can be assessed by written laboratory reports, questioning, oral reports, or quizzes. For ability area C, students were only rated at the end of Secondary 6 and Secondary 7 by teacher impression.

Teachers were allowed to choose experiments from any topics as long as those experiments covered the required scopes and types of work. As a result, teacher-assessed tasks varied from teacher to teacher and from school to school. For each ability area, teachers were asked to award marks using a 10-point assessment scale, with 1 being very weak and 10 very good. Marked student work was sampled by the HKEAA as part of quality control, but there was no other standardization policy (e.g., a common set of mark descriptors, cross marking of students' reports of practical work, standardization meetings). The HKEAA used a statistical moderation procedure to adjust the raw TAS marks submitted by schools. The chemistry theory papers served as the moderating instruments, but they did not contain any questions specifically designed to assess experimental practical skills. The external moderation procedure assumed that there is a positive correlation between the raw TAS and theory marks. Moderation of TAS marks was done on a teacher basis; the

Table 18.1 Sample chemistry experiments performed by Secondary 6 students

No.	Title of experiment	Assessment[a]	Area[b]	Type[c]
1	To compare the ΔH for the conversion of NaOH(s) to NaCl(aq) by two routes	N	En	Qn
2	To determine the ΔH for the hydration of anhydrous $MgSO_4$ by indirect method	N	En	Qn
3	To determine the ΔH of formation of $CaCO_3$ by indirect method	B	En	Qn
4	To determine the relative molecular mass of a fairly volatile liquid	N	Ch	Qn
5	To develop a simple and systematic method of identifying cations	N	Ch	Ql
6	To identify an unknown inorganic compound	A	Ch	Ql
7	To investigate H-bonding in liquid systems	N	En	Qn
8	To determine the percentage by mass of CH_3COOH in commercial vinegar by titration	N	Ch	Qn
9	To determine the mass of vitamin C in commercial tablets	A, B	Ch	Qn
10	Laboratory extraction of limonene from oranges	N	Ch	P
11	To compare the chemical properties of alkanes and alkenes	N	Ch	Ql
12	To investigate and compare some reactions of methylbenzene and methoxybenzene	A	Ch	Ql
13	To prepare methyl 3-nitrobenzoate from methyl benzoate	A	Ch	P
14	To investigate the rate of reaction between H_2O_2 and I^- ions in acidic solution	N	Ki	Qn
15	A kinetic study of the reaction between MnO_4^- and ethanedioic acid	A	Ki	Qn
16	Nucleophilic substitution reactions of halogenoalkanes	A, B	Ch	Ql
17	The preparation of 1-bromobutane from butan-1-ol	N	Ch	P
18	Purification and boiling point determination of 1-bromobutane	A	Ch	Qn
19	To investigate the general chemical properties of ethanol	A	Ch	Ql
20	To investigate and compare the chemical properties of butylamine and ammonia	A, B	Ch	Ql
21	To investigate the reactions of benzene diazonium chloride	N	Ch	P, Ql
22	Preparing a crystalline derivative of carbonyl compound	A	Ch	P

Notes [a]*A* the experiment was assessed through laboratory performance, *B* the experiment was assessed through written report, *N* the experiment was not used for assessment
[b]*Ch* changes in substances and patterns in changes in substances, *Eq* Equilibria, *Ki* Kinetics, *En* Energetics
[c]*Qn* Quantitative exercises, *Ql* Qualitative exercises, *P* Preparative exercises

Table 18.2 Sample chemistry experiments performed by secondary 7 students

No.	Title of experiment	Assessment[a]	Area[b]	Type[c]
1	Boiling-point composition diagrams for nonideal liquid systems	N	Eq	Qn
2	To determine the partition coefficient of succinic acid between water and ether	A	Eq	Qn
3	To determine the K_c of $Fe^{3+} + SCN^- \rightleftharpoons FeSCN^{2+}$ by colorimetry	N	Eq	Qn
4	To determine the K_{sp} of $AgIO_3$ by titration	A	Eq	Qn
5	The chromatographic separation of amino acids	A	Ch	Ql
6	To construct and measure the e.m.f. of some electrochemical cells	N	Eq	Qn
7	To investigate the effect of changes in $[Cu^{2+}]$ on the potential of the $Cu^{2+}(aq)/Cu(s)$	A	Eq	Qn
8	To measure Ka for bromophenol blue and benzoic acid	B	Eq	Qn
9	To investigate the pH changes during acid–base titration	N	Eq	Qn
10	To prepare some chlorides of elements in the third period of the Periodic Table	A	Ch	P
11	To determine the number of molecules of water of crystallization in $BaCl_2(s)$ by titration using chromate as indicator	A, B	Ch, Eq	Qn
12	To investigate the general trends in solubility of GpIIA salts using precipitation experiments	N	Ch	Qn
13	To investigate the redox reactions of vanadium	N	Ch	Ql, P
14	Investigation of the oxidation numbers of manganese	A	Ch, Eq	Ql
15	To determine the percentage of Mg in an indigestion tablet by complexometric titration	A, B	Ch	Qn

Notes [a]*A* the experiment was assessed through laboratory performance, *B* the experiment was assessed through written report, *N* the experiment was not used for assessment
[b]*Ch* changes in substances and patterns in changes in substances, *Eq* Equilibria, *Ki* Kinetics, *En* Energetics
[c]*Qn* Quantitative exercises, *Ql* Qualitative exercises, *P* Preparative exercises

mean mark of students within a class may be moved up or down. Thus, moderation may involve increasing or decreasing the marks awarded to the entire class of students rather than rearranging the order or marks of individual students. The moderated TAS marks were aggregated with the theory marks, with a weighting ratio of 20:80, to produce each student's final score and grade.

In 2009, secondary schooling in Hong Kong was shortened from seven to six years. Both HKCEE and HKALE were replaced by the Hong Kong Diploma of Secondary Education (HKDSE) examination. Unlike the HKALE, the HKDSE was designed to be studied by the full range of students, and the first HKDSE examination was held in 2012. Within the HKDSE, there were both external and internal assessments of students taking chemistry. The externally assessed component consisted of two written theory examination papers with weighting equal to 80 % of the total chemistry score. These two theory papers were externally marked. The internally assessed component involved SBA worth 20 % of the total chemistry score.

The rationale for the SBA component was presented in HKEAA (2009). Teachers were required to make at least eight school-based assessments per student in Secondary 5 and Secondary 6. The minimum number of experiments to be completed in Secondary 4, 5, and 6 was not specified by HKEAA (2009). Nor were the chemistry topics (e.g., chemical equilibrium, kinetics, energetics) and maximum class size. The laboratory work included volumetric analysis, identification of cations and anions, and experiments suggested in the chemistry curriculum guide (CDC and HKEAA 2007). Sample assessment tasks and marking criteria were published by the HKEAA (2010). An example is displayed in Table 18.3. Like the former TAS scheme, the SBA scores were externally moderated by a statistical procedure.

Furthermore, the initial design of the SBA scheme for practical chemistry proposed to include investigative project work and nonpractical work as compulsory tasks from 2014 in order to broaden the scope of internal assessment (CDC and HKEAA 2007, 2009). The nonpractical work aimed to assess chemistry students' generic skills such as creative thinking, critical thinking, and communication skills. Below are three examples of nonpractical SBA tasks:

- Design a poster or pamphlet to persuade people to follow the principles of green chemistry.
- Write a report to present the scientific knowledge and concepts acquired after a visit to a chemical plant.
- Develop a multimedia artifact to illustrate the synthesis of polymers.

Table 18.3 Sample assessment criteria for volumetric analysis (HKEAA 2010)

Marks	Remarks
10–9	• There are at least four titration readings (including the trial) • The titration readings are recorded in 2 decimal places • The titration results are accurate (i.e., within $\pm$ 0.05 cm^3) and the standard deviation of the titres is small (i.e., within $\pm$ 0.05 cm^3) • Color changes are accurately recorded • Calculations are accurate and concise
8–6	• There are at least three titration readings (including the trial) • The titration readings are recorded in 1 decimal place • The titration results are reasonably accurate (i.e., within $\pm$ 0.15 cm^3) and the standard deviation of the titres is reasonably small (i.e., within $\pm$ 0.15 cm^3) • Color changes are accurately recorded • Calculations are accurate and concise
5–3	• There are at least two titration readings (including the trial) • The titration readings are recorded • The titration results are barely accurate (i.e., within $\pm$ 0.25 cm^3) and the standard deviation of the titres is reasonable (i.e., within $\pm$ 0.25 cm^3) • Color changes are accurately recorded • Calculations are appropriate
2–1	• There is at least one titration reading (including the trial) • The titration readings are recorded • Color changes are recorded • Calculations are shown

Table 18.4 The requirements for the 2014 Hong Kong chemistry examination

Component	Description	Duration	Weighting (%)
Public examination (Paper 1)	The paper consists of multiple-choice questions and short free response questions. Students are required to answer all questions	2.5 h	60
Public examination (Paper 2)	The paper consists of structured questions about three elective topics: industrial chemistry, materials chemistry, and analytical chemistry. Students are required to select two topics	1 h	20
School-based assessment (SBA)	Teachers assess their students' practical skills at least four times. Chemistry experiments include volumetric analysis, qualitative analysis of unknown substances, and experiments suggested in the chemistry curriculum (CDC and HKEAA 2007). Investigative study is optional	Secondary 5 and 6	20

Unfortunately, owing to large class sizes, time constraints, serious learner diversity, and other difficulties with implementation of SBA, some chemistry teachers complained about the need to conduct SBA in Secondary 5 and Secondary 6. Also, there were grave doubts expressed by teachers and parents at the time SBA was being introduced to other school subjects such as Chinese Language and Liberal Studies. Consequently, HKEAA (2013a) further reduced the minimum number of school-based assessments of practical chemistry, canceled nonpractical work, and treated investigative laboratory work as an optional assessment task. These changes resulted in watering SBA down to include only a few types of practical work and a small number of assessment tasks. The requirements for the HKDSE chemistry examination held in 2014 are summarized in Table 18.4. An investigative study is optional and can be used to replace two traditional experiments. The fact that the internally assessed tasks cannot ensure content representativeness must reduce the validity of SBA scores.

18.3 Methodology

In 2013, a mixed-methods research design was used to investigate Hong Kong Secondary 6 chemistry students' beliefs about SBA. Secondary 6 students were chosen because they had completed all their SBA tasks when data were collected from them. In Hong Kong, schools are classified as Band 1, Band 2, and Band 3 schools by the government based on the ability of their Secondary 1 students. Students of high ability go to Band 1 schools while those of low ability study at Band 3 schools. Six schools were invited to participate in my research, with two schools from each band. In each school, the chemistry teacher was asked to select six students on the basis of their previous chemistry achievement, with two students from the top third of the class, two from the middle third, and two from the bottom third. A total of 36 students were selected from the six secondary schools to take part in focus group interviews, each 30–45 min in duration. Two to three students from each school were organized into focus groups, totaling 13 groups. The focus group interviews were semi-structured to allow room for students to express their views on SBA. Each interview was based around nine key questions:

- Please tell me two examples of chemistry lab experiments used by your teacher for SBA.
- Were the SBA experiments related to your chemistry theory lessons?
- Please tell me how school-based assessments were conducted in your chemistry lab. Were they conducted in the normal chemistry lessons? After school? Were you required to submit lab reports? Any time-limit for the completion of a lab report?
- After a school-based assessment, did your teacher let you know how to improve practical skills? If so, how?
- What do you think are the strengths of SBA?
- What do you think are the weaknesses or limitations of SBA?
- In your view, is it important for the external chemistry examination to have an SBA component? Why?
- Some students believe that SBA should be an integral part of the external chemistry examination. Do you agree with that view? Why?
- Is there anything else you would like to add about your reasons for why SBA should or should not be an integral part of the external chemistry examination?

During each interview, I served as a facilitator, keeping discussion focused and ensuring that each student had opportunities to express his or her views freely. The semi-structured interviews were conducted in Cantonese and digitally recorded. The coding process of the qualitative data consisted of three phases. First, verbatim transcripts were made from the digital records. Then, a research assistant and I independently analyzed a subset of the transcripts, focusing on the factors affecting students' beliefs about SBA. We compared and discussed the coding categories until a consensus coding scheme was obtained. Finally, the research assistant and I, working independently, applied the coding scheme to analyze each transcript. The inter-rater reliability was 95 %.

To determine the relative importance of the major factors affecting students' beliefs about SBA, a quantitative survey was administered in 2013. Based on the findings of focus group interviews, at least three questionnaire items were constructed to measure each factor affecting students' beliefs about SBA (see Table 18.5). The items were in Chinese. A total of 306 Secondary 6 chemistry students from ten schools participated in the survey. The data were collected toward the end of the academic year for Secondary 6 students. They were invited to rate 16 items on a 7-point scale (1 = strongly disagree, 7 = strongly agree). The reliabilities of student responses to the individual items and to the four measurement scales

Table 18.5 Reliability estimates and item-total correlations

Scale and item	Item-total correlation
Value of SBA (estimated α = 0.88)	
• The weighting of SBA in chemistry should be more than 20 %	0.62
• SBA is a fair examination system	0.67
• SBA in chemistry should be canceled. (coded reversely)	0.72
• SBA is good for chemistry learning	0.72
• SBA should be kept in the chemistry examination	0.80
Enhancement of validity (estimated α = 0.67)	
• SBA is more accurate than an external practical examination to assess student performance	0.44
• SBA can accurately assess students' practical skills	0.55
• Chemistry teachers are the best persons to assess their own students' performance in practical work	0.47
Formative functions of SBA (estimated α = 0.87)	
• SBA is a good system because teachers can provide students with frequent feedback on how to make improvement	0.66
• SBA can provide students with good opportunities to apply what they have learned from theory lessons	0.73
• SBA experiments are useful because they can help me review chemistry concepts	0.73
• SBA can help me to acquire a wider range of practical skills than external practical examinations	0.69
• SBA should be kept in chemistry because students can see their progress in learning laboratory skills	0.73
Effects of SBA on student motivation (estimated α = 0.90)	
• SBA makes chemistry laboratory work become more enjoyable	0.78
• SBA can increase my interest in studying chemistry	0.78
• SBA can increase my interest when doing chemistry experiments	0.83

were examined on the basis of item-total correlations and values for Cronbach's alpha, respectively. The construct validity of student data was tested by exploratory factor analysis. Multiple regression analysis was used to compare the predictive power of different factors affecting students' beliefs about SBA.

18.4 Results

18.4.1 Student Interviews

Overall, about 70 % of the 36 students interviewed had reservations about the value of SBA, and there was no discernible difference between students from the three bands of schools or from different achievement levels within a class. For example, 25 students did not believe that SBA is a fair examination system. Twenty-two students stated that the weighting of SBA in the chemistry examination should be lower than 20 %. Their unfavorable beliefs about the value of SBA are illustrated by the quotes below, and the number inside the parenthesis refers to the coding system for focus groups when interview data were analyzed.

> I don't think the current SBA scheme is well designed. My teacher didn't allow us to do project work. I want to experience the different phases in a scientific investigation. (4)
> SBA is not a fair assessment method. Chemistry teachers in different schools may design different SBA experiments. Even students in the same class may be assessed using different experiments. (13)
> I think either SBA or an external practical exam is okay. No assessment method is perfect. (3)
> Some teachers may not have the capability to assess their students' lab skills by direct observation. HKEAA does not monitor the actual assessment procedures used by individual teachers. (5)
> The weighting of SBA is a bit heavy. It should be less than 20 %. Also, the moderation method does not make sense. HKEAA should not use theory marks to adjust SBA marks. (9)
> I heard that a lot of teachers in other schools are not serious when conducting SBA. HKEAA should improve the SBA scheme. (11)
> We spent too much time on writing lab reports. My teacher should be reasonable in his demands. I think it's more worthwhile if students are allowed to spend their time to prepare for theory papers. (2)

Only 35 % of students reported positive experiences with SBA in their schools and believed that SBA is worth implementing in chemistry. Three major factors affecting their beliefs about SBA emerged through the analysis of the interview data. Some representative student quotes are presented below to illustrate the characteristics of these three factors.

Validity of SBA. In interviews, those students who valued SBA uniformly viewed practical work as an important component of school chemistry. They commonly cited the accuracy of teachers' assessments as the main reason for implementing SBA in Hong Kong.

> SBA is good because it can assess lab skills that cannot be assessed by written theory papers. Lab work is the most important part of chemistry. (8)
> There are eight SBA assessments across a two-year period. So, students have more than one chance to be assessed. I think SBA is more accurate than an external practical exam. (10)
> An external practical exam cannot cover a wide range of analytical techniques. I think my teacher is the best person to accurately assess my practical skills. (7)

However, many students across focus groups queried the validity of teachers' assessments because their teachers had relied on written lab reports when making school-based assessments. In other words, Hong Kong chemistry teachers generally used an indirect rather than a direct method of assessment of practical skills.

> I heard that in some schools, the chemistry teachers just look at their students' lab reports. They don't observe and record their students' actual performance skills when conducting SBA experiments. Some lab skills cannot be assessed using written lab reports. (1)
> Some students may be good at writing lab reports. They may even copy another student's work or results. (4)
> Written lab reports cannot assess whether a student actually performed experimental skills properly, such as flame test and distillation. (5)

Formative Functions of SBA. In interviews, 22 % the students stated that the SBA scheme can provide them with useful information about their development of chemistry practical skills. Some students also indicated a desire for increasing the weighting of SBA and expanding the scope of internal assessment.

> My teacher asked us to conduct titrations for SBA in Secondary 5. The chemical principles of titration were already taught in Secondary 4. So, SBA can help me review chemical knowledge when conducting titrations. (12)
> SBA is better than an external practical exam because I can obtain frequent feedback from my chemistry teacher on how to make improvement. So, after conducting an SBA experiment, I know where and how to improve my practical skills. (8)
> When worksheets or lab reports are marked and returned to us, my teacher always points out our weaknesses so that we would not make the same mistakes again. She is a very professional teacher. (6)
> Continuous assessment can also be used to assess other important skills such as oral presentation skills. The weighting of SBA may be slightly increased to cover other performance skills. (10)

In contrast, about 80 % students reported that they had not received any detailed, formative feedback from their teachers. Some students suggested that SBA should last for three rather than two years so that teachers' assessments can facilitate students to learn chemistry in Secondary 4 and cover a wider range of topics.

> My teacher didn't care about SBA. She didn't provide detailed feedback after marking my worksheets and lab reports. I just received a single grade. No further comments were provided by her. (4)
> We were asked to identify unknown cations and anions in several lab experiments, but my teacher didn't tell us how to improve manipulative skills. (11)
> Why was SBA not implemented in Secondary 4? For example, the chemical principles of volumetric analysis were taught in Secondary 4, but all the titrations were conducted in Secondary 5 rather than Secondary 4. The timing of our lab experiments was problematic. I think a few SBA experiments may be done in Secondary 4. They may be related to topics such as metals, redox reactions and electrochemistry. (1)

Effects of SBA on Motivation. Nearly 50 % students across focus groups stated that SBA can motivate them to learn school chemistry. They enjoyed their hands-on experiences in the chemistry laboratory, especially SBA tasks well embedded in their normal chemistry lessons.

> I like laboratory work. It can increase my interest in studying chemistry. SBA is good because it assesses practical skills. (10)
> SBA can make students pay more attention to lab work, including lab safety and time management. They carry out their lab experiments more seriously. (7)

However, about half of the students in the sample hated SBA due to heavy workloads, pressure, or repetitiveness of the same type of laboratory work. They especially disliked SBA tasks administered after school or under examination conditions.

> In my school, SBA experiments were very time-consuming. Sometimes, we had to stay at school until 6 pm to finish our lab reports. (2)
> Each SBA lab was like a mini practical exam. I was not allowed to talk to my classmates when conducting experiments. I don't like this kind of learning environment in school. (3)
> In the last six months, we repeated the same type of lab work – titration. It's boring. My

teacher said the titrations were aimed to train our manipulative skills so that we could get high SBA scores. He is very exam-oriented. But I would like to carry out other types of experiments such as determination of the activation energy for a reaction and preparation of an organic compound. (13)

Clearly, the three quotes above indicate the dissonance between students' and teachers' expectations. On the one hand, some students believed that their teachers were too demanding or acted as examiners rather than classroom teachers and long labs, examination conditions and repeated experiments were not necessary. On the other hand, some teachers intentionally concentrated on only two types of practical work specified in the SBA scheme (i.e., titrations and identification of unknown substances) to drill students' skills.

18.4.2 Questionnaire Survey

The item-total correlations ranged from 0.44 to 0.83 and the Cronbach's alpha values varied between 0.67 and 0.90 (see Table 18.5). Hence, the student data were of acceptable reliability. The dimensionality of the 16 items was analyzed by maximum likelihood factor analysis. Only one factor with eigenvalue greater than 1 was generated and accounted for 54.3 % of the item variance. Further research is being planned to refine the items. Means, standard deviations, and Pearson correlations are shown in Table 18.6. On a 1–7 rating scale from 'strongly disagree' to 'strongly agree,' the value that chemistry students placed on SBA was not high ($M = 3.79$, $SD = 1.42$). The four variables were all positively correlated, and the correlation between students' beliefs about the value of SBA and their beliefs about the formative functions of SBA was the largest ($r = 0.88$, $p < 0.01$).

The results of the multiple regression analysis predicting chemistry students' beliefs about the value of SBA are displayed in Table 18.7. The linear combination

Table 18.6 Pearson correlations, means, and standard deviations for variables

	Variable	1	2	3	*M*	*SD*
1	Value of SBA				3.79	1.42
2	Enhancement of validity	0.69[a]			4.35	1.21
3	Formative functions	0.88[a]	0.73[a]		4.17	1.28
4	Effects of SBA on motivation	0.76[a]	0.59[a]	0.75[a]	3.69	1.50

Note [a]Correlation is significant at the 0.01 level (2-tailed)

Table 18.7 Results of multiple regression analysis predicting students' beliefs about the value of SBA

Predictor	Beta	Structure coefficient	Partial correlation	Part correlation	Unique variance explained (%)
Validity	0.096*	0.775	0.144*	0.066*	0.4
Formative	0.649**	0.984	0.626**	0.362**	13.1
Motivation	0.212**	0.848	0.294**	0.139**	1.9

Note $R^2 = 0.796$, *p < 0.05, **p < 0.001

of predictors was significantly related to students' beliefs about the value of SBA, F (3, 302) = 393.58, $p < 0.001$. The sample multiple correlation coefficient was 0.892 and R square was 0.796, indicating that 79.6 % of the variance of students' beliefs about the value of SBA in the sample can be accounted for by the linear combination of the three predictors. All the standardized beta coefficients were significant. Table 18.7 also presents the structure, partial and part coefficients for each predictor variable. The most powerful predictor was the formative functions of SBA, followed by the effects of student motivation to learn chemistry. The structure coefficient for the formative functions predictor was equal to 0.984, meaning that this predictor can explain 96.8 % of the total variance accounted for by all the three predictors. Partial correlation represents the relationship between each predictor and the dependent variable, controlling for the effects of all other predictors in the model. Squaring the part correlation gives the unique variance explained by a predictor, and 13.1 % of unique variance was explained by the formative functions predictor.

18.5 Discussion

The results of focus group interviews indicate that most chemistry students doubted about the worth of SBA due to reasons such as lack of inquiry-based project work, inappropriate moderation method, heavy workloads, and unfairness of teacher assessment practices. Implementing inquiry-based laboratory work in science education has been a challenging and divisive issue in Hong Kong. Given the shortage of instructional time, Hong Kong teachers generally think that it is impossible to fit several inquiry-based laboratory experiments into their regular teaching schemes. Even for guided inquiry laboratory experiments, my earlier research (Cheung 2011) revealed that Hong Kong chemistry teachers tend to believe that students dislike conducting this kind of practical work and it is not feasible for students to design their experiments in the normal chemistry lessons. Recently, Hofstein and Kind (2012) reviewed science learning in and from laboratories and drew the following conclusion:

> The biggest challenge for practical work, historically and today, is to change the practice of 'manipulating equipment not ideas'. The typical laboratory experience in school science is a hands-on but not a minds-on activity. This problem is related to teachers' fear of losing control in the classroom and giving students more responsibility for their learning. Also, the current situation can be blamed on assessment practices that do not pay enough attention to higher-order thinking and a long tradition of developing foolproof laboratory tasks that guide students through activities without requiring deep reflection. (p. 202)

Hong Kong chemistry teachers varied in their SBA practices, their levels of demand for students, and their degree of commitment to SBA. Although investigative laboratory work is an excellent teaching aid to promote minds-on learning activities, it is optional in the current chemistry SBA scheme in Hong Kong. Unsurprisingly, few chemistry teachers organized investigative work for their students.

Furthermore, many students believed that SBA is not a fair assessment scheme and blamed the statistical moderation method used by the HKEAA. There are several ways to moderate SBA scores (Harlen 2007; Queensland Studies Authority 2010), and the weaknesses of statistical moderation are well documented in the literature (Cheung and Yip 2003). According to Harden (2005), “experience shows that moderation of teachers’ judgements, necessary for external uses of summative assessment, can be conducted so that it not only serves a quality control function, but also has an impact on the process of assessment by teachers, having a quality assurance function as well” (p. 221). The HKEAA is therefore encouraged to consider existing SBA moderation methods in other countries and to weigh up the advantages and disadvantages of different moderation methods to address Hong Kong students’ concerns about SBA.

The results of focus group interviews also indicate that those students who valued SBA touched on at least one of the three major factors: SBA can enhance the validity of public examinations; SBA has formative functions to facilitate students to learn chemistry; and SBA can motivate students to learn chemistry in school. As presented in Table 18.7, the results of multiple regression analysis show that the most powerful predictor of student beliefs about SBA is the formative functions of SBA, followed by the effects of SBA on student motivation to learn school chemistry. These findings have important implications for the implementation of SBA in Hong Kong and suggest that many students may not fully understand why SBA is more valid to assess their practical skills than written theory papers or an external practical examination. For many assessment specialists (e.g., HKEAA 2013a, b; QAC 2005), enhancement of the validity of public examinations is the most important reason for implementing SBA. For example, the HKEAA (2013b) published a booklet to guide Hong Kong students to complete SBA. It described the main rationale for SBA is to “enhance the validity of the public assessment and extend it to include a variety of learning outcomes that cannot be assessed easily through public examinations” (p. 1). Perhaps the HKEAA needs to explain in more detail why SBA can enhance validity of public examinations and provide specific examples to illustrate the concept of validity. Kennedy et al. (2008) also discussed the relationship between SBA and validity:

> In the Hong Kong context, the inclusion of school-based assessment based on the teachers’ judgment as part of a broader examination system has been an important step forward to try and ameliorate the negative ‘backwash’ from external summative assessment… School-based assessment undertaken by teachers can contribute to external summative assessment in a way that enhances the consequential validity of summative assessment. (p. 204)

SBA cannot enhance the validity of the external chemistry examination unless specific assessment criteria are used by teachers and the assessment tasks cover a wide range of practical skills. Unfortunately, the current chemistry SBA scheme does not provide adequate content representativeness. In England, Brown (1998) compared two methods of marking SBA biology investigations and found that if biology teachers’ marking was loosely criterion-based around four skills (i.e., planning, implementing, interpreting and concluding, and researching) rather than by the use of a structured mark scheme, teachers' assessments were not different from the objectives assessed by the theory papers. Brown's (1998) finding confirmed that school teachers' assessments may not enhance the validity of an external examination unless appropriate assessment criteria are used by them.

The most powerful predictor of students' beliefs about the value of SBA is its formative functions. Students who believed that SBA can help them learn school chemistry in Secondary 5 and 6 tended to believe that SBA should be an integral part of the public chemistry examination. Because the value that chemistry students placed on SBA was not high ($M = 3.79$, $SD = 1.42$), the HKEAA should explore how to strengthen the formative features of SBA in Hong Kong. In the UK, QAC (2005) documented that most teachers "treated coursework as a method of formative assessment until the deadline date was reached" (p. 13). In Australia, SBA has long been used to replace public examinations in Queensland (Harden 2005, 2007). Student work collected in portfolios is used to provide feedback to students at the time it is completed as well as being used later in assessing their overall attainment in a school subject. Thus, the same piece of student work is used for both formative and summative assessments in Queensland. Kennedy et al. (2008) have argued that if the design of summative assessment in Hong Kong can be better harmonized with a learning orientation, summative assessment can play a useful rather than a destructive role in the lives of students.

The second most powerful predictor of students' beliefs about SBA is its effects on student motivation to learn school chemistry. As expected, most students interviewed liked chemistry laboratory work and thought that SBA can provide them with more hands-on experiences. However, about half of the students interviewed did not find SBA of practical chemistry motivating. This finding contradicts QAC (2005). According to QAC (2005), assessment of coursework is "a powerful motivator for many candidates in many subjects, giving them a chance to study an area in greater depth and take more responsibility for their own learning" (p. 5). In New Zealand, practical research projects are built into the chemistry course. Chemistry students carry out open-ended investigation and they are allowed to design their own experiments in support of a research project (Ofqual 2012).

Many Hong Kong students lacked motivation to participate in SBA partly because their chemistry teachers had emphasized learning laboratory manipulative skills through drill without careful consideration for students' needs and interests. The coverage of laboratory experiments was not as wide as intended by the chemistry curriculum (CDC and HKEAA 2007). Even worse, chemistry theory lessons and laboratory work were not well integrated in the teaching plans. Some chemistry teachers stopped organizing practical work for Secondary 4 students or stopped organizing additional practical work as soon as they had completed the minimum number of SBA tasks. It is important to note that practical work is an effective teaching and learning aid in school chemistry. When teachers plan their chemistry lessons, they should build in opportunities for their students to carry out various types of practical work, including laboratory experiments in physical, organic, and inorganic chemistry.

Additionally, during the interviews, some students described SBA labs as mini practical examinations and had to work under the pressure of allowed time, reducing their motivation to carry out laboratory work. This finding should be a major concern to the HKEAA because this kind of assessment practice is not in line with the rationale behind SBA (HKEAA 2013a). In England, Gioka (2008) also found that some science teachers required their students to conduct experiments in silence under examination conditions. They treated classroom teaching and school-based assessment as two separate events, and refused to answer students' questions. I fully concur with Gioka (2008) that SBA should emphasize the assessment of students' routine work in lessons. Similarly, Harden (2007) has suggested that SBA tasks may be embedded in normal student work. To empower Hong Kong teachers to grow professionally, the HKEAA may offer practical workshops to teachers to extend their conceptual knowledge of SBA and assessment skills. The planning and implementation of these workshops should involve the SBA supervisors, coordinators and Education Bureau.

18.6 Conclusion

For school chemistry, the overarching reason to introduce SBA is to enhance the validity of external examinations and encourage teachers to provide their students with opportunities to carry out various types of practical work to improve learning. The HKEAA (2009, 2013a) has revised the SBA scheme considerably over the past three years. Implementing SBA in secondary schools is not easy, but doing so is essential if we want to improve the external examination system in Hong Kong. Chemistry teachers have to face a lot of challenges when implementing SBA, including serious learner diversity, time constraints, and large class sizes. Learner diversity is a very challenging issue in particular, because the HKDSE was designed to be taken by the full range of Secondary 4–6 students. To provide adequate content representativeness, the HKEAA should not continue to water the SBA scheme down to include only a few types of chemistry laboratory work. One possible way to improve the current SBA scheme is to encourage teachers to implement inquiry-based laboratory experiments (Cheung 2011) and include them within regular chemistry lessons.

Understanding students' beliefs and concerns will aid the successful implementation of SBA. To date, there have been relatively few empirical studies investigating secondary school chemistry students' beliefs about SBA. Thus, student is a missing voice as far as research on SBA is concerned. The results of my interviews and questionnaire survey indicate that overall Hong Kong chemistry students are skeptical about the worth of SBA. The major factors which affect students' beliefs about the value of SBA include its validity, formative functions, and effects on student motivation to learn school chemistry. The most important predictor of student beliefs about the value of SBA is the formative functions of

SBA. Therefore, the HKEAA should strengthen the formative features of the current SBA scheme.

A related critical issue is the need to provide Hong Kong chemistry teachers with professional development activities that explicitly teach them how to make internal assessment in the laboratory without turning it into another examination. Professional development activities can also facilitate teachers to reflect on their SBA practices (Yung 2012). However, Hong Kong chemistry teachers have few opportunities to participate in professional development activities (Cheung and Yip 2003). The HKEAA has seen its main task as organizing public examinations rather than dealing with teacher education, whereas the Education Bureau of the Hong Kong Government has viewed SBA as a matter of the public examination system. Only half-day SBA workshops of one-time nature are organized for new chemistry teachers. In Asia, few countries implement SBA of science practical work successfully. Singapore, for example, has made efforts to use SBA to replace the one-time practical examination administered at the end of GCE O- and A-level science courses (Hoe and Tiam 2010; Towndrow et al. 2010). The findings of my study contribute to our knowledge about the design and management of assessment innovation.

As with any research, certain limitations were present in this study. The construct validity of student data collected by the questionnaire items was not good; the four measurement scales failed to yield four separate factors in factor analysis. Further research is needed to improve the quality of questionnaire items. Another limitation is that the present study dealt with only Secondary 6 chemistry students' beliefs about SBA. There is a need to determine the beliefs held by Secondary 4 and 5 chemistry students. A longitudinal study may be conducted to track any changes in student beliefs about SBA over time.

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Chapter 19
Assessing Israeli Students' Knowledge in Science—Policy and Practice

David Fortus

Abstract Other than brainpower, Israel lacks natural resources. As a result, the economy is strongly dependent on its hi-tech, military, and cyber industries. To ensure that the country has a continuous supply of highly trained scientists and engineers, science and mathematics education should be natural priorities. While this appears to be a national policy, in practice it does not always seem to be the case. Students' learning of science, mathematics, and technology is assessed by national tests in elementary, middle, and high school. Students, teachers, and schools are under great pressure to succeed on these tests, leading to a situation where a significant percentage of instructional time is dedicated to preparing for these tests. In parallel, Israel participates in the Trends in International Math and Science Study (TIMSS) and the Program for International Student Assessment (PISA). Since there is great pressure to improve Israel's standing in these tests, teachers are expected to prepare their students for these tests, so many complain that rather than evaluating the performance of the system, tests have become the driver of the educational system. An outcome of this situation appears to be decreasing motivation to learn science, with fewer students choosing to study science as an elective. The minister of education has promised to decrease the testing load and increase the time available for meaningful learning.

19.1 Introduction

Israel is a small country. Its size is only 22,000 km^2 and its population is 7.5 million. It has very few natural resources, mainly potash and magnesium bromide from the Dead Sea. In 2009, a significant offshore reserve of natural gas was found in the Mediterranean Sea, near Lebanon. This reserve has the potential to become the country's main natural resource. In spite of this lack of natural resources, Israeli economy is robust. This is largely due to the prominent role

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played by Israel's world-class hi-tech, cyber, military, and para-military industries. Israel has the highest number of start-ups per capita in the world. In 2009, it was second only to the US in the number of companies on NASDAQ (2009). In 2008, it had the highest venture capital investments per capita in world, more than 2.5 times that of the US, which had the second highest rate of investment (Dow Jones 2008). Both of these statistics are indicative of the prominence of science and technology know-how in Israel's economy.

To maintain this competitive technological edge, it is a national Israeli priority to support science and technological education at all levels. A key component in ensuring the effectiveness and efficiency of any aspect of education is the existence of a robust assessment system. In 2005, the ministry of education established the National Authority of Measurement and Assessment in Education (called RAMA in Hebrew—an acronym). Although RAMA is funded by and continues to provide services to the ministry of education, it remains autonomous of the ministry in its operations and so maintains a degree of objectivity regarding the ministry. RAMA is responsible for designing, grading, and analyzing all national examinations, and oversees Israel's participation in TIMSS (International Association for the Evaluation of Educational Achievement and TIMSS International Study Center 1996) and PISA (Program for International Student Assessment 2003). The remainder of this chapter describes the national assessment system for science education that is in place in Israel.

19.2 The MEITZAV

For many years, almost since the declaration of independence in 1948, the only large-scale assessment of students' knowledge in science in Israel were the matriculation examinations (called BAGRUT in Hebrew) which was given to twelfth grade students majoring in science, in physics, chemistry, or biology. All other students were not required to be tested in science. This changed in 1992, when a national committee examined the state of science, math, and technology education and published ten guiding principles, accompanied by recommendations (State of Israel: Ministry of Education Culture and Sport 1992). The government embraced the committee's entire report with all its principles and recommendations and embarked on a major national reform of it science, math, and technology education. I quote, verbatim, six of the principles from this report:

1. *Today, knowledge of science and technology is the most important economic asset*. More than ever before, the industrial production, economic strength, and military power of a nation are dependent on its population's scientific and technological qualifications. Comprehensive and advanced education in science and technology is at the base of every success and innovation in a wide variety of fields, including defense, industry, agriculture, energy, health, communications, and the environment. The scientific infrastructure may be perceived as a

plant which yields fruit after a decade or two. Education in science and technology lies at the heart of the scientific infrastructure.

2. *Today—and even more in the future—mathematics, science and technology are part of the general education required of every contributing member of society.* Naturally, we do not claim that every person must be a scientist. Nonetheless, a certain ability to think quantitatively and scientifically, the capability to understand and grasp a scientific or technological problem, and an understanding of the basic rules of the language of mathematics, science and technology are essential components in training future professionals, teachers, members of the armed forces, musicians, farmers, businesspeople, school principals, politicians, or any other profession that requires a basic education. A basic knowledge of science and technology is no less vital for the advancement of the less privileged sectors of society, and a special effort should be made in this direction.
3. *Today, science and mathematics are interrelated and they can affect one another in a variety of unexpected ways.* Mathematics and science are the basis for all technological innovations. The boundaries between biology and biotechnology, computer science and electronics, and physics and most technological fields are artificial and outdated. Fields such as environmental science, energy, and agriculture cannot be defined as either science or technology, having elements of both. In the past, technology was considered more of a skill, and work in a technological field did not directly and profoundly involve science. Today, every technological occupation demands an interdisciplinary scientific background.
4. *The teacher plays a central role in science and technology instruction.* The best programs and the best-equipped laboratories will not prove themselves without good teachers. In the end, every subject in the education system stands or falls on the quality, qualifications, and dedication of its teachers.
5. *Science and technology require experiments and laboratories.* The academic side in science and technology education is vitally important. Nonetheless, a scientific theory that has not been confirmed by experiments has no validity, and it is agreed that purely theoretical studies have no place in technological fields. Scientific experimentation, laboratory time, and hands-on work with scientific phenomena and technological systems play a central role in the learning process.
6. *A broad-based approach is required if improvements are to be made in teaching mathematics, science and technology.* Good results can only be produced through an integration of curricula, text books, laboratory aids, computer courseware, well-educated and appropriately trained teachers, well- equipped and properly maintained laboratories, sufficient classroom hours, and a guidance and support system for teachers.

Four of the report's main recommendations were

1. Instruction in mathematics, science and technology should be expanded to include all students in preschool, elementary school, and junior high school, as well as high school students, (in both academic and technical tracks} who do not

receive a broad education in the sciences. This requires, in part, specially trained mathematics teachers at the elementary school level, additional hours for mathematics, science and technology at the junior high school level, and making science and technology part of the required high school curriculum.

2. We must integrate courses in science and technology in the curriculum of students who do not choose to enter a scientific or technological track in high school. The integrated program of science and technology in preschool and elementary school should be expanded. A discipline that incorporates both science and technology should be introduced in the junior high school on a wide scale. Science studies should be expanded in all specializations and tracks of technological education, just as technological studies should be offered in academic high schools.
3. Our recommendations are that teachers should be trained to specialize in teaching mathematics at the elementary school level; computers should be intensively integrated into the teacher training process, in all disciplines and for all age-levels of the education system; technical assistance should be given to teachers who operate laboratories; a range of in-service training workshops should be offered to teachers in all fields of science and technology; support and guidance centers should be established for teachers of science and technology as well as for those who use computers to teach different disciplines; professional journals should be published for educators who teach different scientific and technological subjects; we should create incentives for teachers in development areas and disadvantaged neighborhoods.
4. The integration of laboratories in all subjects and at all age-levels should be emphasized. This requires building additional science rooms and laboratories in elementary and junior high schools, constructing science corners in preschools, updating and upgrading the equipment in the existing laboratories, ensuring that professionals will maintain and use the equipment properly, and most important, a complete and continual integration of academic studies and laboratory experimentation.

The report led to the initiation of one of the largest reforms in Israeli K-12 education. Facilities were built, new curricula developed, and massive teacher training programs were undertaken. Looking back at this report, it is remarkably comprehensive. However, there was one surprising omission: almost no attention was given to the need to revise the national assessment framework to align with all the other recommended changes. So, for example, even after the report was accepted by the government and its recommendation implemented, students continued to be tested in science in twelfth grade only and only if they were science majors. No attention was given to assessing the science knowledge of students, who were not majoring in science or to that of students at younger grades.

Once the reform process was underway, it became clear that regional inspectors needed a regular feedback mechanism, beyond school visits, to allow them to monitor the progress the schools under their jurisdiction were making and what difficulties they were facing. The ministry of education developed a survey that measured students' knowledge of science content and their attitudes toward school. This survey soon developed into a series of tests that were required of all schools and students in Israel; it exists until today and is called the MEITZAV, which is a Hebrew acronym for "measures of school efficiency and growth." The official purpose of this test is to provide school headmasters with information about the achievements of their students. In practice, as we shall see, many teachers view the implemented intent of the test somewhat differently.

The MEITZAV is given in four subjects: Hebrew or Arabic (depending on the students' mother-tongue), mathematics, English, and science and technology. It is administered in second (only the section on mother-tongue), fifth, and eighth grades. It also includes a section on school environment, which is completed by the students, teachers, and headmaster. It is given each year to about half the schools in Israel, in different subjects, so that every school is evaluated in each subject once every 4 years. In the years in which a school is not tested, they are provided with the tests anyway, together with rubrics, to allow the tests to be administered and reviewed internally, with the intent that they will give the teachers and the school headmasters useful feedback in identifying strengths and weaknesses. There are schools that use these exams in lieu of internal final exams.

The science tests are aligned with the national science standards. Elementary school lasts until sixth grade and middle school runs from seventh through ninth grade; however, since the tests are given in fifth and eigth grade (before the end of elementary and middle school), they do not assess knowledge of all topics students are expected to learn at each grade band. However, the standards dictate which topics are to be taught in which year, in which order, and how much time is to be allotted to each topic, so the developers of the tests know which topics should have been taught before the test is administered, and design them accordingly. The tests are cumulative, that is, they assess everything students have earned in science before the test was administered. They are intended to assess both science knowledge and skills, at varying levels of cognitive difficulty. They include both multiple-choice and open-ended items.

The results of the tests and their comparison with national averages are sent to the schools' headmasters and the regional inspectors. The tests do not contain any information about individual students.

As with many other standardized tests, the MEITZAV has the potential to be a useful tool by providing policy-makers, inspectors, headmasters, and teachers information about schools' strengths and weaknesses, helping them identify where attention is needed, which schools need support, whether changes that have been made seem to be effective or not, and so on. However, in practice, there is a general sense that the MEITZAV has become too important; instead of assessing how well schools are helping their students construct a deep and integrated understanding of science, it has become a whip, a high-stakes instrument that drives education instead of assessing it. It has become the tail that is wagging the dog. Science teachers often feel that they are evaluated by their headmasters according to their students' results on the MEITZAV, creating for them the sense that the goal of science education in their schools is to succeed in the MEITZAV. Likewise, headmasters often get the same feedback from the school inspectors. The public and the media have castigated schools that perform poorly.

As a result, a significant percentage of the time allotted to science is spent preparing for the MEITZAV, memorizing facts and excess drilling using tests from earlier years, adding additional tests to the students' schedule in order to "prepare" them for the MEITZAV by simulating the MEITZAV conditions. Other negative responses to the perceived danger in under-achieving on the MEITZAV are making sure low achieving students are "sick" (stay home) on the day of the test, allotting additional instructional time to subjects which are to be tested in the MEITZAV on a given year at the expense of subjects which are not going to be tested, and assigning the best teachers to the grades that are to be tested on a given year.

Many think that the main drawback of the MEITZAV is that it limits teachers' autonomy by creating pressure to perform and emphasizing breadth at the expense of depth. Teachers feel that their hands are tied, they cannot experiment, try new pedagogical approaches, cannot follow their own passions unless they can convince their headmaster that they will support student achievement on the test. It is possible that the MEITZAV's main downside is that it emphasizes, in the students' eyes, performance over mastery, leading to declining student motivation to learn science (Vedder-Weiss and Fortus 2012). Ever since the MEITZAV was introduced in 2002, the number of students choosing to matriculate in one of the sciences in Israel has declined. Thus, it seems that the inept use of the test is having dire consequences for a country that is almost completely dependent on scientific and technological know-how for its economic survival.

In response to this trend, the minister of education announced, near the end of 2013, that the MEITZAV will not be held in its external version in 2014 (it will still be provided to schools for their internal use). A committee will be convened that will evaluate the value of the test and provide recommendations for the future.

19.3 Matriculation

In order to graduate from high school, students need to collect credits. Credits are given for each subject in which students pass a matriculation examination. To matriculate, students must pass matriculation examinations at a minimal level in the following subjects: mathematics (3 credits), English (3 credits), Hebrew (2 credits), history (2 credits), citizenship (2 credits), literature (2 credits), and bible (2 credits). Students are allowed to take these tests at a higher level, if they wish to do so, in which case they get more credits for that subject. Thus, they can take a mathematics exam at the minimal level (3 credits), at an intermediate level (4 credits), or at a high level (5 credits—similar to the AP level in the US). In addition, every student is required to study and be tested in at least one subject, beyond the subjects listed above, at an expanded level (5 credits). Such a subject can be a science subject, theater, geography, cinema, psychology and sociology, Jewish studies, etc. Surprisingly, for a country which is so dependent on science and technology for its economic well-being, students are not required to take a matriculation examination in science and technology. However, this option is available for those who wish to do so, in the following subjects: physics, chemistry, biology, biotechnology, and earth science.

Near the end of ninth grade or during tenth grade, students typically choose which subjects they wish to emphasize. By choosing which subjects they wish to emphasize they are also implicitly choosing which subjects they will study no longer. Thus, if somebody chooses to emphasize on biology, they study no more physics. If somebody chooses to emphasize on a nonscientific subject, they will learn no more sciences. Thus, a situation is created in which about 1/3 of the students study science, in one form or the other, throughout high school while the rest do not. This leads to a situation where the general science literacy of high school graduates is poor because most students stopped studying science in ninth or tenth grade and the rest studied either physics or chemistry or biology or earth science, so they are literate in only one scientific discipline.

A students' final grade in each subject is an average of the grade they received in the matriculation examination (the external grade) and the grade given to them by their teacher in that subject (the internal grade). However, if the average of the internal grades given by a school in a particular subject is significantly higher than the average of the external grades received by that school's students, the weight of the internal grade in determining the final grade may be decreased to 30 or 10 %, but never canceled completely. Teachers typically give their students an internal grade according to their year-long performance and their results on an internal examination. This internal examination is given approximately two weeks before the matriculation examinations and is meant to simulate the matriculation examination. A student's grade-point-average (GPA), which is considered by the university authorities when the student applies for post-secondary studies, is a compound average of the grades the student received in the matriculation examinations. In this way, subjects that were studied at a higher level (they are worth more credits) have greater weight in determining the student's GPA.

The matriculation examinations in a certain subject are checked by teachers who taught that subject that year. The tests are shuffled to make sure that teachers only check tests completed by students from schools in which they do not teach. The tests are identified only by a personal identification number, without any reference to the school or to the student's name. Each test is checked by two teachers. No marks are made by either teacher on the test. The teachers check the tests using a scoring rubric published by the ministry of education. The student's external grade is the average of the scores given to his/her test by the two teacher-checkers. If the difference between the scores given by the two teachers to a test is too great, a third teacher (designated a senior-evaluator) will also check the test; the score given by the senior-evaluator becomes the student's external grade. The teachers are paid for this work. Being a teacher-checker is not compulsory, and many choose to do it because it is viewed as an excellent opportunity for professional development.

Students who have been diagnosed as having special difficulties, such as dyslexia, limited eyesight, new immigrants and therefore not proficient in Hebrew, etc., are provided with special testing conditions, such as extending the time allowed (up to 25 %) to complete a test, enlarged fonts, use of an electronic dictionary, having the test read to them, ignoring spelling mistakes, and so on.

The matriculation examinations in each of the science subjects have several parts. For example, in the physics examination there will be one part on mechanics, one part on electromagnetics, one part on optics, one part on twentieth century physics (an introduction to quantum and relativistic mechanics), and one practical part in which the students are assessed on their ability to perform an experiment. The practical part may be replaced with an individual project where students investigate topics of their choice. The structure of the examinations in the other scientific subjects is similar—different parts covering different core topics, a practical section, and perhaps a section on a topic the teacher chose.

As with the MEITZAV, many concerns have been voiced about the matriculation system:

1. Since the outcome of the time students spend in high school is measured entirely by their matriculation grades, most of high schools are focused on rote learning of the material required to succeed in the matriculation exams, rather than developing curiosity, creativity, and thoughtfulness. Every year, months are spent preparing for the matriculation tests rather than learning a range of topics meaningfully. The existence of the matriculation exams does not theoretically preclude meaningful learning; it just decreases the likelihood of it occurring.
2. Teachers feel disempowered; they are caught in a race to cover everything that needs to be taught for the matriculation exams, leaving them no time to be creative and engage their students in contemporary issues that may be relevant to them.
3. High schools are seen as factories that manufacture grades rather than institutes that educate for values.

As a result of ongoing public outcry against the matriculation exams, the minister of education has decided to decrease the number of tests that students are required to take to matriculate and to postpone all testing until eleventh grade, so that ninth and tenth grade can be spent without the pressure of the matriculation exams looming in the background.

19.4 TIMSS and PISA

Israel has participated in TIMSS since 1995. Israel has consistently received unsatisfactory ratings (from its perspective) on both the mathematics portion and the science portion of the test. In 1999, it was rated 28 out of 38 in mathematics and 26 out of 38 in science. It was one of the few countries whose achievements significantly declined between 1995 and 1999. Between 1999 and 2003 Israel significantly improved its standing, being rated in mathematics as 19 out of 45 countries. In science, Israel was placed 23 out of 45. In 2007, Israel placed 24 out of 49 in mathematics and 25 out of 49 in science.

After placing consistently near or below the median on both the mathematics and science parts of TIMSS for over a decade, a concerted effort to improve Israel's standing was initiated by the ministry of education. Many teachers complained that rather than learning mathematics and science, students were spending most of their time preparing for tests. In 2011 Israel leaped upwards, scoring 7 out of 42 countries in mathematics and 13 out of 42 in science. However, it appears that this upwards bound may have been artificial and may not accurately reflect the state of science and math education in Israel, since nearly a quarter of the country's students, those that come from the weakest sectors, did not participate in the test (Ser 2012).

Israel's scores on PISA have steadily improved over the years, but despite programs to prepare students for this test, Israel remains below the OECD average, placing 40 in math and science out the 65 countries that participated in the 2012 PISA.

19.5 Discussion

Despite Israel's reputation as a "start-up nation" (Senor and Singer 2011) with a hi-tech-based economy, suggesting a highly learned population in mathematics, science and technology, evidence seems to indicate otherwise, with the country's students performing below their peers in OECD countries on TIMSS and PISA. Either these tests do not measure the knowledge and skills that underlie Israel's technological prowess, or the success of the country's economy is drawn from the know-how of people who graduated from high school before Israel began participating in these tests. In the first case, one should wonder, if not knowledge of science, mathematics and technology, what are the kinds of knowledge and national characteristics that support an innovative technological society and whether these knowledge and characteristics are being fostered in students studying now in K-12 education? In the second case, Israel has much to be worried about because it indicates that the present economic successes are doomed to fade away as the present scientists and engineer's age and retire.

Realizing the dependency of the country on scientific and technological superiority, in order to maintain and improve the level of science education in Israel, the country reformed its entire science, mathematics, and technology curricula and teacher professional development programs, but failed to give similar attention to the revamping of its assessment system, leading to a situation where high-stakes tests determine schools and teachers' standing and students' chances of being accepted into universities. Students are over-tested and under-motivated to learn science, leading to a situation where much effort is spent on rote learning and most students do not get a sufficient grounding in science before leaving high school.

This situation is worrisome, to say the least. Whether the country's leaders will have the foresight and political clout to make the necessary changes remains to be seen.

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Chapter 20
Didactics of Chemistry as a Science: History in Russia

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Abstract This chapter describes the history of didactics of chemistry in Russia. The eighteenth and nineteenth centuries were characterized as a period of tremendous growth in terms of the teaching of chemistry. At the beginning of the twentieth century, a preeminent network of teachers emerged, and their work led to the development of didactics of chemistry as a science. The concept and study of didactics emerged during the first half of the twentieth century and resulted in the elaboration of new methods and curricula. However, by the second half of the twentieth century, didactics of chemistry was in crisis—due to weaknesses in its methods and lack of feedback from teachers—and it lost its scientific basis and turned instead into a set of claims. To revive didactics of chemistry in Russia, old methods need to be revised and proven and their scope revealed.

20.1 Rationale

Didactics of chemistry (literally “methodology of teaching chemistry”) is regarded in Russia as the scientific foundation for teaching chemistry. Its subject is the process of teaching chemistry. Its most important foci are

- How to arrange content for effective teaching
- Which methods and modes should be used
- In which forms should the teaching be executed.

In some European countries, this area of science is referred to as “didactics of chemistry” and many English-speaking countries use the term “research and practice in chemistry education.” However, there are scientists and teachers who do

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not regard didactics as a valid science. Instead, they treat didactics of chemistry with suspicion and even hostility. This is true in Russia as well as overseas (Scerri 2003).

In Russia, the development of didactics as a science was difficult and controversial. Many interesting ideas evolved, and some of them were integrated into practice while others were abandoned. Because of the language barrier, didactics of chemistry developed in Russia separately from its development in other countries. As a result, the developmental history and outcomes of didactics in Russia oftentimes reiterated findings from other countries, failed to consider problems solved in other countries, and seemed disconnected from the advancements being made in other countries. Unfortunately, the historical account of didactics as a science presents a chronological list of educators and their contributions without considering the larger picture, which includes a dramatic and controversial exchange of ideas not only at the individual level but also at the national level. As a result, most educators are not aware of much of the history behind didactics and thus repeat old mistakes and reinvent old ideas only under new names. This is why we think that the history of didactics of chemistry in Russia will be interesting not only for Russians but also for the international audience.

The task of delivering the Russian experience to the international audience is quite challenging due to language problems. For example, there are several terms in Russian that cannot be translated into English equivalents. Thus, some of the subtleties of Russian didactical ideas will be lost in this article; however, the present article is an excellent first step in introducing the Russian experience and supporting the future of chemistry education across the globe.

We considered the following factors as impacting the state of didactics of chemistry teaching (Телешов 1997):

1. General development of science,
2. Chemistry as a separate subject at schools and tertiary institutions (when and how much),
3. Pre-service and in-service teacher training; teaching chemistry as a separate course,
4. Curricula for chemistry,
5. Learning texts for chemistry: textbooks, problem books etc.,
6. Societies of educators to develop and improve scientific education,
7. Possibilities to discuss didactical and pedagogical problems in press, in circles, and at congresses, meetings, and pedagogical exhibitions,
8. Editions on didactics (periodicals or non-periodicals),
9. Supplies for teachers,
10. Government relations: whether officials take into account the opinion of educators and whether educators are involved in government institutions,
11. Scientists and specialists in didactics who teach, and
12. Research in didactics of chemistry.

Drastic, interrelated, and quite sudden changes in these factors usually are regarded as the beginning of a shift in a historical stage in the scientific development of didactics of chemistry. Also, historical and social contexts are also taken into account.

20.2 Stage I. Pre-Science: Linear Accumulation of Experience (Before 1864)

The first professor of chemistry in Russia was Mikhail Lomonosov (1711–1765), who performed lectures on chemistry in St. Petersburg (1752–1753) for four students who chose chemistry as their focus of study (Ломоносов 1955). He proposed some ideas that could be regarded as didactical. For example, he concluded that the success of teaching requires proper usage of speech.

> One needs to recount speak with a clear and smooth voice, not strong, not weak, not monotonous but raising and lowering, accompanying the speech with motions of head and body. The main achievements of the science should be formulated briefly and plainly and dictate to let the students write them down. The statements should be accompanied with experiments, because the initial point of cognition is a sensory perception (Ломоносов 1952), p. 354.

Lomonosov changed the Russian view on chemistry. Before Lomonosov, chemistry was regarded as a skill or craft involving the procurement of substances by analysis and synthesis. However, we cannot consider Lomonosov to be the founder of didactics of chemistry as a science because he did not question and check the adequacy of his didactical ideas.

After 1774, chemistry became a mandatory subject at mining school where future mining engineers were taught beginning at age 15–16. Chemistry teaching was supported by chemical experiments that were conducted by the staff of the laboratory or by the students themselves. The students and their supervisors also visited manufacturing laboratories in St. Petersburg and described the chemistry they saw taking place (Соколов 1830). In 1786, "folk schools" (four grades) were launched where some chemical data was included into the subject "Natural History" (Телешов 2004a). The textbook for folk schools was written by Зуев (1786) who based his text on the close connections between science, practice, local geography, and culture. He demanded explanatory reading and conversation, conscious absorption of knowledge, obviousness, and a proper sequencing of topics (Ганелин 1950, pp. 27–32). The first textbook on chemistry was published in 1808 by Шерер; however, it was not intended for use in schools. The first school textbook was written in 1834 by the famous chemist Hermann Henrich Hess (Гесс 1834). Hess claimed that he "tried to describe chemistry in the way that the student understands it without a teacher." He presented inorganic chemistry's main concepts and presented only the well-established facts for organic chemistry.

Around 1836, chemistry was introduced in military schools (that had never before been under the jurisdiction of the Ministry of Education). In 1841, the textbook on chemistry for military schools (Щеглов 1841) was issued, and later, Воскресенский et al. (1852) developed a curriculum on chemistry for military schools. So the curriculum came about after the textbook. At any case, the textbook contained almost all of the information that was known at that time, and all students were expected to learn all of the material.

The future of chemistry teaching in general public schools was much less bright. The only type of public secondary schools in Russia at the beginning of the nineteenth century was the classical gymnasium with its emphasis on ancient languages (Latin and Greek), history, and so on. Science was not the focus of these schools. Natural history was taught in the classical gymnasium; however, in 1828, it was excluded from the curriculum "for apprehension of freethinking development" (Аникеев 1915) and was only returned to the curriculum in 1854.

Until 1861, chemistry had been taught at several universities and higher level educational institutions, military academies, and mining schools. Not only teachers but also scientists (including Hess and Mendeleev) worked at secondary schools (predominantly for extra salary). Later, it was pointed out that their experience as teachers ultimately helped them to later develop more effective chemistry textbooks (Шпачинский 1893).

In the 1800s, experience gained through teaching was preserved as tradition rather than viewed as the result of scientific comprehension. However, it was difficult to maintain even these teaching traditions because the position of chemistry in the curriculum was unstable. The circulation of the textbooks was limited, so teachers and professors did not have a choice in textbooks and often used hand-written notes instead of textbooks. In 1865, the Ministry of Education called for writing textbooks on chemistry and other branches of science. Unfortunately, this directive failed and either no textbooks were offered or the textbooks that were offered were rejected (Георгиевский 1900, p. 52).

The year 1861 is an important date in Russian history. In that year, serfdom was abolished all over Russia and this stimulated both industrial development and public life (including pedagogy). Several pedagogical circles emerged. One of the circle leaders, Nicolay Raevsky, proclaimed the main goal of teaching chemistry in gymnasia to be the confirmation of the laws of chemical phenomena by experiment so students understand the essence of chemical processes. Experiment was the main means of teaching (Телешов 2010). So the idea of inductive teaching, that later influenced inquiry-based, problem-based, and other modern methods of teaching (Prince and Felder 2006) was proclaimed (however not implemented) in Russia in the middle of the nineteenth century. Industrial development meant there was a growing demand for people with good education in STEM ("real education" as it was called at the time). The classical gymnasia that existed during this period could not satisfy this demand. So, in 1864, the system of real schools was established, where the emphasis was on science, engineering, and mathematics, and classic languages were abandoned. Chemistry became compulsory in real schools, so the number of students learning chemistry drastically increased ushering in a new stage for didactics of chemistry.

20.3 Stage II. Pre-Science: Networking Accumulation of Experience (1865–1900)

Launching real schools coincided with a jump in the development of chemistry in Europe and Russia. Butlerow (1861) from Kazan University proposed the theory of structure of organic compounds. Менделеев (1869/1926) from St. Petersburg discovered Periodic Law. Both of them used their discoveries not only as a scientific advancement but also as a didactical tool to base the structure of their high school textbooks on organic (Бутлеров 1864/1953) and inorganic (Менделеев 1869–1871) chemistry. In the prefaces to those books, they also presented the system of their didactical ideas. Butlerow claimed that the theory of chemical structure is "a firm basis of a real knowledge when the facts, connected with common ideas, easily go into memory, each on its own place and become chains of a real scientific system" (Бутлеров 1864/1953, p. 11) this anticipated the ideas of cognitive psychology (Reid 2008). He considered atoms as chemically undividable (but divisible by other methods), atoms as influencing each other, and molecules as more than the sum of their atoms (a new formation). According to Butlerow, to know chemistry meant to know facts and theory. Mendeleev acquainted students "with the main data and conclusions of chemistry and their significance for understanding nature and practical activities" and the description of "conclusions with the ways how they were made." Thus, Mendeleev anticipated the ideas of context-based and inquiry-based learning (NRC 2000). However, we cannot consider Mendeleev or Butlerow as the founders of didactics of chemistry for the same reason Lomonosov is not the father of didactics—they did not question the adequacy of their ideas.

The increasing number of students in chemistry at real schools and in natural history in gymnasia mandated an increase in the number of teachers. This large pool of teachers began to share their experiences. In cities with several real schools (e.g., St. Petersburg, Moscow, Warsaw, Smolensk), the teachers arranged pedagogical circles. They influenced the development of didactics since their initial discussions were comprised of new ideas and ways of teaching. The circles then grew into societies (with no division between scientists and teachers), which also discussed didactical ideas in their meetings. In the 1870s, several scientific and pedagogical congresses were held, and about 100 pedagogical museums were opened. All of these developments were the result of teachers with almost no official support.

However, one must understand that the number of teachers involved in these didactic activities was quite small. For example, in Moscow—the biggest Russian city—there were about 10 gymnasia, one real school, and one military school. It would not be an exaggeration to say that the majority of scientists and science teachers knew one another personally.

Unfortunately, the curriculum used in the real schools conflicted with the requirements of the universities that included Latin and Ancient Greek in their entrance exams. So, the graduates from real schools could not enter university, and thus, these schools became unpopular. In 1871, science was excluded from the classical gymnasium curriculum because it was deemed “morally dangerous” (Полянский 1915). In 1890, chemistry as a distinct science was removed from the curriculum in real schools (with some chemistry content still delivered within the physics curriculum). However, in 1890, the Financial Ministry (not the Ministry of Education) established the so-called commercial schools. These schools went from nine in 1890 to 125 in 1900. They were secondary schools that educated students for “blue collar” manufacturing jobs. Chemistry was an obligatory part of the commercial school curriculum.

At this stage, about 20 different school textbooks were being published. Some textbooks were based on Periodic Law (Альмединген 1885; Бекенев 1898; Ковалевский 1880; Лавров and Нечаев 1893), while others did not even mention it. The majority of the authors were scientists who also taught in schools. The first problem book (Панпушко 1887) attached to a textbook (Потылицын 1887) was issued in 1887. Beginning in 1865, the Ministry of Education published a list of recommended textbooks that took into account both “moral” and “scientific” factors. Obviously, the quality of textbooks was weak. Between 1865 and 1900, the Ministry of Education announced three contests for the best textbook; however, none of the eight contestants won the prize for best chemistry textbook (Георгиевский 1900). The circulation of textbooks remained limited, and no formal distribution system existed. As a result, only certain textbooks were available in specific locations and at specific times.

The number of professional teachers (i.e., those who just taught and did not conduct scientific investigations) increased. The increase in the number of teachers increased the demand for teacher training from educational institutions. Consequently, the first courses for pre-service teacher training were also established around that time.

In conclusion, during the second stage, the teaching of chemistry spread throughout the Russian educational system. The number of teachers grew exponentially, and these teachers formed networks for sharing didactic information. It was the prerequisites for emerging didactics of chemistry as a science.

20.4 Stage III. Didactics of Chemistry as a Science (1901–1918)

The first sign of qualitative turnabout was a sudden and simultaneous revision of approach to educational materials. Before 1901, the only type of educational material was the textbook (occasionally with a problem book attached). However, in 1901, a science teacher named Leonid Sevruk issued a didactical pack on science that included not only a textbook for students (Севрук 1901) but also a manual for teachers on how to teach using the textbook (Севрук 1902). This idea was taken up by the majority in the educational field, and even today the majority of the school textbooks are accompanied by teacher manuals.

In 1900, prince and businessman Vyacheslav Tenishev founded in St. Petersburg a private commercial school. Several bright teachers (Valerian Polovcov, Sergei Sozonov, Leonid Nikonov, and Grigory Grigorjev) gathered to teach there. We could state that this circle was a cradle for the didactics of science. In that circle, new textbooks and approaches were discussed. These discussions developed into the first course on didactics of science at St. Petersburg University (launched by Polovcov) and the first textbook on this subject published in 1907 (Половцов 1907).

Polovcov's textbook was met with mixed reactions; however, the arguments were more speculative than evidence-based. Just several quotes (Григорьев 1907): "Teaching is a creation and didactics will never create a good teacher"; "it is useful to get acquainted with methods of other teachers, however it is just a pedagogical practice"; "a teacher has to know what is the content of his subject, its scope, the main principles and which questions should be elaborated in the classroom, however the book delivers didactics by Polovcov rather than didactics of science". Here, the problems of didactics of chemistry are formulated in ways that can be scientifically investigated.

At the beginning of twentieth century, several teacher training courses were established. To become a teacher, one needed a two-year course after graduating from university. The students and professors in these teacher training courses discussed and systematized didactical ideas, and their findings were published (ПК-ВВЗ 1911; ТКУ 1908). The courses in 1904 grew into the Women's Pedagogical Institute (Телешов 2004b) and later, the Pedagogical Academy. In Pedagogical Academy, Sergei Sozonov conducted the "Didactical Conversations" on teaching chemistry (22 h), and Vadim Verhovsky developed the 24 h course "Methodology of Teaching Chemistry in Connection With Practical Works" (ТПУ 1910). These could be considered the first courses on didactics of chemistry in Russia.

The networking of teachers continued and blossomed. In 1902, two pedagogical congresses were held (January in St. Petersburg and December in Warsaw). Journals on didactics were launched (*Science and Georgaphy*, 1896–1917; *Nature at School*, 1907; *Science and Visual Teaching*, 1909–1910; *Science at School, 1912–1915*). In 1914, a grand congress of teachers of chemistry, physics, and cosmography took place, where teachers and scientists discussed terminology.

Specialists in didactics of chemistry collaborated with state commissions that prepared school reforms (ТВУК 1900; МРСШ 1915; МРСШ-ПП 1915). The exhibition of educational equipment was held in 1912 in St. Petersburg. Curricula employing demonstrations and students' experiments were developed. Textbooks for all types of schools were written. Manuals on practical activities and guided tours were written based on the experiences of their authors.

However, the curricula were criticized mainly for their overload. This remains a major criticism even today (Millar and Osborne 2000) despite the fact that preventing overload is one of the main tasks of didactics. "It's impossible to push the entire curriculum into 2 h a week without rout learning" (РШ 1984). "They try to push all the known scientific data into the curriculum… it will be invincible unless the school refuses scientific systematization in favor of small set of pedagogically useful things" (Добольский 1900). "It is strange that our curricula remain immutable as tables of Covenant… the curriculum is the last thing, not the first" (Созонов 1901). "All the content should be acquired in the degree that the student can use it… meaning that everything superfluous and less important should be eliminated… and the students take all the necessary facts from the handbooks" (Лермантов 1905). "Curricula is nothing in comparison with methods, but nobody discusses methods" (Володкевич 1905, pp. 45–46). "People who develop curricula should take into account the cognitive working abilities of an ordinary student… whereas the authors included there everything they considered important… with no estimation of difficulties in studying… believing that to demand is enough to get executed" (Лермантов 1906).

Thus, by 1917 (the Revolution in Russia), the problems of didactics of chemistry were formulated, the first textbooks were issued, and the first courses were launched. So, one can state that it was at this point that didactics of chemistry emerged as a science.

20.5 Stage IV. Broadening Applications and Struggle Between Didactical Schools (1918–1941)

Just after the October Revolution (1917), the new communist government boosted the education system. It established basic courses for illiterate adults (more than a half of the population) all over the country. Four-year (later changed to seven-year) school became obligatory for every child. Chemistry was included in the school curriculum. Developing national industry required well-trained and highly-educated personnel, so chemistry education was developed in high schools and technical schools as well. Chemistry also fit the communist ideology: instead of "moral danger" it became "a school of revolutionary thinking" (Leo Trotsky).

From the time of the Revolution through to the collapse of the Soviet Union, teaching of any subject was expected to not only transfer knowledge and teach specific skills but also transfer "communistic" and "materialistic" norms and values. This latter point has been the core problem of Soviet didactics of chemistry and remained an issue up to the collapse of the Soviet Union (mainly because nobody could operationally define "communistic" and "materialistic").

Didactics of chemistry faced many new challenges. Despite the drastic increase in the number of students and increased requirements for chemical education, in 1923, 42 % of schools did not conduct chemical experiments, and 84 % of schools had no student laboratory experiments (Райков 1923). After 6 years of the Revolution, there were even claims that there was still no chemistry in school (Верховский 1923).

In the 1920s, didactics of chemistry eventually separated from didactics of science. Two competing didactical schools were formed: "Petrograd school" (Vadim Verhovsky) and "Moscow school" (Peter Lebedev).

In 1919, Vadim Verhovsky claimed that the core condition for studying chemistry was broad chemical experiments. "Atomic hypothesis should be delivered only when a student stored enough facts, acquired the basic chemical laws and learned chemical language…. Periodic law should be given only after nonmetals, as a generalization, but not at the beginning, as a dogmatic scheme" (ПП 1919, pp. 77–78). He diminished the significance of curricula claiming that "the best curriculum will give no results if the teaching is not based on experiment… it should be just brief and arranged didactically" (ЕО 1924, p. 324). He specified that such a systematic curriculum required 4 h of classroom and laboratory lessons per week.

On the contrary, Peter Lebedev in Moscow was inspired by the ideas of Dewey (1916) that fit with the spirit of revolutionary innovations. His curriculum was based on "complex themes" of practical significance (in vocational schools that illustrated technological processes) that was close to modern context-based learning with all its attributes (Heikkenen 1988; Gilbert 2006). Each "complex theme" required certain applications that required certain theoretical knowledge. The sequence of topics was determined by the links between the objects—neither scientific, nor cognitive logic. Lebedev only introduced core concepts of chemistry that could be induced from experiments (for example "atom" and "molecule") in order "not to be didactic" (Шаповаленко 1963, p. 95). Basing teaching of chemistry on practical inquiry activities (close to modern inquiry-based learning), he used a workbook (instead of a textbook) as the main teaching tool (Телешов 2006). Theory, which students were expected to learn independently, was considered supplemental to the experiments.

He criticized Verhovsky's approach as "bourgeois" because Verhovsky became a professor before the Revolution. Situated in Moscow—the new capital of the country—Lebedev had greater means to influence the Ministry of Education, and his approach prevailed.

In 1931, the Communist Party Central Committee issued a resolution on elementary and secondary school (ЦК ВКП(б) 1931). It stated that "the secondary school doesn't give enough basic knowledge; doesn't prepare pupils to technical and high schools; doesn't train serious well-developed builders of socialism, that can connect theory with practice". Much later, similar arguments against the constructivist approach were independently repeated in Western literature (Kirschner et al. 2006). The resolution rejected all the constructivist ideas and required systematic curriculum. Verhovsky's approach fit the resolution. Lebedev's did not. Verhovsky was put in charge of setting down the systematic curriculum and textbook, which would not be altered for many years (Верховский 1935; Верховский et al. 1935; Верховский et al. 1937; Верховский 1947). In 1931, Verhovsky declared that there were three tasks related to teaching chemistry at secondary school: (a) to acquaint students with the main chemical productions (skills and technical outlook); (b) to link the system of chemical knowledge to the manufacturing process and chemistry as a science; and (c) to develop the Marxist-Leninist worldview, active participants for the communism movement, and masters of machinery. He still argued that the course should be based on first-hand knowledge of chemical processes from factories and laboratories (Верховский 1931).

Verhovsky involved two representatives from Moscow—Yakov Goldfarb and Leonid Smorgonsky (Lebedev declined to participate) and together they merged the systematic curriculum with Lebedev's workbooks. In 1936, they issued a book called *Didactics of Chemistry at Secondary School* (Верховский et al. 1936) that was more of a manual on how to use the textbook than a textbook about didactics as a science. In 1934, the first problem book that supported the textbook (Гольдфарб and Сморгонский 1934) was published. However, Verhovsky's idea of basing the course on first-hand experience with chemical processes was not broadly implemented because chemical manufacturing was not yet widespread and so first-hand experience in chemical factories was not available to many students.

The number of pedagogical institutions increased. At the end of the 1930s, the first doctoral degrees in didactics of chemistry were awarded. Between 1937–1938, in-service teacher training institutions in Moscow and Leningrad were opened. At the same time, the *Chemistry at School* journal was launched.

By the beginning of the Great Patriotic War (1941), didactics of chemistry in Russia was well under way. The didactic pack consisted of a textbook, workbooks, problem book, and teacher's manual. The system of pre-service and in-service teacher training was also well established. Young teachers who were developing into specialists in didactics began to replace the old school specialists or take up new niches.

20.6 Stage V. Further Expanding (1946–1970s)

After the Great Patriotic War (1941–1945), the educational system underwent rapid development. Further industrialization raised the role of chemistry in the opinion of the authorities to the highest level in history. In 1952, the polytechnic education was developed. In 1956, the eight-year education became compulsory, and in 1958, the program of "chemisation of economy" was put forward by the Communist Party. It required new well-trained personnel. Thus, the number of chemistry lessons was enhanced to 3 h a week. At the beginning of the 1960s, the 10-year education became compulsory. In fact, the task was to teach everybody chemistry in a professional and practical manner. This was the new challenge for didactics of chemistry.

In 1946, the Academy of Pedagogical Science was established. This academy became the primary supporter of research into chemistry education. The next generation of specialists in didactics was trained. Some of them worked part-time in schools. They conducted observations and experiments to reveal successful as well as ineffective ways of teaching. For example, Sergei Shapovalenko and Pavel Gloriozov arranged a large-scale investigation (involving 60 schools) to check the sequence of topics in the course of basic chemistry (Шаповаленко and Глориозов

1952). This investigation resulted in changes to the curriculum. For example, content about acids and bases was separated from content related to nonmetals. Nowadays, the most popular curricula in Russia still follows the sequence of topics recommended by Verhovsky and shaped by Shapovalenko and Gloriozov. Western and Asian chemistry educators focused on the sequence of chemistry topics much later.

Gloriozov investigated the conditions to form practical skills and found out that effective manipulations require the understanding of theoretical background (Глориозов 1959). Dmitry Kirjushkin asked students to draw a burning candle with and without preliminary instructions and found that the number of essential details was much lower in the second case. This confirmed that instructions increase the quality of observations (Занков 1954). This research also confirmed the benefits of guided inquiry over open inquiry (Cheung 2008). At the same time, Konstantin Parmenov was highlighting the confusion associated with teaching and learning color names, equipment names, and so on (Парменов 1959). Kirjushkin enumerated the scientific methods in didactics that were used at that time and pointed out the usual mistakes: description and analysis of experience (often omitting key methodological issues), examination of schools (with loss of results), and pedagogical experiment (with many limitations) (Кирюшкин 1958). Kirjushkin underlined that the methodology of experiments was not well elaborated.

Many enthusiastic teachers detailed their ways of teaching particular topics ("what did we do"). These methods were published in the *Chemistry at School* journal and in specialized books. Шаповаленко (1963) categorized teaching methods and tried to establish their scope (in a speculative rather than evidence-based way). The arguments on categorization took place and no consensus was reached. Unfortunately, the particular methods were soon forgotten because nobody tried to gather them and connect them with the curriculum.

At the end of this period, several textbooks on didactics of chemistry and many reports on teachers' experiences were published. They were partly evidence-based and partly claims-based. The focus was on transmission of knowledge and the transmission of norms and values (the problem that was not solved). However, all these books were practical manuals with little attention paid to methods and discussions on evidence-based theory. The methods of didactics of chemistry were not yet developed. We think that these problems led to the further stagnation of didactics of chemistry.

20.7 Stage VI. Stagnation (1970s–1980s)

At this stage, didactics of chemistry seemingly was still developing. The number of institutions, doctoral dissertations, students, etc., grew. The system of pre- and in-service teacher training institutions worked. The first specialized chemical school (Sergei Berdonosov) was established.

However, at this time didactics of chemistry did not generate new ideas. The culture of didactical investigations degraded with fewer and fewer reports on didactical observations and experiments and more and more speculative articles being published. Throughout the whole history of didactics in Russia, curricula were considered adequate if they were officially adopted. Methods were considered adequate if they were accepted by other teachers who tested them (or tried to test them). This might have been a fair system if open and authentic feedback had been permitted, but there was no feedback loop. So the confirmation of acceptance of the methods often was inadequate.

Professional teaching of chemistry to everybody failed—chemistry became less and less popular. The attitudes of society toward education changed. Earlier, education had been perceived as a good social elevator that motivated students. So early work in didactics assumed that students would naturally pursue education and put in the necessary effort. Even the textbook on didactics issued in Цветков (1981) used the words “motive” and “motivation” only five times in 209 pages (including “social motivation” in context of career-guidance). In the manual to the school textbook (Ходаков 1980), these words were not mentioned at all. Psychological aspects of didactics were also neglected.

20.8 Stage VII. Degradation (Since the 1980s)

When the old school specialists in didactics aged, they were replaced with less talented people who worked in pedagogical institutions just for salaries (that was true for all the branches of didactics). A strong hierarchy of specialists in didactics was established. Now information within the system flowed only one way: ideas came from the top of the hierarchy (chiefs of the institutions) and flowed to the bottom (research fellows and teachers). The top specialists did not value or even perceive information “from the ground” and instead regarded their own isolated and unidimensional work as absolute truth.

The new general books just repeated old ideas, eliminating the need to present evidence of effectiveness (e.g., Чернобельская 2000). The texts contained no doubts, discussions (except for terminology), evidence, or even descriptions of what would happen if a teacher did this or that: “While investigating physical properties the following algorithm is used: a teacher shows the specimen and asks to enumerate its physical properties” (Космодемьянская, Гильманшина, p. 41). Very often the expectations were arrogated to the students as their real actions: “… why there is no general formula of volatile hydrogen compounds for alkaline metals in the Periodic table? The students reasonably answer that they don’t form volatile compounds.” (Габриелян 2001, p. 8).

By this time, the whole society faced a problem that eventually led to the collapse of the Soviet Union: imitation instead of action. Didactics also faced this problem: the specialists pretended that they did a tremendous job when in reality, they did nothing. They began to use obscure quasi-scientific language (“For binary ways of integration the adequacy [a key to a lock] of integration processes in learning to integration processes determined by a teacher in course of teaching is typical") (Пак 2004, p. 256). Many of their statements could not be verified, such as "It will be good, if a teacher will repeat with the pupils what is the allotropy and by what causes it is recalled" (Габриелян 2001, p. 12). Very often the new works contained old ideas under new names.

> Collective system of learning, collective teaching each other, collective lessons, adaptive learning system, groups of different ages, couple-centered learning technology, technology of natural education–all of these new methodsl boiled down to the same thing: students taught each other (Громыко 2011).

We should add that these "new" ideas were implemented by Bell and Lankaster at the beginning of the nineteenth century (Rayman 1981). The majority of articles on didactics of chemistry resembled "scientific spam" and seemed to be published just to get a degree or a line in a report. The requirements for degrees in pedagogy fell to their lowest level (Фельдштейн 2011).

Thus, through the end of the twentieth century, the majority of practical teachers lost any respect toward didactics treating it as phrase-mongering and in-service training—as wasting time. The best teachers admitted in public with no shame that they did not read pedagogical literature—it was very difficult to find something useful amidst the rubbish.

Chemistry became one of the most unpopular school subjects. In 2012, only 8 % of graduates chose to take the Unified State Exam in chemistry. Only 9 % of them got an excellent score whereas 11 % failed (ФИПИ 2012). We ascribe this to the degradation of didactics of chemistry. The content of chemistry remained the purview of specialists in chemistry and was not relevant to the general public. The chemical experiment was almost totally eliminated and this further decreased interest in chemistry (Zhilin 2013)—chemistry turned into something about chemical symbols. Among all the methods of teaching, only lectures and problem solving remained.

At the beginning of the 2000s, Russia's educational system was a mess with reform on top of reform hindering true progress. The most vivid example involves the first educational standard (with emphasis on content) that was implemented in 2004 and the second standard (with emphasis on meta-subject skills) that was implemented in 2012. Students entered school with no standard but finished school according to the second standard. Such decisions were made without the benefit of scientific investigations and turned didactics just into a tool for supporting decisions. The most common title for an article or conference presentation was "Bla-bla-bla in context of requirements of the new education standard."

Thus the outcome of didactics of chemistry mostly turned into unfounded claims and scientific spam. The result was a very low level of chemical education.

20.9 Prerequisites for the Renaissance

Currently, chemistry is part of the curriculum at eighth and ninth grade (2 h a week) and tenth and eleventh grade (1 h a week at the basic level and 3 h per week at the specialized level). Chemistry is still not a popular subject, and this remains a great challenge to the didactics of chemistry. On the other hand, in the 2000s, a small stratum of well-off people who appreciated the benefits of good education arose. They wanted to provide their own children with a solid and comprehensive education and were willing to pay for it. They were not interested in the opinion of the authorities and wanted to pay only for the teaching methods that worked. Now they are the main demanders of didactics of chemistry as an evidence-based science, encouraging development of new methods and requesting establishment of the effectiveness of old methods (e.g., Zhilin 2014).

In the early 1990s, many people with scientific backgrounds began teaching in schools. They did not have a pedagogical education and thus reinvented the old methods and repeated the same old mistakes. The most common of them being teaching chemistry by beginning with the structure of atoms (Кузнецова 2012). Their enthusiasm along with the enthusiasm of a new generation of specialists led to the development of new teaching methods and discussions on didactical problems however, without discussing the scope of these new methods (Берсенева 2004). A few specialists still develop didactics at the scientific level and/or successfully implement new practical ideas. Each of them deserves a separate article. Various problems are currently under study: understanding limitations of ICT in teaching chemistry (Mikhail Dorofeev), taking into account the system of values of individuals while teaching chemistry (German Fadeev), developing creativity while teaching chemistry (Pavel Orzhekovsky), determining estimation abilities in chemistry (Elena Volkova), involving motivated pupils in scientific work (Sergei Semenov), teaching chemistry using natural cognitive activity (Elena Vysotskaya), investigating informal education (Vyacheslav Zagorsky), and so on. However, their findings are not connected with each other and impact only a small number of teachers. Important Western ideas, first of all—cognitive models (Reid 2008) and Johnston's triangle (Johnstone 1999) are almost unknown in Russia.

Influenced by sociology and psychology, didactics of chemistry is about acquiring new methods (e.g., the interview). There are attempts to use quantitative assessment tools (for example item response theory); however, they are often used erroneously. For example, very often the t-test is used without checking normality of distribution. Even while processing the results of the Unified State Examination, claiming to use Item Response Theory, the final score is calculated based on the total score (ФИПИ 2008) whereas item response theory requires recalculation based on the test scores for each item (Yu 2014). However, these problems are at least beginning to be raised and discussed.

Today, an enormous set of teaching approaches and methods are available. Some of them are more successful and others are less effective. Some of them are old methods just given a different name. Some of them are just spam. The main challenge of contemporary didactics is to put all of these methods in order and find their scope using evidence-based tools. This necessitates the establishment of a database of the methods already described.

Currently, there is a demand for a renaissance of didactics of chemistry. There are challenges for a revived didactics, but there are skilled people who are able to meet these demands. However, there is currently no system in place to encourage people to do the work necessary to move the didactics of chemistry forward.

20.10 Conclusions

Didactics of chemistry as a science emerged in Russia at the beginning of the twentieth century as a result of (a) accumulated experience in teaching science (and teaching chemistry in particular) and (b) networking between a relatively small number of motivated teachers. It developed during the first half of the twentieth century elaborating new methods and curricula. However, the limited number of methods that were used and the hierarchy of specialists working independent of feedback led to stagnation of didactics in chemistry—it collected a profound set of methods but their scope was not discussed. The claims became less and less founded and the ideas became less and less applicable to real teaching. Currently, we can speak about a small number of specialists in didactics of chemistry who treat it as a science but cannot speak about didactics of chemistry as a scientific system that significantly influences chemical education.

Despite the current state of didactics of chemistry, a large set of teaching methods has been accumulated. To revive didactics of chemistry, we should revise the methods and reveal their scope using evidence-based tools. The creation of a database of the available methods is one of the essential tasks yet to be completed.

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Chapter 21
Commentary: Assessment: The Pros and Cons of this Necessary "Evil"

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Abstract Attempting to provide a summarizing commentary that unified the three chapters in this section initially seemed like a daunting task. After all, the two chapters by Cheung and Fortus are clearly about, with Cheung focusing on assessment of students' practical skills in Hong Kong and Fortus taking on the broader issue of assessing Israeli students' knowledge in science. The latter uses the issues with assessment to address issues related to policy and practice, while Cheung is more focused on specific practical skills within the science curriculum. Nevertheless, the two chapters are both clearly related to assessment. However, the third chapter written by Teleshov and Zhilin addresses the history of didactics of chemistry and how it has been viewed in Russia from the eighteenth century to now.

Attempting to provide a summarizing commentary that unified the three chapters in this section initially seemed like a daunting task. After all, the two chapters by Cheung and Fortus are clearly about, with Cheung focusing on assessment of students' practical skills in Hong Kong and Fortus taking on the broader issue of assessing Israeli students' knowledge in science. The latter uses the issues with assessment to address issues related to policy and practice, while Cheung is more focused on specific practical skills within the science curriculum. Nevertheless, the two chapters are both clearly related to assessment. However, the third chapter written by Teleshov and Zhilin addresses the history of didactics of chemistry and how it has been viewed in Russia from the eighteenth century to now. "Didactics" is a value laden word with clearly different meanings in western countries than in Europe. In North America, didactics or didactic instruction is viewed as synonymous with a lecturing teaching approach and has a negative connotation. In Europe, it is synonymous with the pedagogy and the study of teaching, lecture, and otherwise. In either case, the final chapter in this section seemingly focuses on chemistry teaching in Russia and whether it was/is perceived as a science. Assessment does not appear to be a focus at all, however in my mind the issue of

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how chemistry teaching has and is perceived in Russian educational history is as much about assessment as the first two chapters. The connection should be clear by the end of my commentary. Your patience is appreciated.

Assessment and evaluation often go hand-in-hand, with the former being the most associated with the measurement of learning, teaching, and curriculum and the latter with decisions associated (Hopkins 1998) with the meaning of what has been measured (e.g., assigning grades, making curricula decisions). Although the two are not synonymous, from here on in this commentary I will simply refer to both as "assessment." Clearly, assessment is absolutely necessary in one form or another in educational endeavors. Quite simply we need, as teachers, administrators, parents, and other stake holders in education, to see how well we are doing with respect to the goals and objectives in the educational programs required by our various countries, states, provinces, etc. Alternatively, assessment often takes on the role of significantly impacting how we teach and construct curriculum. It impacts the perceptions of teachers, students, and administrators in ways that are often considered detrimental (Shepard 2001). Hence, the title of this commentary.

Much of the chapter written by Cheung focuses on what has been occurring in Hong Kong since their adoption of the assessment of practical skills in 1978 and of new science standards in 2009. The data he collected stems from his research on the School-Based Assessment (SBA), which was implemented in 2009. Practical skills refer to what is often referred to as "laboratory/process" skills in some parts of the world. Prior to 2009, Judith Lederman and I had the pleasure of working with the Ministry of Education in Hong Kong focusing on inquiry teaching, nature of science, and the assessment of both. This work was in anticipation of the new 2009 standards. In short, the professional development providers in Hong Kong needed assistance on how to help teachers implement the new standards, and, of course, assessment of the success of the new standards was looming in the background.

As we worked with teachers and professional developers in Hong Kong, we found that the change in the science curriculum was much more than curricula changes we had experienced in the Unite States and elsewhere. The change was a significant cultural change in the educational system. Laboratories/practicals, let alone inquiry instruction, were not common practice in the curriculum and when they were included they were more akin to demonstrations as opposed to extended student-centered activities. We were told this was primarily for reasons of safety. Cheung's data exhibited some of these issues as well. The overriding method of assessment in science in Hong Kong was national tests. These tests typically assessed subject matter knowledge as opposed to any practical skills, since practical was not part of the culture. The changes recounted for 1978 and 2009 now included assessments of practical skills. As a consequence, science teachers now were compelled to include more practicals in their instruction. However, because the practical skills to be assessed were well-known, the teachers tended to repeat multiple times the same practicals. The practicals included were an effort to provide drill and practice for students, so they could perform well on the SBA. The practicals/laboratories, which are usually viewed as a means to facilitate students' understanding of subject matter, were viewed almost exclusively along the lines of an assessment. Interestingly, the students surveyed in Cheung's work like the formative aspects of the practicals as well as the affordance of a different way to learn subject matter. Teachers, on the other hand, focused on the assessments that would be administered and, in some cases, worried about the time the practicals would take away from more formal instruction.

In summary, the culture of high stakes testing and the new inclusion of practicals in these assessments, had the effect of constraining the intended instructional value of practicals. Practicals are meant to engage students' curiosity and allow them to experience authentic science. However, the overriding culture of high stakes national tests was simply viewed as another "thing" to be assessed. Students are being exposed to practicals in a rather repetitive manner with the focus simply being on performing well on a set of practical skills. The allure of "doing" science is being negatively impacted by the assessment approach. Assessment is driving instruction and learning.

A similar situation is recounted by Fortus, but at a seemingly higher level (i.e., policy). Israel, like Hong Kong, follows high stakes national tests to assess science learning. Israel gives close attention to scores on the TIMSS and PISA assessments because they are concerned about their standing in international comparisons. A new reform to improve science, mathematics, and technology education was embarked upon in 1992, which strongly advocates inquiry, laboratories, STEM education, integration, and literacy. The reform principles are quite similar to what is being valued in Hong Kong and many other countries throughout the world. However, Fortus notes that nothing was done to reform the national assessment framework to align with the recommended changes in the curriculum. There is a new series of assessments, but they are not well aligned with the reform documents. So, there is now a reform-based science, and technology curriculum, but the national assessments are still assessing low level learning and memorization. The new assessment used is called the MEITZAV, which translates into "measures of school efficiency and growth." The general perceptions by teachers is that the MEITZAV has become "too important" and most of the instructional time is spent on preparing students to do well on this assessment rather than using the assessment to see how well the new curriculum is doing. In Israel, there is little emphasis on practical work because this is not assessed on the MEITZAV but the situation is really not different than Hong Kong. In each case, the heavy emphasis on a national test has created a system where the assessment is driving the system. Again, this is a situation where an assessment approach has created a negative impact on teaching and learning. Instead of improving students learning and interest in science, the focus is on improving students' scores on a test.

I grew up in the New York City school system. One aspect of that system was the Regents Examination. The "major" subjects (e.g., mathematics, science, English, history, and foreign language) had Regents courses and these courses were particularly helpful for getting admission to universities. The science and mathematics had separate courses and examinations for the various mathematics and science courses. They were and are New York's version of college preparation courses. However, to get Regents credit in these areas you needed to pass the Regents Examination for that subject. These tests were statewide and the logic was that it provided an assessment that universities could view as standard. It was the same measure regardless of where you attended high school in New York State. These tests were so high stakes that if you were getting an “A” in a class and you failed the Regents Examination, you did not get credit for that course. So, all teachers would focus their attention on these tests and getting their students to perform well. Indeed, I recall my teacher racing to complete the curriculum by the end of February so they could review test questions from these tests with students during March–May. The exams were given in mid-June. Publishers helped teachers as they sold review books that included actual exams from the past 10 years (e.g., Tarendash 2004). So, in class instruction revolved around answering questions from prior Regents exams. In 10th grade (1966), I remember my biology teacher telling us that the only molecular formula we needed to recognize (not be able to produce) was glucose, so if we were asked about any molecular formula, the answer was glucose. This is the most explicit comparison of what we have read in the chapters by Cheung and Fortus. This is teaching to the test at its most drastic level. Just as a side note, in New York you could supervise a student teacher only after you had taught for five years and you could show that your students had achieved an 80 % score level on the Regents exams over the past three years.

Later in life, I became a biology teacher and for part of my high school teaching years I taught at a high school in New York State. Yes, now I was a teacher in the high stakes assessment system. I could not bring myself to teach as I was taught. Being the trouble maker I am, I chose to teach as I thought was the best approach for my students and assumed that they would still do well on the Regents exam and also learn so much more. It is possible to not give into the assessment system, but it takes a lot of courage and stubbornness. This is not a good situation.

When I was a high school teacher in Illinois, after I was handed the state science curriculum, the first question I asked was, “Is this assessed on a statewide test?” The answer was no. I put the curriculum on a bookshelf and never looked at it again. I think this was a good thing, but I am biased. The important point here is that we are all, like it or not, heavily influenced by the assessment system. The question we should all ask as readers of the chapters by Cheung and Fortus is whether the existing situation is beneficial or harmful. The last chapter in this section may provide a different perspective.

The chapter by Teleshov and Zhilin on the history of chemistry teaching in Russia is, on the surface, unrelated to the previous two chapters. I contend that this is not the case. Any analysis of curriculum will quickly illustrate how culturally embedded curriculum and teaching is within the fabric of society and its needs. Such was seen as the case in the previous chapters and in the most explicit statement in the Teleshov and Zhilin chapter noting that in 1871 science was excluded from the Russian gymnasium curriculum because it was “morally dangerous.”

The early years of the “study of teaching” followed a similar pathway to other parts of the world in that a good teacher was seen as being born. That is teacher education programs could not create a good teacher. Some people were born to be teachers while others are not. This was the conception of effective teaching commonly known as “presage” variables. There was some progress toward the acceptance of the idea that there was some “science” behind educating a teacher, but this eventually fell apart during the 1980s and beyond. According to the authors, the isolation of Russia from other countries and their research on teaching stymied the progress of didactics of chemistry in Russia. In general, the general flow of advice on how to teach came from the top of the hierarchy (chiefs of the institutions) and flowed to the bottom (research fellows and teachers). In short, didactics of chemistry had turned into unfounded claims and "scientific spam." The authors further claim many cognitive models based in Western ideas are unknown in Russia and a variety of research-based ideas in design and statistical models are most often inappropriately used.

In short, what we have seen as having occurred in Russia is a failure to develop a sound didactics of chemistry, as well as didactics of any science area, as a result of inadequate evidence supporting various teaching approaches. The assessment of recommendations was inadequate or totally missing. Do we have a situation in which the lack of adequate assessment has failed to provide supportive evidence and created a "field" with no accountability? It seems to me that this is the case and I would presume the authors of this chapter would agree. It is for this reason that I think the three chapters in this section are related around the topic of assessment. It is also for this reason that I believe the three chapters as a whole illustrate both the negative and positives of assessment. Yes, assessment is a necessary "evil."

The chapters by Cheung and Fortus clearly show the commonly seen negative impacts of assessment. In Hong Kong and Israel, the strong impact of doing well on national assessments has lead to changes in teaching that are directed toward the test as opposed to students. In addition, the high stakes assessments have created negative attitudes in teachers as well as students. This phenomenon is not unique and there are numerous examples throughout the world (Shepard 2001). In the Teleshov and Zhilin chapter, we are provided with an interesting and intriguing chapter of the "development" of didactics of chemistry in Russia. This "development" is clearly constrained by the lack of adequate assessment and accountability. That is, a strong assessment program was needed, but lacking, in order to convince detractors that there is validity to the idea that you can develop valid techniques for educating teachers on how to teach.

When all is said about assessment, it is clear that it is necessary to evaluate our teaching, learning, and curricula. It is also necessary to advance the idea that teaching is at least partly a science. Assessment is an "evil" when it perverts the purpose of education as it has in Hong Kong and Israel, as well as many other places that have yielded to high stakes assessments. However, it clearly would have been necessary and beneficial in the advancement of Russian thinking about the didactics of chemistry. As you reflect on your reading of these three chapters, ask yourself and your colleagues about how we can best balance these seemingly antithetical roles of assessments. Is there a solution? Is it possible to strike such a balance? Assessment and evaluation serve various purposes. The problem arises when the designed purpose is allowed to diffuse over into other areas of concern, which are usually more political than educational.

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Part IV
Innovative Technology in Science Education

Chapter 22
Innovative Lesson Plans in Chemistry Education for Broadening Sustainable Society

Hiroki Fujii and Haruo Ogawa

Abstract Expanding Education for Sustainable Development (ESD) is one of the big challenges for education in Japan. Science educators are also tackling the link between science education and ESD, and focusing on promoting students' understanding of key concepts for sustainable development and enhancing their abilities in making appropriate judgments on science, technology, society, and environment (STSE) issues. We developed chemistry lesson models for upper secondary school that reflect the viewpoints of ESD. The lesson topics cover bioenergy like biodiesel, biological resources like chitin and chitosan, and metal resources like iron. After conducting trial lessons for students in both Japan and Korea, we evaluated the lesson with the outlined objective of promoting students' abilities to make appropriate judgments based on their knowledge of science. The results show that the lessons achieved a measure of success, and also provided an excellent opportunity for the students to consider the possibilities for establishing a sustainable global society.

22.1 Introduction

Science educators in Japan have been tackling the challenge of how to make innovative lessons that broaden sustainable society, following the turning point that was the decade of Education for Sustainable Development (ESD) declared by UNESCO (2005–2014). Consequently, research and practices in science lessons have gradually increased. These lessons have focused on the promotion of students' understanding of key concepts related to sustainable development, such as circulation, symbiosis,

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diversity, preservation and respect for life, and also on that of students' abilities to make appropriate judgments on STSE issues. Examples of issues include natural resources, energy, transport, electronics, food, health, cosmetics, medical treatment, and biotechnology. The above-mentioned key concepts must be integrated with these issues.

We have developed chemistry lesson models for upper secondary school that enhance students' abilities to make appropriate judgments on the topic of bioenergy-like biodiesel, biological resources like chitin and chitosan, and metal resources like iron. Through these lessons, the students were expected to be able to: (1) recognize a science-related problem in connection with social and environmental issues; (2) think of possible solutions based on their understanding of content knowledge; and (3) make appropriate judgments directed toward solving a given science-related problem and taking action. Some findings, as shown from the trials and evaluations of the lessons, indicate that they helped promote students' judgment abilities based on their knowledge of science and at the same time facilitated improvement in the students' awareness of and beliefs about bioenergy, biological resources, and metal resources. Moreover, we have expanded our research into a joint Japan–Korea project. The project provided the students in both countries an excellent opportunity to consider the possibilities for establishing a sustainable global society.

In this chapter, the current situation for science lessons that broaden sustainable society and the development of the lesson models in Japan is introduced.

22.2 Understanding of Key Concepts on Sustainable Development

The starting point for promoting ESD was the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil in 1992. The basic action plan for ESD described in Chapter 36 of Agenda 21, which was established by the conference, is as follows: "*Both formal and non-formal education is indispensable to changing people's attitudes so that they have the capacity to assess and address their sustainable development concerns. It is also critical for achieving environmental and ethical awareness, values and attitudes, skills and behavior consistent with sustainable development and for effective public participation in decision-making. To be effective, environment and development education should deal with the dynamics of both the physical/biological and socioeconomic environment, and human (which may include spiritual) development should be integrated in all disciplines and should employ formal and non-formal methods and effective means of communication.*" (UNCED 1992).

After announcing this agenda, the need for ESD has gradually been recognized in Japan. Some pilot schools, including UNESCO network schools, have tried to organize ESD classes by advancing environmental education, intercultural education, peace education, human rights education, etc. However, these trials did not significantly spread because the government's education policy for ESD was not formulated at that time. Subsequently, a worldwide trend of promoting ESD reached its peak after the year 2000. After the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa in 2002, the United Nations adapted the proposal for a Decade of Education for Sustainable Development (DESD) from 2005 to 2014 to popularize the idea of sustainable development, and UNESCO requested member nations to formulate an enforcement plan for ESD. With this as a turning point, a liaison committee, organized by governmental offices including the Ministry of Education, Culture, Sports, Science and Technology (MEXT), formulated an enforcement plan for DESD in 2006 as a guideline for ESD.

According to the enforcement plan, the goals of ESD are: "*1) everyone can enjoy the benefits of high-quality education, 2) the principles, values, and actions needed for sustainable development can be taken into all fields of education and learning, and 3) education and learning can bring the changing of people's actions for realizing a sustainable future in the aspects of environment, economics, and society.*" (Liaison Committee among Ministries and Agencies on UNDESD 2006). Nothing that the first goal is a prerequisite for promoting ESD, and the third goal is the actualization of ESD, the second goal should be concretized in the classroom situation. Therefore, the concrete goals of ESD provide opportunities for people to be able to: (1) understand and think about the principles needed for sustainable development, like preservation and recovery of natural environments, (2) form a sense of value with respect to these principles, and (3) acquire a power of action based on this sense of value.

Subsequently, the enforcement plan describes various principles needed for sustainable development; e.g., preservation and recovery of natural environments, preservation of natural resources, intergenerational equity, interregional equity, gender equality, social tolerance, reduction of poverty, a fair and peaceful society, etc. However, the key concepts contained in the principles are limited. In a report for ESD written by the National Institute for Educational Policy Research in Japan (NIER 2012), concepts like diversity, mutuality, limitation, equity, cooperation, responsibility, etc., are mentioned. The former three concepts relate to the natural, social, and economic environments surrounding human beings, while the latter three concepts relate to the will and action of human beings in groups, regions, societies, nations, etc. (Table 22.1). Moreover, according to the Guidelines for Instruction of Environmental Education (NIER 2007), concepts like circulation, diversity, ecosystems, symbiosis, preservation, respect for life, continuity of life, etc., are also mentioned.

In order to achieve the three above-mentioned concrete goals, it is important first to promote students' understanding of key concepts for sustainable development. In the research and practice of science lessons, concepts must be integrated with science, technology, society, and environment (STSE) issues, such as natural resources, energy, transport, electronics, food, health, cosmetics, medical treatment, biotechnology, etc. Indeed, literature on science lessons that use integration has

Table 22.1 Key concepts for establishing a sustainable society (NIER 2012)

Concepts related to natural, social, and economic environment surrounding human beings	
Diversity	Nature, culture, society, and economics consist of diverse entities differing in the aspects of origin, character, situation, etc., and diverse occurrences of phenomena
Mutuality	Nature, culture, society, and economics mutually influence each other, and substances, energy, and information are communicated and circulated among them
Limitation	The limited environmental factors and resources, such as substances and energy, sustain nature, culture, society, and economics with the irreversible changes taking place within
Concepts related to the will and action of human beings in groups, regions, societies, nations, etc.	
Equity	Sustainable society is based on interregional, intergenerational equity, fairness, and equality that guarantees fundamental rights and enjoys the blessings of nature, etc.
Cooperation	Sustainable society is constructed by people's various adaptations/harmonies and cooperation/collaborations corresponding to situations, interrelationships, etc.
Responsibility	The people who are responsible for focusing on the visions and changes/innovations of the future are the ones who create a sustainable society.

been gradually emerging (e.g., Grace and Byrne 2010; Burmeister and Eilks 2012). Consequently, science lessons focused on STSE issues can enter the limelight and serve as a new starting point for achieving ESD.

22.3 Making Appropriate Judgments on Science, Technology, Society, and Environment Issues

The goals and key concepts of ESD describe viewpoints for planning innovative science lessons. Deliberate and careful planning on how to make proper lesson contents and effective teaching strategies based on the given viewpoints must be introduced. In relation to this subject, Burmeister et al. (2012) described basic models for approaching sustainability issues in chemistry education, Model 1 adopts green chemistry principles for the practice of science education lab work; Model 2 adds sustainability strategies to the content of chemistry education; Model 3 uses controversial questions of sustainability for socioscientific issues, in order to drive chemistry education; and Model 4 integrates chemistry education into ESD-driven school development. Model 1 adopts chemistry experiments with an emphasis on sustainable development, such as microscale experiments and usage of less poisonous substances. Model 2 adds subject matter, in which it appears to utilize basic chemical principles for industrial applications like reducing usage of natural resources and exhaust of waste products. Model 3 sets scenes of decision-making on the topics like the use of biofuel and influences of controlled substances on the human body. Finally, Model 4 integrates chemistry education into school activities, such as saving water and economizing electricity. Through integration, chemistry education plays a part in enriching social awareness and involvement.

These models display proper ways of linking chemistry education and ESD. That is, Model 1 links learning activities for chemistry education to ESD, with the purposes of promoting understanding and consideration of concepts for sustainable development and of forming values in sustainable development. Model 2 links the contents of chemistry education to ESD, and has the same purpose as Model 1. Model 3 links the themes of chemistry education to ESD based on the understanding of concepts for sustainable development. The purpose is to enhance students' ability to make judgments and to enhance decision-making in a social context, and at the same time to form values in sustainable development. Model 4 links the themes, contents, and learning activities of chemistry education and ESD as a whole. The purpose of this model is to encourage students' power of action in their daily lives.

Model 3 has highlighted the promotion of students' abilities in judgment and decision-making as a research interest for science education since the Science-Technology-Society (STS) movement of the 1980s. Various curricula and modules for promoting students' abilities in judgment and decision-making have been developed up until now (e.g., American Chemical Society 1988; University of York Science Education Group 1994; Demuth et al. 2006). Moreover, various ideas on issues-based approaches, including decision-making processes, have been advocated. For instance, Hodson (1994) suggested four levels of sophistication: (1) appreciating the societal impact of scientific and technological change, (2) recognizing that decisions about scientific and technological development are in pursuit of interests, (3) developing one's own views and establishing one's own underlying value positions, and (4) preparing for and taking action. In a separate manner, Lewis and Leach's (2006) idea established a relationship between the understanding of the content knowledge of science and the ability to engage in reasoned discussion of socioscientific issues.

However, few studies have been done in the context of Japanese science education that promotes students' ability in judgment. Therefore, lesson models for chemistry topics and effective teaching strategies that promote ability in high school chemistry are proposed herein. With reference to the above-mentioned studies, the lesson models are focused on judgment ability intervening in decision-making processes. This ability is comprised of three phases: (1) recognize a science-related problem in connection with social and environmental issues, (2) think of possible solutions based on understanding of content knowledge, and (3) make appropriate judgments directed toward solving the given science-related problem and taking action. The lessons are integrated on the topics of bioenergy like biodiesel, biological resources like chitin and chitosan, and metal resources like iron. The lessons on the topic of biodiesel and iron were carried out for Japanese and Korean students as joint research while the lesson on the topic of chitin and chitosan was conducted for Japanese students only.

22.4 Lesson Model on the Topic of Biodiesel

22.4.1 Development of the Lesson Model

The utilization of bioenergy as a renewable energy source is a recent social issue in Japan and Korea. Biodiesel, as a kind of bioenergy, is an alternative diesel fuel. However, students do not have satisfactory understandings of certain things about bioenergy and biodiesel, and they lack the ability to judge energy-related social problems. A lesson model for high school chemistry on the topic of biodiesel is proposed herein, with the aim of promoting students' ability to judge social problems of energy supply. This lesson assesses an assumption that would influence the acquired knowledge of biodiesel in the direction of the ability in judgment.

The aim of this lesson model is to promote students' ability to judge social problems of energy supply by applying their knowledge of science through an improved model of the Berlin analog (Kirschenmann and Bolte 2006, 2007). The contents of the lesson are composed of the following items.

– Lecture (60 min): "Energy situation and development of bioenergy/biodiesel"
– Experiment (180 min): "Generation of biodiesel" and "Comparison of biodiesel and diesel as chemicals"
– Group discussion (90 min): "Evaluation of biodiesel and diesel as fuels from the standpoint of energy" and "Planning for the utilization of biodiesel."

Materials for the lecture, worksheets for the experiments, and evaluation sheets for the group discussions were developed. These instructional materials were modified based on the original Berlin model. Contents from Japanese and Korean school textbooks were incorporated into the materials and manual to serve as supplements and to facilitate easy use for Japanese and Korean students.

22.4.2 Trial of the Lesson Model

The lesson model was carried out with 21 Japanese and 19 Korean students in 11th grade for 2 days in August 2011.

Lecture: The lecture covered the topic of world energy consumption, including in Japan and Korea, dependence on fossil fuels, reserves and price of crude oil, amounts of CO_2 exhaust, and the latest trends in the development of renewable energy around the world like bioenergy. Moreover, lectures on oils, fats, and fatty acids and the generation of biodiesel by transesterification of colza oil with methanol were presented to the students.

Experiment: Students' activities in this part included synthesis of biodiesel and measurement of calorific values, viscosities, and flash points among colza oil, biodiesel, and diesel (see Appendix). A chemical comparison of biodiesel and diesel was also conducted.

Group Discussion: Biodiesel and diesel were evaluated as fuels from the standpoint of energy. Moreover, the students discussed a plan to utilize biodiesel for a certain town. Discussion focused mainly on both the advantages and disadvantages of biodiesel for the promotion of bioenergy, as students themselves took on the role of consumers.

22.4.3 Evaluation of the Lesson Model

First, the appearance of ability in judgment was evaluated through two questionnaires and a group discussion. Regarding the questionnaire given to the students before and after the lesson, reasons for agreeing with or opposing the construction of facilities for energy supplies like fossil fuels, wood, biodiesel, biogas, wind, solar batteries, and nuclear power were enumerated. The number of reasons showed an increase of about 1.5 times per student after the lesson (Fig. 22.1). Specifically, after the lesson on energy supply facilities that use biodiesel was discussed, the number of reasons increased by about 1.8 times for Japanese students and 1.9 times for Korean students. The nature of the reasons was varied (Fig. 22.2). For instance, not only was the ecological aspect identified, but also reasons related to aspects of science (chemistry) and technology. These reasons increased after the lesson. Moreover, an aspect of sustainability also appeared significantly. These results show that students could sufficiently provide reasons for judging the possibilities for biodiesel as energy.

Another questionnaire was given to students after the lesson. When the prompt: "Write down ten criteria that are important to your assessments of the two kinds of fuel, i.e., biodiesel and diesel," was presented, various criteria from the standpoints of usefulness, cost, easiness of and prospects for manufacturing, responsible concern for the environment, fuel efficiency, etc., were raised (Fig. 22.3). Subsequently, assessment ratings for the two kinds of fuel were determined by the following rules:

– Choose five of the ten criteria that you want to use for the assessment. Determine the importance or the weighting factor of each criterion by allocating a total of 20 points to the chosen criteria.

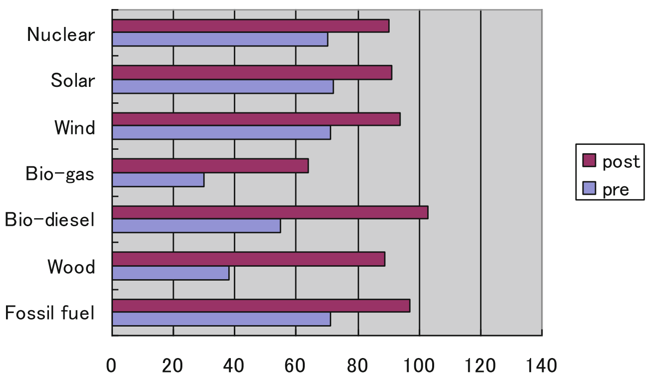


Fig. 22.1 Number of reasons for agreement and opposition (Japanese students)

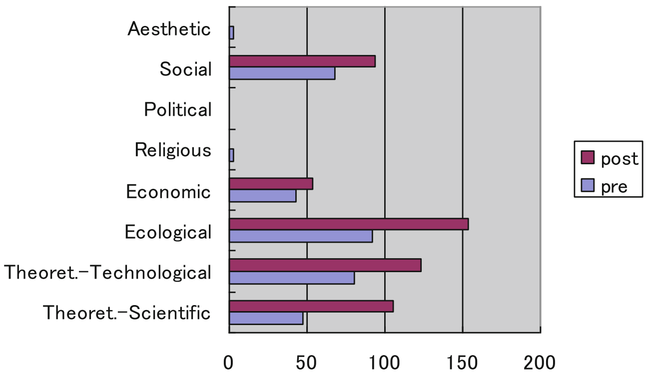
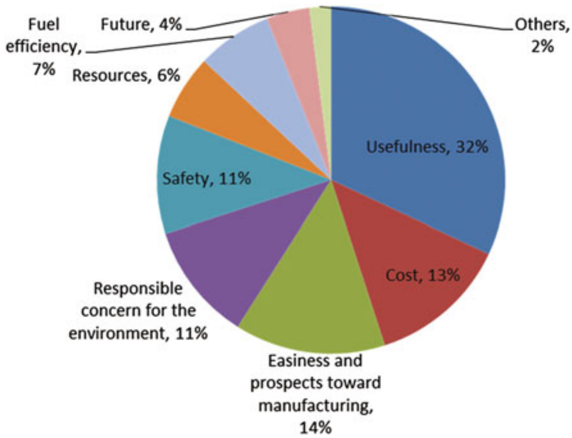


Fig. 22.2 Number of reasons from different standpoints (Japanese students)

Fig. 22.3 Criteria for assessing biodiesel and diesel as fuels (Japanese and Korean students)



- Assess biodiesel according to each criterion and allocate it a grade (5 = very good to 1 = inadequate).
- Calculate the weighted grades by multiplying the grade of the respective criterion by the weighting factor. Then, sum up the weighted grades. In order to calculate the "final grade," divide the sum of the weighted grades by 20.
- In order to assess diesel, use the same rule as that for biodiesel fuel.

The average of the "final grades" for Japanese students was 3.3 for biodiesel versus 2.7 for diesel, and that for Korean students was 3.5 for biodiesel versus 2.7 for diesel. Biodiesel clearly had higher assessments.

Moreover, the students discussed the plan to utilize biodiesel in a certain town as an example. Their sketches of the plan based on the discussion were indicative of various standpoints, such as the environment, the economy, the technology, and sustainable community. For instance, a female Japanese student who was conscious of the environment in the town paid attention to the cooperation between agriculture and the utilization of biodiesel. Her description was: "*The people cultivate corn and extracted oil. After the extraction, the dregs of the corn are also used as feedings of livestock, and then the dung of livestock is used as fertilizer for corn. The people should build a cycle like this to develop an ecological town that does not produce waste.*"

Second, acquired knowledge was evaluated through the Concept Map drawn by the students. Terms demonstrating knowledge of the raw materials and properties of biodiesel, e.g., colza oil, renewable energy, and carbon neutral, increased remarkably in number for both groups of students after the lesson. This type of knowledge can be understood as connecting different categories of knowledge, and as the formation of networks of knowledge, e.g., "*Bioenergy → Biomass → Utilization of waste → Waste treatment → Reduction of* CO_2 *exhaust*" *and* "*Biodiesel → Vegetable oil → Plant →* CO_2 *→ Environment → Carbon neutral.*"

Finally, regarding the relation between judgment and acquired knowledge, eight students who formed a practical plan for utilizing biodiesel from comparatively various viewpoints were watched. Each student individually mentioned common words, such as "environment" and "newness," in their responses, as shown in the evaluation tools (Table 22.2).

The lesson model was able to promote students' ability to judge energy-related social problems, not only from the perspective of environment, economy and society, but also science and technology. At the same time, significant relations between students' ability in judgment and their acquired knowledge of the scientific properties of bioenergy and biodiesel surfaced.

22.5 Lesson Model on the Topic of Chitin and Chitosan

22.5.1 Development of the Lesson Model

Chitin and chitosan are natural polymer compounds obtained from shells of crab and prawn. They belong to the group of polysaccharide, along with starch, cellulose, etc. Research into chitin and chitosan has been promoted for about 30 years. Currently, they are used for health food, antibacterial agents in clothes, cosmetics (shampoo, milky lotion, etc.), medical treatment materials (artificial skin and suture string), agricultural materials, wastewater treatment materials, etc., and have become one of the most widely used chemical substances in our daily lives. Chitin and chitosan are introduced as chemical substances with bright prospects by Japanese high school chemistry textbooks. However, the development of the lesson model on the topic of chitin and chitosan has hardly advanced. This study proposes a lesson model on chitin and chitosan for Japan, aimed at promoting students' ability to judge how they utilize these chemical substances in their daily lives.

The aim of this lesson model is to promote students' ability to judge the propriety of utilizations of chitin and chitosan by applying their knowledge of science. The contents of the lesson are composed of the following items.

Table 22.2 Relations between ability in judgment and acquired knowledge

Appearance of ability in judgment				Acquired knowledge
Evaluation tools	Group discussion: planning for the utilization of biodiesel	Questionnaire 1: criteria of the assessment of biodiesel and diesel	Questionnaire 2: reasons for an agreement with or opposition to the construction of facilities of energy supply	Concept map: knowledge about bioenergy and biodiesel
Student A	The people cultivate corn and extracted oil. After the extraction, the dregs of the corn are also used as feedings of livestock, and then the dung of livestock is used as a fertilizer for corn. The people should build a cycle like this to develop an ecological town that does not produce waste	**Environment**, **resources (reserves)**, combustibility, efficiency, weight, time for manufacture, viscosity, easiness of manufacture, price, safety	Agreement: **earth friendly,** good efficiency Opposition: requirement of much time	**Environment**, corn, plant, colza oil, it can be worked a car, revitalization of a town
Student B	The people set up a filling biodiesel station	**Burden for environment**, easiness of production, fuel consumption viscosity, limit or not (future), cheap	Agreement: **good for environment**, reduction of waste Opposition: high cost, no precedent because of the newness	**Good for environment**, new energy, diesel, light oil, motorbike, methanol solution

– Chemical structure of chitin and chitosan

1. Lecture (30 min)
2. Activity: "Making of molecular models" (60 min)

– Raw material and manufacturing process of chitin and chitosan

3. Lecture (30 min)
4. Lab experiment: "Formation of chitin and chitosan" (60 min)

– Features and use of chitin and chitosan

5. Lecture (30 min)
6. Lab experiment: "Anti-mold examination" (60 min), "Aggregation of dirt and collection of heavy metal ion" (60 min), and "Making of chitosan film used as a semipermeable membrane" (60 min)

– Gathering information on chitin and chitosan

7. Activity: "Gathering information from web sites" (30 min)
8. Study tour: "Manufacturing factory for chitin and chitosan" (1 day)

– Evaluation and utilization of chitin and chitosan

9. Classroom discussion and presentation: “Evaluation of the propriety of utilizations of chitin and chitosan” (60 min)

Materials for the lecture, worksheets for the experiments, and evaluation sheets for the classroom discussion and presentation were developed and utilized.

22.5.2 Trial of the Lesson Model

A lesson model was conducted for 18 students in 11th and 10th grade for 3 days in July 2009.

First day: Lesson contents 1–4 and a part of content 6 were performed. In content 1, the lecture on high molecular compounds, polysaccharides, polymerization, and the structure of chitin and chitosan was given to students. In content 2, the knowledge acquired from the lecture was confirmed by making molecular models as a student activity (Fig. 22.4). In content 3, the lecture on crab shells, which had initially been considered waste but now serve as the source of an important biomass, was presented. Then, a method of forming chitin from shells (removal of calcium and protein) and also a method of forming chitosan from chitin (deacetylation) were explained to the students. In content 4, the students made chitin and chitosan powder from a kind of crab (Fig. 22.5). In a part of content 6, students examined chitosan’s controlling effect on the proliferation of mold by adding chitosan solution to the agar medium.

Second day: Contents 5, selected parts of content 6, and content 7 were conducted. In content 5, the lecture on various uses of chitin and chitosan was given to the students. In content 6, an experiment on aggregation of protein solution in water (for instance, the solution of skimmed milk) from chitosan solution was performed. Then, the students made chitosan beads from the solution, and colorized the beads with heavy metal ions (Cu^{2+}, Ni^{2+}, Co^{2+}) as a chelate complex (Fig. 22.6).

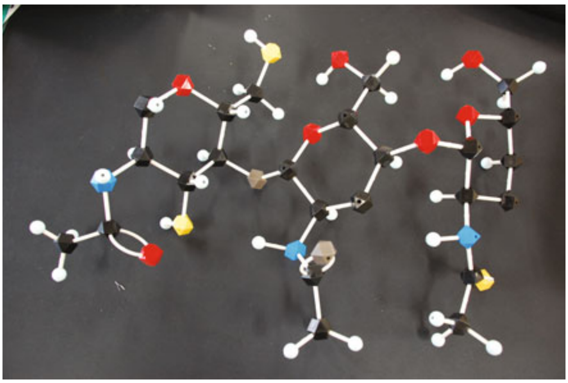


Fig. 22.4 Molecular model of chitin

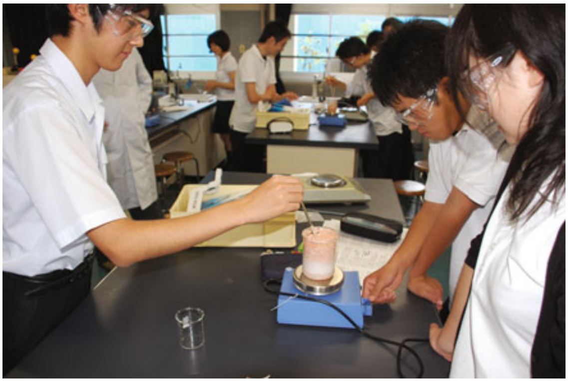


Fig. 22.5 Formation of chitin from crab shells (removal of calcium)

Fig. 22.6 Formation of a chelate complex by using chitosan beads

Moreover, they made chitosan film from the solution. In content 7, they collected information about chitin and chitosan using related web sites.

Third day: Contents 8 and 9 were implemented. In content 8, a factory tour was organized, and manufacturing and research sites for chitin, chitosan, and glucosamine were inspected (Fig. 22.7). In content 9, the possibilities for the use of

Fig. 22.7 Factory tour: crab shells as a raw material of chitin and chitosan

chitin and chitosan, and the propriety of their utilization as a healthy food were discussed.

22.5.3 Evaluation of the Lesson Model

Through the concept map, words associated with chitin, chitosan, and glucosamine were enumerated by the students before and after the lesson. The number of words increased by around 16 words per student after the lesson, while it had been around eight words per student before the lesson. The contents of the words show that the students acquired not only knowledge of basic chemistry concepts but also knowledge of the application and utilization of chemistry. Relations between the words show that students were able to connect the categories of knowledge and form networks of knowledge (Fig. 22.8).

Using a questionnaire, the students wrote freely on the possibilities for the use of chitin and chitosan after the lesson. About 80 % of students expressed a number of ideas about chitosan controlling the proliferation of mold and that, therefore, the water permeability of chitin sponges makes them a useful material for medical treatment. One of the students had the original idea that the best use of the above-mentioned characteristics would be application to the development of mats for pool locker rooms. Then, the propriety of chitosan's utilization as a supplement for obesity prevention was freely written about by the students (Gräber 2009). About 60 % of students expressed the similar idea that it was unnecessary to use the supplement for individual body balance. One of the students answered: "*Chitosan would not have to be used because it might obstruct not only assimilation of fat but*

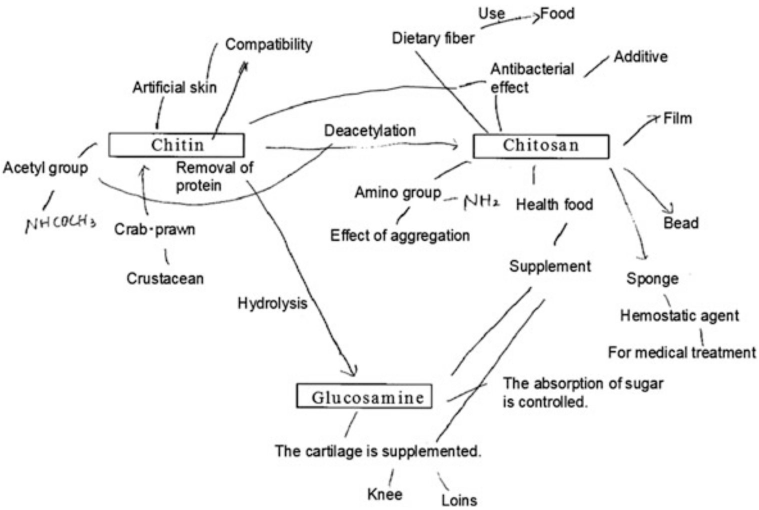


Fig. 22.8 Student's concept map: network of the knowledge on chitin, chitosan, and glucosamine

also that of fat-soluble vitamins." Students made appropriate individual judgments based on the knowledge of science that they acquired through the lesson.

22.6 Lesson Model on the Topic of Iron

22.6.1 Development of the Lesson Model

A material iron has widespread importance for our lives. Many machines, buildings, and life goods are made of iron. Moreover, a large amount of natural resources and energy sources, such as iron ore, coal and water, are needed for the production of iron. Therefore, we can understand the utilization of materials in today's life and society by paying attention to iron, and consider a direction for the development and the utilization of materials in the future. A lesson model on the topic of iron for high school chemistry is proposed herein, aimed at promoting students' ability to judge utilizations of iron. This study examines an assumption that influence students' ability in judgment to creative representations on natural phenomena.

The aim of this lesson model is to promote students' judgment abilities based on the knowledge of the features of iron. The contents of the lesson are composed of the following items.

- Lecture (120 min): "Iron: raw materials, manufacturing, utilization, and history"
- Experiment (120 min): "Metal plating on iron sheet and corrosion protection by plating on iron sheet"
- Study Tour (half day): "Steelworks"
- Activity (180 min): "Gathering information on iron and other materials for automobiles using web sites" and "Evaluation of utilization of iron and other materials for automobiles."

A manual for the lecture, worksheets for the experiment, and evaluation sheets for the activity were developed and utilized.

22.6.2 Trial of the Lesson Model

The lesson model was carried out with 36 Japanese students and 30 Korean students in 11th grade for 2 days in January 2011.

First day: lectures and study tour were carried out. First of all, the lecture on "What kinds of materials is an automobile made from?" was given in order to foster student interest in the topic of iron. Then, the lecture about (1) the raw materials for iron, (2) the manufacturing of iron, that is, the actual manufacturing process and the saving of energy and reduction of carbon dioxide, (3) the utilization of iron: types of use, alloy, protection against corrosion, and recycling of iron, and (4) history of iron. In parts of content (2), reduction of iron oxide with hydrogen instead of coke was demonstrated in a teacher experiment. During the study tour, steelworks was inspected and information about iron was gathered.

Second day: lesson experiments and an activity were conducted. The experiment on metal plating (tin, zinc, and nickel) on iron sheets was performed (Fig. 22.9). Then, the corrosion protection of plating on iron sheets was tested with a potassium ferrocyanide solution. After scratching it with the tip of a nail and dropping sodium chloride solution on it, color changes were compared (Fig. 22.10). In the activity, information about iron and other materials for automobile components was collected using web sites. Then, possibilities for the utilization of iron and other materials were discussed as a group activity, and models of future automobiles made from prospective materials were creatively sketched as an individual activity.

22.6.3 Evaluation of the Lesson Model

In the case of terms related to iron, as enumerated by the students, those terms demonstrating knowledge about the physical properties of iron increased

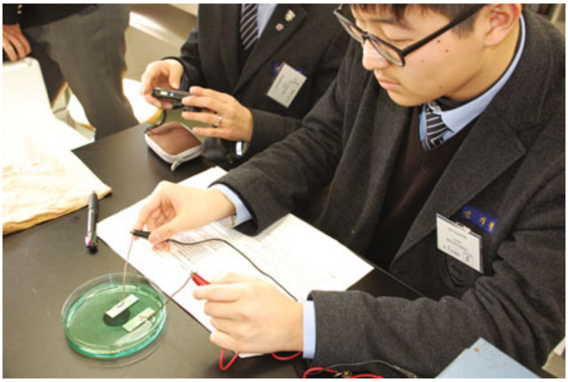


Fig. 22.9 Metal (Tin, Zinc, and Nickel) plating on iron sheet

Fig. 22.10 Corrosion protection of plated iron sheet

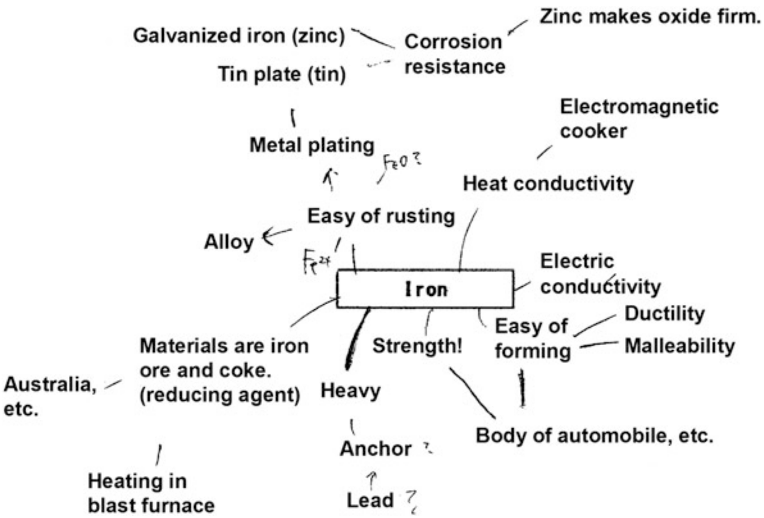


Fig. 22.11 Acquisition of knowledge about physical properties of iron (after the lesson)

remarkably in number among Japanese and Korean students after the lesson. The number of related terms enumerated per student was about 1.9 times higher for Japanese students and 2.5 times higher for Korean students. This type of knowledge can be understood as connecting different categories of knowledge, and as the formation of networks of knowledge (Fig. 22.11).

Regarding the assessed materials (steel, aluminum alloy, and synthetic resin) from the standpoint of utilization for automobile bodies, about 43 and 32 % of the assessment criteria enumerated by Japanese and Korean students, respectively, were related to the physical properties of the materials (specific gravity, strength, hardness, durability, forming, etc.) (Question 1 in Fig. 22.12) (Fujii et al. 2009). Then, the performance value assigned by the students' assessments displayed their judgment based on acquired knowledge of the physical properties and other features (price, recycling, etc.) of materials (Question 3 in Fig. 22.12).

In the case of materials selected in rough sketches for use in the parts of future automobiles, eight students showed creative representations, including originality, practicality, sensibility, and/or inclusiveness (Finke et al. 1992). For instance, a female Japanese student, whose creative representation displayed originality, calculated final grades that were higher for synthetic resin, as well as steel, in the assessment of materials (Fig. 22.13). Thus, students' representations were based on the judged value of materials' features, including their physical properties. A relation between students' creativity and judgment ability related to the features of materials, including iron, was found by this lesson.

1 Assessment of Material

Carry out your own assessment of the three materials (steel, aluminum alloy, and synthetic resin) in the aspect of the utilization for automobile's body. 自動車のボディをつくるという点で評価する。

(スチール アルミニウム合金 合成樹脂)

1) Write down ten criteria which are important for your assessment of three kinds of materials (steel, aluminum alloy, and synthetic resin), in individual work.

- ○ ・耐久性
- ○ ・価格
- ・比重
- ○ ・加工しやすさ be processed easily or not (manifacture)
- ○ ・作られるさいに環境にやさしいか。 earth friendly
- ○ ・手に入れやすいか。 get easily or not
- ・広く使えるか。
- ○ リサイクルできるか
- ・
- ・

2) Select five of the ten criteria which you want to use for the assessment, in group work.

- cost
- strength
- recycling
- easy to make
- weight

3) Assessment of the material steel:

List your selection of criteria and determine the importance factor of each criterion by allocating a total 20 points to the five criteria.

Assess steel after each criterion and allocate the performance value to it (5 = very good to 1 = inadequate).

Calculate the total value by multiplying the performance value of the respective criterion with the importance factor. Then add the single total value. In order to calculate the final grade, divide the sum of the total value by 20.

Steel		1 ~ 5	
Criterion	Importance factor	× Performance value	Total value
③ A price/cost	5	4	20
① B strength	7	4	28
C recycle be able to	2	3	6
② D easy to manufacture	4	4	16
④ E weight	2	1	2
Sum	20		72
			: 20
Final grade			3.6

Write the reason why your group determines the importance factor and the performance value to each selected criterion.

Fig. 22.12 Worksheet assessing automobile materials (Omission of assessment of aluminum alloy and synthetic resin in Question 3)

22.7 Remarks

Innovative lessons in chemistry education that are effectively linked to ESD can advance students' knowledge of the science of energy and natural resources, and also promote their abilities in making appropriate judgments on STSE issues. These abilities reflect students' understanding of key concepts in sustainable development, such as limitations of energy and natural resources, and the mutual relationship that exists between the natural environment, economics, and society.

For further implementations of this study, we suggest some points directed toward developing effective lessons. First, it is crucial to choose topics that are highly relevant

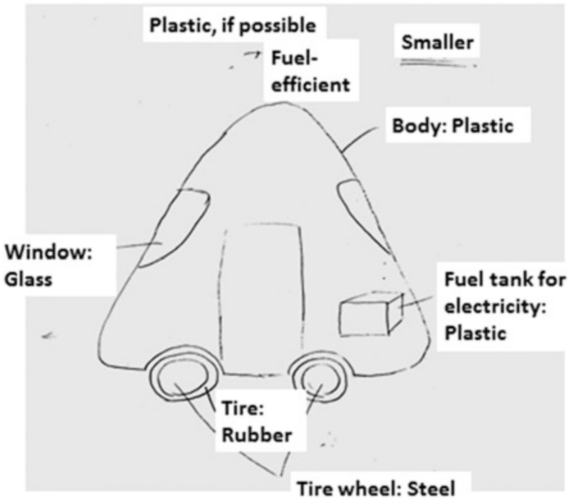


Fig. 22.13 Materials of some parts of a future automobile

to students. These topics will raise their awareness concerning STSE issues, and promote understanding of problems related to science. Second, it is also important to integrate within the lesson several components, like lectures, experiments, and inspection tours of factories. Through this integration, students will be aware of the realities of both modern society and their daily lives. Finally, in order to promote students' ability to make appropriate judgments, it is necessary to provide appropriate learning situations in which they can apply their knowledge of science and display their creativity in addressing issues that will positively promote a sustainable society.

Viewed from the ideological perspective of science education herein, these linkages may demonstrate an important standpoint. Namely, they adapt the standpoint that the objective of science education is to enhance students' understanding of the nature of science as a way to contribute to the development of human society, and at the same time to promote reflection on the importance of science in human life. This standpoint demands that students develop general education skills represented in an individual's judgments and actions as a responsible member of society. As a result, they can take part in active decision-making that concerns society as a whole and contribute to creating a sustainable society in the future.

On the other hand, some of the lessons introduced in this chapter elucidate that a joint project between Japan and Korea can achieve a measure of success in promoting students' judgment ability on STSE issues. The project provides the students in both countries an excellent opportunity to consider the possibilities for establishing a sustainable global society. We expect that this project will become a platform to establish collaborations in science education research and practices in the coming of a new era in Asia.

Acknowledgments The work described in this chapter was supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (C), No. 22500818. The authors gratefully acknowledge the collaboration of Atushi Hiramatsu, Ryoichi Utsumi, Yusuke Ohgata, and Sung Hoon Kim in developing the lesson models.

Appendix: Worksheets for the Experiments on Biodiesel

Synthesis of Biodiesel

Purpose: To synthesize biodiesel from waste cooking oil and verify the product.

Preparation:

Experimental instruments

□ graduated test tubes □ 50 mL beaker □ a pestle and mortar □ a dropping pipet

□ a rubber stopper □ a glass rod □ an electric balance □ a capillary

□ a wide-mouthed reagent bottle □ a spray □ forceps □ a hot plate

Materials

□ waste cooking oil □ methanol CH_3OH □ sodium hydroxide NaOH

□ Thin Layer Chromatography plate (TLC)

□ TLC coloring reagent (vanillin-sulfuric acid)

□ TCL eluent (heptane: diisopropyl ether: acetic acid = 15:10:1)

A: Synthesis of Biodiesel

Safety goggles!

Procedure:

□ Weigh out about 0.7 g of sodium hydroxide (NaOH) and grind into powder with a pestle in a mortar. Transfer grinded NaOH into a beaker, then add 20 mL of methanol to dissolve NaOH completely. (This is sufficient for 10 experiments)

□ Add 10 mL of waste cooking oil and 2 mL of methanol with NaOH from procedure 1 into a graduated test tube and top it with a rubber stopper.

□ Holding the stopper firmly with the thumb, shake vigorously up and down for 3 min. (Observation ①)

□ Let the test tube sit for 30 min. Observe that the mixture separates into two layers while leaving the stopper on the tube. (Observation ②)

□ The biodiesel layer will float on top. Read the scale to measure the amount of biodiesel obtained. (Observation ③)

Observations:

□ ____

□ ____

□ __________ mL (What can be said from this result?) __________

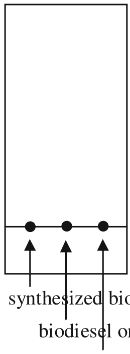
B: Verification by elution

Procedure:

① Add about 10 mL of eluent in a wide-mouthed reagent bottle and put the lid on. Wait for a while to let the eluent vapors saturate the air in the bottle.

② Draw a straight line 1.5 cm from the bottom edge on a TLC plate with a pencil. (Make sure not to scrape off the thin layer on the plate.)

③ Spot 3 kinds of materials on the line drawn. See the figure on the right. Place the synthesized biodiesel on the left, biodiesel on the market in the center, and the cooking oil alone on the right.



④ Slowly place the TLC plate with 3 spots in the reagent bottle with eluent using forceps.

⑤ Remove the TLC plate when the eluent front reaches about eight-tenths of the plate.

⑥ Place the plate in the draft chamber and spray vanillin-sulfuric acid on it.

⑦ Place the plate on the hot plate in the draft chamber to heat and develop color. Record the result.

Notes:

Measurement of Viscosity

Purpose: To perform a quick measurement of viscosity of biodiesel, colza oil (raw material of biodiesel), and diesel oil, and compare the viscosity of the respective oils.

Preparation:

Experimental instruments

□ a glass tube with an iron ball in colza oil □ a glass tube with an iron ball in biodiesel

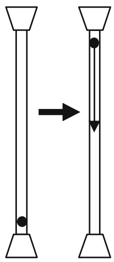
□ a glass tube with an iron ball in diesel oil

(a glass tube with 7 mm outer diameter and 1000 mm length, an iron ball with 4 mm diameter)

Procedure:

□ The three tubes with an iron ball and colza oil, biodiesel, or diesel oil are topped at both ends with rubber stoppers. Turn the tube with colza oil upside down so the end with the iron ball is on top. Start the stopwatch when the tube is turned completely, and measure and record the time in seconds until the iron ball reaches the bottom of the tube.

□ Perform the same procedure with biodiesel and diesel oil.



Results:

	Falling Time [s]		
	Colza oil	Biodiesel	Diesel Oil
1st			
2nd			
3rd			
Average			

Conclusion: What can be said from the results?

Discussion: Examine the viscosity of different kinds of liquid fuel. What is the advantage of liquid fuel with low viscosity?

Measurement of Calorific Value of Biodiesel and Diesel

Purpose: To obtain the calorific values and calculate the calorific values per unit volume of biodiesel and diesel oil.

Preparation:

Experimental Instruments:

□ an Erlenmeyer flask (500 mL) □ a stand, a bearing ring □ a thermometer

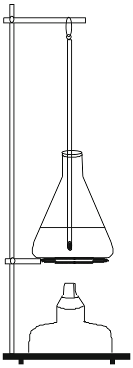
□ a graduated cylinder □ an electric balance □ forceps □ a stopwatch

Materials:

□ an alcohol lamp with biodiesel □ an alcohol lamp with diesel oil □ distilled water

□ a box of matches

Procedure:



- Put 200 mL of distilled water in an Erlenmeyer flask and assemble the stand as shown on the right. Fix the bearing ring that supports the flask 11.5 cm from the surface of the bench surface.
- Light the alcohol lamp with biodiesel and adjust the flame size to 2–3 cm by turning the wick up or down by the forceps, then put out the fire. Perform the same procedure on the alcohol lamp with diesel oil to adjust the flame size.
- Weigh out the two alcohol lamps and record the weight before combustion.
- Light the alcohol lamp with biodiesel and place it under the flask just beneath the thermometer, then start the stopwatch.
- Record the temperature every 30 s. Be careful that the flame does not flicker with wind.
- Put the lid on the lamp to put out the flame after 7 min.
- Continue recording the temperature every 30 s for 2 min after the flame is put out.
- Weigh out the alcohol lamp and record the weight after combustion.
- Repeat steps ④–⑧ using the alcohol lamp with diesel oil.

Results:

1. Weight of Alcohol Lamps

Table 22.3

Liquid fuel	(a) Weight before combustion [g]	(b) Weight after combustion [g]	(c) Combusted mass [g] ($c = a - b$)
Biodiesel			
Diesel oil			

2. Water Temperature Change

Table 22.4

Time [min]	Temperature [℃]		Time [min]	Temperature [℃]		Time [min]	Temperature [℃]	
	Biodiesel	Diesel		Biodiesel	Diesel		Biodiesel	Diesel
0			3.5			7.0		
0.5			4.0			7.5		
1.0			4.5			8.0		
1.5			5.0			8.5		
2.0			5.5			9.0		
2.5			6.0					
3.0			6.5					

3. Record anything you noticed such as appearance of combustion.

Conclusions:

□ With the result shown in Table 22.3 and density, calculate the combusted volume of each liquid fuel.

Table 22.5

Liquid fuel	(d) Density [g/cm^3]	(e) Combusted mass [g] ($e = c$)	(f) Combusted volume [cm^3] ($f = e/d$)
Biodiesel	0.88		
Diesel oil	0.81		

Record calculation process:

□ With the result shown in Table 22.4, calculate the temperature increase and calorific values with combustion of biodiesel and diesel oil. Then, calculate the calorific value of each fuel per unit volume.

Table 22.6

Liquid fuel	(g) Temperature increase [℃]	(h) Calorific value [J]	(i) Calorific value per unit volume [J/cm^3] ($i = h/f$)
Biodiesel			
Diesel oil			

*The following formula is generally used to calculate calorific value:

When the temperature of a material with the specific heat of c [J/℃ g], mass of m [g] increased by T [℃],

The heat absorbed by the material Q [J] = mcT.

In this experiment, the specific heat of water is 4.18 [J/℃ g], and the mass of the water is 200 [g]. So Q [J] = 200 × 4.18 × T

An instance of calculation:

Calorific Value 200 × 4.18 × 23.6 = 1.97 × 10^4

200 × 4.18 × 18.6 = 1.55 × 10^4

Calorific Value per unit volume 1.97 × 10^4/1.34 = 1.47 × 10^4

1.55 × 10^4/1.16 = 1.34 × 10^4

Discussion: What conclusion can be drawn from the results of calorific values per unit volume (Table 22.6) and the recorded appearance of combustion?

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Chapter 23
Role of Open Educational Resources to Support School Science Education in India

Sudhakar Agarkar

Abstract Although science teaching has witnessed a paradigm shift in recent years, a majority of schools in India continue teaching in traditional style with a sole aim of preparing students for examinations. With a view to change this scenario a project was undertaken to develop open educational resources for students, teachers and parents. Student's resources pertain to relevant games/puzzles, hands on activities, self-assessment tests and remedial/enrichment material. Teachers' resources provide guidelines to prepare teaching aids, achieve meaningful teacher–pupil interaction, manage classroom effectively and conduct action research. Resources for parents deal with everyday science, health/hygiene, out of school activities, identification/nurture of talent and parenthood in the 21st century. Sections on answers to children's questions, biographies of scientists, relevant articles on science education are common to all. These resources were developed in workshops involving practising teachers, science popularisers, social workers and parents. The units submitted by these authors in regional language were digitised and uploaded to the specifically designed website (www.mkcl.org/mahadnyan) that can be accessed free of cost. The field testing of these resources undertaken in about 200 schools catering to different sections of the society showed that they are quite effective in enhancing pupil-pupil, pupil–teacher and pupil–parent interactions.

23.1 Introduction

Since the latter part of the nineteenth century, our lives are influenced greatly by Information and Communication Technology (ICT). Developments in ICT have also influenced school education. E-learning as emphasised by Zemsky and Massey

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(2005) has a tremendous potential in the present situation. In many developed countries blackboards are replaced by ‘Smart Boards’ that facilitate effective teacher–pupil interaction. A computer and LCD projector are invariably made available in each classroom in these countries. Websites have become sources of information both for students and teachers. Realising the influence of ICT on school education National Aeronautics and Space Administration (NASA) has come out with an idea of Classroom of the Future (COTF). Established in different parts of the country COTF is trying to develop new methods of knowledge exploration using the available facility of ICT (www.cotf.edu). At the Open University in UK (UKOU), technology is being profusely used for teaching through distance mode. The Knowledge Media Institute (KMI) of the UKOU is working in the area of making use of ICT to improve teaching learning process in schools (www.kmi.open.ac.uk).

In the background of this international scenario one gets a dismal picture when one looks at the Indian education system. There is a large diversity in Indian education system. On one hand there are privately managed international schools that charge hefty tuition fees and provide good educational facilities. On the other hand, there are schools that lack even essential facilities. In the majority of these schools ICT has barely made its headway. India boasts to be providing IT experts to multinational companies. The software exports from India runs into billions of dollars. These developments in ICT have hardly benefited the school education in India. The situation in schools catering to students coming from socially disadvantaged communities is quite grave.

India, being a large country, is divided into different states formed on the basis of the language spoken by the people in the region. Following the policy of education through mother tongues, a large number of schools are operated both by the Government and private agencies to teach in regional languages. For example, Marathi is the language spoken by the people of the state of Maharashtra. Almost all the schools under the aegis of the local self-government, educational societies and tribal development departments of the government use Marathi as a medium of instruction. The teaching in these schools remains teacher-centred and textbook dominated. There is, therefore, a dire need to change this scenario. It is in this context an innovative project entitled “Open Educational Resources for Schools” (OER4S) has been launched by the Homi Bhabha Centre for Science Education (HBCSE) in collaboration with Maharashtra Knowledge Corporation Limited (MKCL) and Indian Consortium for Educational Transformation (ICONSENT) to improve the quality of education in Marathi medium schools of the state of Maharashtra. The project aimed at designing appropriate educational resources that can be used by school students, their teachers and parents. This chapter gives a comprehensive account of the project implemented in the state of Maharashtra in India for six academic years from 2007–2008 to 2012–2013.

23.2 Open Educational Resources

23.2.1 Meaning of OER

The phrase 'Open Educational Resources (OER)' was first coined in 2002 at UNESCO's Forum on the Impact of Open Course-ware for Higher Education in Developing Countries. OER are teaching, learning and research resources that reside in the public domain or have been released under an intellectual property licence that permits their free use or repurposing by others. These resources include full course, course materials, modules, textbooks, streaming videos, tests, software and any other tools, materials or techniques used to support access to knowledge (UNESCO 2002). The Organisation for Economic Co-operation and Development (OECD) defines OER as: "digitised materials offered freely and openly for educators, students, and self-learners to use and reuse for teaching, learning, and research. OER include learning content, software tools to develop, use, and distribute content, and implementation resources such as open licences" (OCED 2007). The Commonwealth of Learning has adopted the widest definition of Open Educational Resources (OER) as 'materials offered freely and openly to use and adapt for teaching, learning, development and research' (COL 2000). For public library of Science (PLoS) open includes free access, unrestricted distribution, authors retains right to attrition and papers are deposited in public online archive.

23.2.2 OER Movement

The OER movement gained momentum in the first decade of twenty-first century. OER foundation has been set up to facilitate free sharing of knowledge among the information seekers (www.oerfoundation.org). Internationally, there is a growing concern among higher education institutions to create Open Course-ware (OCW) contents and participate in the open education movement. Between 2002 and 2007, the Hewlett Foundation, invested a huge sum in its own OER initiative. UNESCO has created a Free and Open Source Software Portal and with the International Council in Distance Education (ICDE) it has set up a task force to develop an international approach to OER. The Teacher Education in Sub-Saharan Africa (TESSA) consortium created by, and working across, nine countries in Sub-Saharan Africa began supporting education in Africa. Open Learning Initiative (OLI) by Carnegie Mellon University, China Open Resources for Education (CORE), Open Learn Project of the UK Open University, Best First Year On Line Project of Canadian Virtual University and Athabasca University, The Open University of Israel's portal, the Multilingual Open Resources for Independent Learning (MORIL), Paris Tech OCW project of eleven member universities of France and Japanese OCW Alliance of ten participating universities in Japan are some of the prominent OER initiatives. Some more OER projects are emerging at universities in Australia, Brazil, Hungary, Iran, Russia, Spain, Saudi Arabia and Korea (Daniel et al. 2006). There are many other institutions and business houses and even individuals, creating open course-ware content like Apple Learning Interchange (www.ali.aple.com), Connexions, EducaNext (www.educanext.org), Eduforge (www.eduforge.org), iBerry (www.iberry.com), Gateway to Educational Materials (GEM), OCW Finder, Wikiversity, World Lecture Project, Maricopa Learning Exchange. Among the more notable of the many other current OER projects are EduTools, GLOBE, the African Digital Library, the Knowledge Commons and the Open Content Alliance. There are a large number of Open Access (OA) journals worldwide and the number is continuously increasing. Freely accessible encyclopaedias like Wikipedia are growing in size and quality day by day.

23.2.3 OER in India

Efforts are being made in India to transform it into a knowledge society. Access, equity and quality are the main foci of new initiatives in school and higher education in India. Knowledge Commission (2007) set up by the Government of India has brought out these aspects very clearly. Nowadays, many institutes are taking initiatives specifically for creating open educational tools and resources that are directed towards basic sciences and engineering education. One significant undertaking in this area is the National Program on Technology Enhanced Learning. It is a joint venture by seven Indian Institutes of Technology (IITs) and the Indian Institute of Science (IISc) funded by the Indian Ministry of Human Resource Development (MHRD), to enhance the quality of engineering education in the country by developing curriculum-based video and web courses (http://nptel.iitm.ac.in). Another illustrative open education initiative is Eklavya, launched by Indian Institute of Technology, Bombay. In this project, content developed in various Indian languages is distributed over the Internet. The Eklavya project has developed an Open Source Educational Resources Animation Repository (OSCAR) that provides web-based interactive animations for teaching. OSCAR also provides a platform for student developers to create animations based on ideas and guidance from instructors. Funding for the Eklavya and OSCAR project comes mainly from private industries. A third prominent initiative, E-Grid, supported by the MHRD and the Indian Institute of Information Technology (IIIT), provides subject-specific portals that are developed and maintained by subject domain experts. Currently, this programme offers OER only for science and engineering. A Confederation of Indian Industry (CII) has developed a collaborative e-Learning system and portal under its initiative Shiksha India, which will help Indian students search for contents in difficult topics. The portal (www.eshikshaindia.in) can be accessed by anyone free of cost and will equip schools with e-Learning facilities help students understand difficult concepts better. The portal is basically designed for students aged between 12 and over. Similarly, Brihaspati (www.brihaspatisolution.co.in), and Vimukti (www.vimukti.com), Sakshat (www.sakshat.ac.in), E-Gyankosh (www.egyankosh.ac.in), Vidyanidhi (www.vidyanidhi.org.in), etc., help Indian students in making their learning easier.

Despite the promising sets of projects mentioned above there has been no systematic national effort to develop a strategy for designing and delivering OER for disadvantaged groups of students (Sharma 2005). Such a strategy would need to address the development of OERs for a wider range of disciplines in regional languages, as well as to allow greater adoption among teachers and students. The need for OER is growing and likely to continue to do so as jobs, technology and knowledge change rapidly. Connectivity to the Internet is increasing in the country with great speed. Low-cost computers and enhanced mobile phones are being developed in the country. The time, thus, is ripe in India for developing and distributing OER that address local needs and requirements.

23.3 Identification of Resources

The task of identifying resources was undertaken through the meeting of experts, practising school teachers, science/maths popularisers, social workers and enthusiastic parents. Resources supporting school science from grades 1 to 10 were designed for all the three stakeholders of school education: students, teachers and parents. These terms are used here with wider connotations. All those who have willingness to learn irrespective of age or educational qualifications are called as 'students'. Similarly, teacher is a person concerned with school education directly or indirectly. Along the same lines, all those who wish to provide support to their wards in their educational endeavour are termed as 'parents'.

While preparing material for students the entire syllabus of school science prescribed by the Bureau of Text Book Production and Curriculum Research, Government of Maharashtra was analysed. Through this analysis, 36 main concepts in science were identified. Inputs are provided to the students for each of these concepts. They pertain to conceptual clarifications, interesting anecdotes, explanation of technical terms, tests for self-assessment, additional information, problem solving assignments, etc.

Needs and requirements of the practising science teachers were taken into account while preparing resources for them. The field work carried out by HBCSE in rural part of India brought out the fact that the practising teachers need inputs in three areas: Content, Pedagogy and Assessment (Kulkarni et al. 1994). Resources designed based on these experiences include Clarification of crucial concepts in school science, teaching aids/PowerPoints that can be used in the classroom proceedings, Activities that can be performed in the classroom, projects that can be given as an assignment to the students, pedagogic guidelines for effective classroom management, etc. Issues like research and innovation in science education and assessing students' learning with focus on Continuous Comprehensive Evaluation (CCE) are also discussed under OER for teachers.

Resources for parents were designed based on the felt needs of the society in twenty-first century. They pertained to science in everyday life, health including community health and hygienic practices, changes in parenthood (based on twenty-first century demands), out of school activities to support school science, identification and nurture of talent with emphasis on multiple intelligence, etc.

Apart from specific resources directed to fulfil the requirements of students, teachers and parents, additional resources were also designed that would prove useful to all stakeholders. Known as the common resources they include: (1) Life sketches of scientists, (2) Answers to Children's questions, (3) Articles on current trend in school education and (4) Information about events and awards.

23.4 Development of Resources

23.4.1 Resource Generation Workshops

The open educational resources were developed through specifically organised workshops at HBCSE and at other places in the state of Maharashtra. Experts from various fields concerned with school education were invited for the workshops. They were first acquainted with the concept of open learning. The importance of open source for self-learning was emphasised and model OER was made available for the perusal of the resource persons. It was noticed that the majority of resource persons had a tendency to write material in a dull and dry traditional textual style. It took a long time to convince them that units prepared in a nontraditional style would better appeal to the user. Some of the styles adopted were as follows.

23.4.1.1 Storytelling

There is a long tradition of storytelling within India. Stories from Panchatantra, which is an ancient Indian technique of moral stories using animate as well as inanimate objects around us, are told in informal settings in Indian homes. Since storytelling appeals to people of all ages, it was thought appropriate to use this style in writing and explain the concept through a relevant story.

23.4.1.2 Dialogue Mode

The traditional style of giving information about a concept does not lead to active participation of the learner. To achieve this end, it was suggested to prepare units in a dialogue mode. This dialogue could take any form: a discussion between a pupil and a teacher, conversation between two children, argument between a child and an adult.

23.4.1.3 Question–Answer Mode

Children are curious by nature. Teachers and parents also have many unanswered questions. It has been noticed that the question–answer sessions arranged in a school setting are appreciated both by teachers and students (Agarkar et al. 2002). Hence, question–answer mode in the development of OER was also adopted.

23.4.1.4 Success Stories

Practising teachers, parents and voluntary workers continuously innovate in communicating science content. Some of the innovations failed but many of them succeeded. These success stories, it has been noted, goes a long way in motivating others to follow the new style. The resource persons were, therefore, encouraged to put down their success stories for the benefit of all concerned with school education.

23.5 Processing of Resources

Through the workshops, HBCSE received units written in regional language Marathi. These units had to be processed before they could be published on the website. The work actually needed five steps: digitization, illustration, quality check, tagging and compilation. Each of these steps is described below.

23.5.1 Digitization

Devanagari is the script used for writing in Marathi. There are various softwares available in the market to digitize material written in Devanagari script. However, many of them have limitations as the user must also have the same software with him/her to read the content. In order to overcome this problem, it was decided to use Unicode font that has universal acceptance. Thus, the entire handwritten material was digitised using Unicode package available free of cost.

23.5.2 Illustration

This task was assigned to a well-trained artist. In rare cases, relevant figures were taken from available sources like websites and printed materials. Most of the time, the figures were drawn using computing facility. While drawing pictures, care was taken to ensure that they come as live entity. For that illustrator often resorted to cartoon drawing.

23.5.3 Quality Check

The units that were digitised and illustrated were then subjected to quality assurance. This task was entrusted to subject experts, method masters and social workers. Quality assurance methods were strictly applied on all the digitised units. Care was taken to ensure that the content is accurate and unambiguous; illustrations used are appropriate, activities suggested are relevant; sequencing of the points supports logical presentation; pictures, diagrams, sketches are used where necessary and contributes to better learning. Language also formed an important criterion in quality assurance. It was ensured that the language is simple and appropriate for the stage, technical terms used in the descriptions are explained, metaphors used are suitable and does not convey inaccurate or wrong message. Necessary changes were made in the units based on the inputs received through Quality Assurance Workshops.

23.5.4 Tagging and Compilation

Once the unit has been finalised it was tagged suitably to indicate the stakeholder (students, teacher or parent), level (primary, upper primary or secondary), topic and the subtopic where it should go. The finalised units were compiled using Content Development and Integration Tool (CDIT) made available by MKCL. This tool allowed the resources to be put together in specific boxes. Once adequate material was put together by HBCSE, the Web-master from MKCL published the material on the specially designed website.

23.6 The OER Website

23.6.1 Designing

The responsibility of designing and maintaining the website for the project was entrusted to the MKCL. It was named as mahadnyan, to indicate the initiative taken by Maharashtra in this crucial area (www.mkcl.org/mahadnyan).

23.6.2 The Home Page

The Home Page of the website has a welcome address written both in English and Marathi. On the left hand side it displays logos of all three participating institutions involved in the implementation of the project. The page also has windows that can give information about the project, nature of material prepared for students, teachers and parents. One can also look at the details of the workshops held for the development of OER. An important aspect of the home page is the choice to log in as a student, a teacher or a parent. Before one logs in, there is a need to register first.

23.6.3 Accessing the Resources

To facilitate the access, the resources are divided into four categories: Resources for Students, Resources for teachers, Resources for Parents and Common resources. Common resources are made available for each of the stakeholders (students, teachers or parents). In order to access these resources, a person needs to log in into his/her account. When a child logs in as students, he/she would get access to resources for students as well as common resources. Nature and scope of these resources are discussed in the following sections.

23.7 Resources for Students

The resources for students are arranged concept-wise. For convenience, they are divided into three categories: primary, upper primary, and secondary (See Appendix). While developing these resources care is taken to ensure that technical terms used in the descriptions are explained with their etymologies. Ample examples from daily life are given to illustrate the point. Some simple activities are suggested to gain practical experience. In short, it can be said that these units are prepared in such a way that a typical child from a typical village will be able to read and understand without adult intervention.

Once the student clicks on the main concept, he/she can see the list of sub-concepts. He/she can then choose one of them depending on her/his requirement. Under each sub-concept, one finds resources in the form of articles, activities, skits, power points, etc. Student has a choice to click on one of them as per his/her liking. He/she can either save the page, send it to someone or print it for further use.

23.8 Resources for Teachers

If a person registers as a teacher, he/she would also get two options: Common resources and Open Educational Resources for teachers. If he/she clicks on the second option, resources relevant to teaching of school science would appear. For convenience they are grouped under six headings: (1) Conceptual Explanations, (2) Teaching Aids, (3) Experiment/Activity/Project, (4) Pedagogic Guidelines, (5) Research/Innovation and (6) Assessment of Students' Understanding. Teacher has the freedom to choose the resources that he/she requires for immediate use. Nature of content under each heading is described below.

23.8.1 Conceptual Explanations

Primary and upper primary schools in India rarely appoint a specialised science teacher. The understanding of science among these teachers, with just high school education, is certainly inadequate. In contrast almost all the secondary schools would have appointed a specialised science teacher. But, they would have to teach all branches of science irrespective of their subject of specialisation at their graduation. Hence, many of them are unable to give justice to the subject that they have not studied at higher level. Taking these needs into account, a folder on Conceptual Explanations is included. Since it is almost impossible to explain all the concepts in school science, some major concepts, found difficult by teachers, are selected and explained through examples. Wherever required, a reference material for reading is suggested. Once a teacher clicks on the main folder entitled conceptual explanation he/she would get a list of subfolders: concept maps, lesson plan and explanatory notes.

23.8.1.1 Concept Maps

Concept map is an idea where relationships of the concept at hand with major as well as minor concepts are shown (Canas and Novak 2009). The practice of preparing a concept map has been used effectively in teaching different subjects both at school as well at college levels. A large number of such maps are prepared for important concepts in school science and are made available on the website. In addition suggestions to prepare similar maps are provided for the benefit of teachers.

23.8.1.2 Lesson Plan

The guidelines for preparing lesson plans are provided in teacher training colleges. Based on these guidelines practising teachers are expected to prepare their own plans and implement them in the classroom in dealing science concepts. However, the practice of preparing lesson plan is not followed regularly in all schools. Hence, this section attempts to help teachers for preparing lesson plans. Sample lesson plans encompassing the activities to be undertaken by the teacher, assignments to be given to the students and the method of evaluation to be followed at the end of the lesson are given as illustrative examples.

23.8.1.3 Explanatory Notes

Due to limitations on the number of pages, the concepts in science are treated very briefly in textbooks. Usually, additional explanations, illustrative examples and relevance of school content to daily life are brought out through the teachers' handbooks. However, the practice of using such handbooks hardly exists in Maharashtra. Hence, explanatory notes to clarify scientific concepts are provided in this section.

23.8.2 Teaching Aids

It is often advised that concepts in science should be taught using teaching aids. The picture in the classroom is, however, contrary to this expectation. Teaching aids are seldom used during day to day teaching. In order to help teachers using teaching aids they were made available on the website under two headings: (1) PowerPoints and (2) charts and models.

23.8.2.1 Power Points

With the advent of technology, the use of PowerPoints is becoming common in school education. However, one hardly witnesses the use of PowerPoints in Marathi medium schools. Difficulties encountered by teachers are twofold. First, teachers are not competent in preparing PowerPoints and second there are many packages used for typing Marathi that uses Devanagari script. In order to solve this problem it was decided to prepare power points and make them available so that teachers can use them directly in their classrooms. The material is processed using Unicode package. As a result, the material can be downloaded whenever they want without any difficulty.

23.8.2.2 Charts and Models

It is well known that charts and models play a key role in explaining science concepts. Once again, there is a problem of resource crunch as only a few charts and models are available in school laboratory. As a result, teachers cannot lay hands on many charts and models in their schools. Guidance is, therefore, offered to teachers on how to make charts and models using easily available material. At the same time inputs are given on how to use available charts and models effectively to clarify scientific concepts among students.

23.8.3 Experiment/Activity/Project

Role of experiments, activities and projects in the teaching of science is beyond doubt. This section attempts to give helping hand to the teachers in these areas. The resources in this category are divided into three parts: experiment, activity and projects.

23.8.3.1 Experiments

Most of the primary and upper primary schools do not have well equipped laboratories. Even in secondary schools laboratory space and resources are often inadequate. In such cases teachers have to resort to easily available material to perform experiments. In one of its field projects HBCSE had designed a kit of apparatus that can be used to perform all the experiments at primary and upper primary stages of education. Descriptions of this kit along with a sample of experiments that can be performed are given in this section. Care is taken to make sure that these activities are easy to perform and can foster interest among both teachers and the students. The value of each experiment in explaining concepts in school science is highlighted.

23.8.3.2 Activities

Teaching in Indian schools is mainly chalk and talk. Teacher goes on giving information and students, accepting passive role in the classroom, devote to simply listening to what has been said or told. There is hardly any opportunity for students to take an active role in classroom deliberations. In this context a variety of activities are suggested in this section where students can play an active role.

23.8.3.3 Projects

Although the project-based teaching is adopted in many developed countries, it is hardly practiced in Indian schools. The main reason is that teachers have no experience in teaching through projects. Moreover, they do not have access to relevant projects that can be used in the teaching of science. With a view to overcome these lacunae, a large number of projects are described in this section. In addition, first hand experiences of engaging students in educationally relevant projects are given. It is not necessary that projects be implemented in school itself. They can be given as home assignment where students work on the projects during their leisure time and come out with some good findings (Agarkar 1992).

23.8.4 Pedagogic Guidelines

Teachers teaching at primary levels usually possess the qualification of Higher Secondary School Certificate Examination (H. S. S. C.) and Diploma in Education (D. Ed.) while teachers teaching at upper primary and secondary classes have Bachelor's degree in Science (B. Sc.) and a Bachelor's degree in Education (B. Ed.). Thus, school teachers have some exposure to pedagogic techniques and principles of education. These inputs once received, however, are not adequate as they are of general nature. In actual practice, a teacher might be dealing with a special group of students like tribal children, students of factory workers or students whose parents are engaged in frontier research. The needs and requirements of these groups of teachers are different and they have to adjust with them. Second, the thinking of how children acquire knowledge has undergone drastic changes in the recent past. These changes demand serious thinking in the way classrooms are arranged, activities performed and assignments given. It is, therefore, necessary that practising teachers be given inputs in all the above matters. They are categorised as (1) Learning difficulties, (2) Teaching methods and (3) Classroom management. Resources have been prepared and made available under each of these three categories.

23.8.4.1 Learning Difficulties

The state of Maharashtra adopts a non-retention policy in primary classes. It means students are pushed to higher levels without ensuring mastery in learning. As a result, many students reached higher grade levels with poor initial knowledge. This situation often creates problems in discussing concepts in science that demands previous knowledge. In such cases, remedial inputs need to be given to the students. This section focuses on identifying learning difficulties and providing remedial inputs as understood in a project undertaken at HBCSE to teach science and mathematics to socially deprived students (Agarkar 2010).

23.8.4.2 Teaching Methods

Teaching method that a teacher follows in the classroom is based on a variety of things. First, it depends on the personality of the teacher. Second, it depends on the teacher's awareness of new developments in school education. Third, it depends on different models available to the teacher. This section, therefore, provides resources that discuss the changing scenario in educational psychology from behaviourism to constructivism. The impact of this change on science education is elaborated. An open ended approach of teaching is now advocated in school education all over the world. Ample examples on how it can be achieved in science classes are provided through these resources.

23.8.4.3 Classroom Management

It is now well accepted that a teacher has to be a good manager to achieve success in handling classroom effectively. Classroom management has received great importance in recent years in India as a large number of first generation learners have entered the school system (Kulkarni 1978). With the advent of technology and the spread of television all over the country the expectation of different sections of the society has also changed and the teacher has a big challenge in fulfilling these expectations. At the same time the teacher has a responsibility of developing citizens who can use their knowledge to deal with problems within a specific context. A variety of relevant resources in this regard are provided in this section.

23.8.5 Research and Innovation

Science education research as a discipline that received recognition towards the last half of the twentieth century (Fensham 2000). Many universities came forward to establish departments of science education. Faculties working in these departments came out with many innovative ideas for the teaching of science. A large number of science education projects were undertaken in different parts of the world. Information available in this context is huge. An attempt, however, was made to provide concise information of research activity in science education. Under this main theme, there are three sections: (1) Review of research (2) Recent trends in education and (3) Action research.

23.8.5.1 Review of Research

Serious research is being pursued in science education all over the world. Most of these research have been published in peer reviewed journals written in English or foreign languages like French, Japanese, Chinese, German, etc. Teachers working in the state of Maharashtra hardly have access to these journals. Even if they are made available many teachers do not have the competence to decode them and use for the benefit of their profession. Hence, an attempt was made to make available some research papers in a simplified manner in Marathi.

23.8.5.2 Recent Trend in Education

The National Curriculum Framework of 2005 brought out by the National Council of Educational Research and Training (NCERT), an apex body in education in India, focuses on constructivist approach of teaching. A lot of research works is being carried out based on this new thinking in education all over the world. In spite of these developments, a large number of practising teachers are ignorant of this approach of teaching. This section attempts to acquaint the teaching community with recent trends in education with its impact on the teaching of science at school level.

23.8.5.3 Action Research

The term action research was coined first to deal with local problems urgently. Entering into education this term has gained a specific meaning as a piece of work undertaken by practising teachers while he/she is in action. As the term specifies, one need not follow a comprehensive design or involved serious research methodology. Nevertheless, teachers need to be familiar with the strategy of educational research and mathematical techniques used to deal with the data collected. This aspect is taken into consideration while writing resources under this section. Ample numbers of action research projects completed by practising science teachers are included in this section.

23.8.6 Assessing Students' Understanding

Assessment of students' understanding is an important task that teachers have to undertake in their profession. Assessment is done for different reasons. First, assessment is conducted to find out the difficult spots in the understanding of the concepts. Tests used for this purpose are commonly called 'Diagnostic Tests'. The success of any teaching is measured by administering achievement tests to find out how far students have acquired the knowledge imparted to them. Apart from imparting information in science, school education envisages behavioural as well as attitudinal changes among students. Tests need to be administered to see how far these objectives are achieved. Such a mode of testing is known as 'Outcome based Testing'. The section on evaluation attempts to provide tests of all three types.

23.8.6.1 Diagnostic Tests

Crucial concepts that are found difficult for a majority of students are identified and sub-concepts embedded within a major concept are found out. Questions are framed for each sub-concept and are put sequentially in the questionnaire. These questionnaires are then administered to the students. Analysis of response sheets enables to understand how well the student has captured the essence of the concept and what is causing hurdle in the understanding. In addition, diagnostic testing would also help to identify misconceptions if any possessed by students. Sample diagnostic tests for some important concepts in school science are given along with the guidelines of how to prepare such tests.

23.8.6.2 Achievement Tests

These types of tests are commonly used in school education. In twentieth century, essay type questions were asked more commonly in school examinations as this mode of assessment tests the writing skill of the child in addition to his/her understanding of the topic. There was a problem of subjectivity associated with this mode of evaluation. In order to avoid subjectivity and to bring in objectivity multiple choice tests were adopted. In this mode of testing, possible alternatives are provided below the question and the child is expected to choose the most appropriate one. Framing of Multiple Choice Questions (MCQ) is a skilful job as the alternatives given should be equivalent and should test conceptual understanding. Hence, the mechanism of creating MCQs along with the sample questions is included in this section.

23.8.6.3 Outcome-Based Tests

As Einstein has said "The real purpose of education is to teach how to think". It is important to see whether children have achieved this skill. At the same time science teaching envisages the development of rational thinking, experimental skills, an eye for detail, analysis and synthesis of data, etc. This section provides a variety of tests being created to assess the development of these skills.

23.9 Resources for Parents

Studies have shown that home environment plays a crucial role in the scholastic progress of a child. Hence, parents have been identified as important stakeholders in school education in designing Open Educational Resources. The resources for parents are divided into six categories: (1) Everyday Science, (2) Health and Hygiene, (3) Parenthood in twenty-first century, (4) Teaching-learning process, (5) Out of school activities to support school education and (6) Identification and nurture of talent. Nature and scope of resources prepared under each of the above categories are given below.

23.9.1 Everyday Science

This section is devoted to acquainting the parents with science that is used in everyday life. The focus is on bringing out scientific method of investigation and presenting the data in a quantitative manner. There is so much science included in everyday events. Take the food we eat as an example. Starting from food production, its preservation and processing there is science at every stage. Moreover, developments in science and technology have provided us a large number of gadgets both at home and at schools. It is necessary that parents must be made conversant with the working of these gadgets. Only then they will be able to explain mechanism and provide guidance for trouble shooting to young children.

23.9.2 Health and Hygiene

When we think of health we usually limit to personal health. There is, however, a need for taking care of family as well as community health as we cannot live isolated from either. Resources under health and hygiene are, therefore, divided into three parts: personal health, family health and community health.

23.9.2.1 Personal Health

Human body is a complicated machine. It runs properly as long as there is a proper coordination among all parts of the body. Lack of coordination can create problems. At the same time an individual can suffer from a variety of illnesses. There are curative measures that an individual has to undergo in such cases. Before that, there are preventive measures that one can follow to avoid such diseases. These preventive measures are discussed. Medical science has witnessed unprecedented growth in the past few years. Doctors now prescribe so many tests to identify the exact cause of a disease. A common person is often ignorant of these tests. An attempt in this section is, therefore, made to explain the mechanism and meaning of various diagnostic tests that doctors usually prescribe.

23.9.2.2 Family Health

Family bonds in India are quite strong. One often finds three generations of people living together in a single house. There are certain advantages of having a large number of family members living together. However, illness can be a curse for such big families. Contagious diseases can quickly spread uncontrollably in such families. Hence, due care has to be taken to maintain family health all the time. Drinking water is an issue of critical importance in any family as it can spread many illnesses especially during rainy seasons. In such a situation, every family has to take care of making drinking water potable using some simple techniques. Issues related to family health are discussed in this section.

23.9.2.3 Community Health

From the time man learned to farm, villages emerged. Now one sees towns and cities with large numbers of people living together. Human beings have witnessed epidemics like plague and cholera in the past. Although we have overcome some of these diseases, there are other problems creeping in. In such cases the health of the community is at stake. Hence, care has to be taken to ensure that community health is maintained well at all times. Defecation in open areas is a major problem in developing countries. A campaign is being launched in India to have toilets for every house. There is a need to create awareness among the masses. This is exactly the point that is made in the article prepared by a teacher working in rural area of the state of Maharashtra.

23.9.3 Parenthood in twenty-first Century

Parenthood has witnessed drastic changes in the past few decades. Mass media has entered each household and become an important aspect of day to day entertainment. Some control has to be brought in for the judicious use of these media. If used properly they can become a good resource of new knowledge. In addition, there are now a large number of resources through which students can get information. Parents have a responsibility to guide children to make proper use of the resources. The main purpose of the contents in this section is to prepare parents to provide balanced guidance to their children in the present world while taking into account the futuristic viewpoint.

23.9.4 Teaching Learning Process

A large number of researchers are trying to understand how learning takes place among school students. Based on this understanding many of them have come out with effective methods of teaching school science. Parents usually are ignorant of these developments and try to help students the way they were taught in their childhood. Such a help can sometime be counterproductive. An attempt is, therefore, made in this section to acquaint parents with research studies in science education and effective methods of teaching developed. It must be mentioned here that the task is quite difficult as technical work has to be described in laymen’s language.

23.9.5 Out of School Activities

Studies conducted in various countries have brought out the fact that home environment is more important to student learning than school inputs. Providing a home atmosphere conducive to school education is the responsibility of the parents. A parent may not be in a position to help directly in science content. Nevertheless, he/she can motivate the child to undertake relevant tasks. For example, they can arrange a visit to a zoo and encourage detailed observations of animals. These observations would certainly help children enrich the information that they have gained in school about animals. Similarly, a discussion on why we should switch off the lights and fans when they are not required would bring out the importance of energy conservation that is so empathetically taught in schools. Such practical guidelines are offered to parents in this section.

23.9.6 Identification and Nurture of Talent

Every child is born as an individual. This individuality can hardly be maintained in school system. The mass education system that we follow in the country treats all on equal footing and wants to teach the same content to all with the expectation that outcome of learning would also be same for all the students. The responsibility of identifying individual talent and nurturing it, therefore, falls on the shoulders of parents. In these days of rat race, marks in the examinations are considered to be the sole criterion of success. Remembering and reproducing information in a given time is certainly a skill worth reckoning. But, it is not the only skill human beings can boast of. Giving importance only to examination scores and forcing the students for that actually kills the talent of other kinds. The research in educational psychology has clearly shown that human being display multiple intelligences. The inputs regarding the identification of intelligence possessed by the child are given in this section. In addition to the identification, it is equally important to nurture the talent by creating suitable opportunities to foster it. Useful guidance in this regard is given to the parents through this section. For example, if a candidate has an inclination towards painting then he/she needs to be encouraged to paint by providing him/her with the requisite materials.

23.10 Common Resources

Whether the person registers as a student, a teacher or a parent, a section on common resources is seen by them all along with the resources meant specifically for them. These resources are of four types: (1) Life Sketches of Scientists, (2) Answers to Questions, (3) Published articles, (4) Open forum. Users have an option of choosing any of these folders. Information provided in each of the folders is outlined below.

23.10.1 Life Sketches of Scientists

The folder on life sketches of scientists gives information about the work of some of the great personalities in science who have contributed to the growth of this discipline. Science is a multinational subject; scientists from different parts of the world have contributed to its development. The number of such persons is quite large and it is almost impossible to give information about all of them. Instead, an attempt is made to refer to scientists whose names appear in the school textbooks. In doing so, focus is kept on the biography of scientists highlighting how they have overcome difficulties and achieved success. In addition, an attempt is made to highlight method of science used by these scientists in their work.

23.10.2 Answers to Questions

This folder includes answers to questions commonly raised by students (Lagu 1978). An attempt is made to provide answers in a simple language without using technical jargon. For convenience, answers to questions are divided into four parts: physics, chemistry, biology and miscellaneous. All those questions that relate directly to the content of school physics are included in the first category. Similarly, the questions that are dependent on school chemistry are included in the second category. Human body is the object of great curiosity for everyone. Moreover, a large number of questions are received about plants and animals around us (Agarkar 1998). All these questions are discussed under the subsection on biology. The questions that cannot be put in any one of the disciplines of science are placed under the fourth category entitled 'miscellaneous'.

23.10.3 Published Articles

School education is a subject of concern for all in the society. Many of them write articles to express their views. It was thought appropriate to get some of the relevant articles to put them on the website. Since only a few articles were available in digital forms, others had to be converted into this format before uploading. In some cases articles had to be scanned and uploaded. For convenience, they are divided into three parts: (1) Articles for students. (2) Articles for teachers and (3) Articles for parents taking into account their relevance.

23.10.4 Open Forum

As a part of open educational resources, a platform has been created for sharing of ideas and experiences among teacher, teacher educators, parents, research workers, educational administrators and school inspectors. The forum, thus, provides an opportunity for exchange of ideas and experiences among all those who are concerned with school education. This platform, named 'Open Forum', forms an important part of the OER website that enables all the stakeholders to know what is going on elsewhere and to communicate with each other. In the initial phases, material received from teachers, teacher educators and researchers is included in the folder. This main folder has two subfolders, namely exchange of ideas and useful information. The first subfolder aims at compiling first hand experiences of practising teachers while the second subfolder aims at providing information relevant to augmenting school teaching in science, e.g. information about institutions and organisations, information about scholarships, competitions and events like conferences or seminars.

23.11 Field Testing

23.11.1 Identification of Educational Institutions

With a view to field test Open Educational Resources developed through the project two educational systems in the state of Maharashtra were identified. One of them was Rayat Shikshan Sanstha with headquarters at Satara in western Maharashtra. Established by a well-known social worker Mr. Karmaveer Bhaurao Patil, the system has more than 100 schools spread over 11 revenue districts of the state. These schools cater mainly to rural as well disadvantaged groups of students. Another system that was identified for the field testing was Shivaji Shikshan Sanstha with its headquarters at Amravati. Established by another famous educationalist Mr. Panajabrao Deshmukh, these schools cater to the needs of students in Vidarbha region of the state of Maharashtra. This system is also quite large with more than 100 schools spread in about eight revenue districts of the state. Cooperation was sought from these societies by explaining the concept of Open Educational Resources for Schools (OER4S) in regional languages and its role to bring about qualitative changes in school education. Requests were made to the management of both educational societies to send a group of science teachers for training to HBCSE. Moreover, decision-makers were convinced to make available the computers with Internet connections to science teachers.

23.11.2 Workshops for Science Teachers

Around a hundred science teachers, each from the two educational societies were invited for a workshop at HBCSE. During these workshops, the teachers were familiarised with the website containing OER. After giving them instructions on how to access the OER, they were given an opportunity to actually see and download them. Apart from resources made for teachers, they were acquainted with the resources for students and parents and also with common resources designed for all stakeholders. Within a span of three days they were trained to acquire adequate skills to locate and download the resources they wanted. With a view to reach to a larger number of practising teachers, additional training courses were conducted in schools. Since both the education systems identified for field testing were very huge and cover many districts, these workshops had to be arranged in different regions. Suitable places with computing facilities were identified for conducting these workshops. Teachers were acquainted with the website and given inputs on how to access the resource of their choice. Adequate practice sessions were arranged so that they gain enough confidence to locate and use OER in the classroom.

23.11.3 School Visits

Visits were made to schools of teachers who were chosen for the field testing of OER. Through the workshops conducted at HBCSE and at various other places in the state, the teachers were familiarised with the OER website. After going back into the system, they tried to access it. However, many of them could not access the website as their schools did not have Internet facility. To overcome this problem OER were provided on compact discs to interested teachers. The experience of using OER by these teachers has been positive.

Apart from school teachers, resources were designed for parents also. Our contact point was a school teacher and we expected to approach parents through them. This idea did not seem to work well. There has been a limited interaction between teachers and parents. Parents come to school when their kids have problems or when there is a meeting of teacher parent association. These interactions are inadequate to pass on the message of OER for parents and to create confidence among them to access them. Additional efforts had to be made to sensitise parents towards the use of OER for the benefit of their children and get feedback from them. The project team attempted to contact a few parents during school visits with some success.

23.11.4 Feedback Received

During the workshops held at HBCSE, an attempt was made to get the opinions of teachers about the resources. A questionnaire was designed to seek relevant information from them. It had two parts: the first part sought personal information about the teacher along with their knowledge of computer and use of the Internet while the second part sought their opinions about OER on the website. Analysis of the data collected through the first part of the questionnaire revealed the following.

1. Computers are making headway in schools. Nonetheless, exposure to the use of computers is very limited for practising teachers. A majority of teachers are still unfamiliar with terms like PowerPoint, pdf, Page-maker, Photoshop, Coral Draw, etc.

2. A large number of teachers have registered for a course called MS-CIT (Maharashtra State Course in Information Technology) implemented by MKCL all over the state of Maharashtra. Many of them have completed the course. However, only a few teachers have the confidence to handle computers effectively.
3. The teachers were familiar with the word Internet as it is used in railway reservations and other activities. However, teachers hardly have competence in locating a particular website for their use. Only about 10 per cent of the teachers had their own email addresses.
4. For a majority of teachers, prescribed subject textbooks were sufficient for teaching school science. They did not see the need to look for any additional material or different mode of interactions in classroom proceedings.
5. Teachers are sceptical about how the use of computer and the Internet will improve the scholastic performance of their students. For a majority of teachers, scores in the examinations are of utmost importance. In their opinions, computers should be used to enhance examination scores and not to enhance understanding.

As mentioned earlier the second part of the questionnaire focused on teachers' opinion towards OER. Qualitative analysis of the data collected brought out the following.

1. In general all the participants appreciated the task of designing OER in the regional language (Marathi) as no such material is available that focuses on school science education.
2. Teachers liked the idea of designing resources not only for school students and teachers but also for parents. Parents, in their opinions, play a crucial role in shaping the behaviour of children.
3. Teachers looked at the common resources positively. The stories about scientists, they felt, would go a long way in motivating students to opt for science related careers. Similarly, the answers to a large number of questions given on the website, teachers opined, would help satisfy students' curiosity to a great extent. The section that appealed the most was the section on open forum. Since this forum enables the teachers to share their experiences and opinions, they thought the website has provided a space for sharing their ideas and experiences.
4. The website, many of the teachers opined, fulfils the felt needs of students, teachers and parents. Hence, the website would prove useful for all the three stakeholders. However, the culture of using resources beyond the prescribed textbook for school related tasks has yet to be spread in India. It would take time for this culture to take roots. Only then the material made available on the website would be used profusely by all the stakeholders.
5. While appreciating the efforts made by HBCSE, MKCL and I-CONSENT, teachers went further to suggest improvements to enhance their effectiveness. First, they have suggested that the resources should be illustrated using good pictures and cartoons. While giving a positive opinion about OER development, they also suggested that the resources should be such that they can be used directly by the teachers in the classroom or outside the classroom.

6. While applauding the efforts in designing the website, the teacher shared their concern about its use in rural areas due to the lack of reliable Internet facilities. Noting that the internet penetration was improving slowly the teachers emphasised the need to augment the efforts so that every school has a dedicated high speed Internet connection.
7. Teachers also noted that many of their colleagues as well as parents are not confident with using computers. It is, therefore, necessary that programmes should be undertaken to enhance computer literacy among teachers, students and parents.

23.12 Outcomes and Implications

Over the span of six years (2007–2013) the project yielded a large number of Open Educational Resources. These resources have been prepared taking into account the needs and requirements of school students, their teachers and parents. More importantly, these resources are made available in the regional language (Marathi), which is the medium of instructions for the majority of schools in the state of Maharashtra. This project has, thus, fulfilled the long felt need of supporting material in regional languages (Kulkarni et al. 1994). It is hoped that these resources would enable to meet the diverse needs of the school system in India.

The feedback received from the teachers, students as well as parents on the OER made available on the website is quite positive. All of them appreciated them and opined that they will certainly help improve teaching learning in the schools of the state of Maharashtra. There is, therefore, a ground to hope that this movement of open educational resources would take roots in the state of Maharashtra and eventually spread to the entire country soon.

A selected group of teachers from all over the state was invited to participate in the resource generation workshops. Moreover, arrangements were made for a large number of practising teachers to field test the resources. The project has, thus, created a network of about 1500 teachers. Some of them have a good flair of writing and are willing to contribute OER units. They can be encouraged to continue preparing OER in the future and realise the dream put forth by National Knowledge Commission (Takwale 2009).

Four different organisations came together to undertake the task of designing OER for schools. Rajiv Gandhi Science and Technology Commission, a state government organisation, made available funding required for the project. The implementation of the project was undertaken by three different organisations, namely HBCSE, MKCL and I-CONSENT. Roles of these organisations were clearly defined since the beginning of the project. HBCSE, being a research institution in science and mathematics education, undertook the responsibility of developing, digitising and uploading the resources using Content Development and Integration Tools (CDIT). MKCL, being a company in the Information Technology sector, undertook the responsibility of designing and maintaining the website. I-CONSENT, a voluntary organisation, mobilised the resources of different institutions. Thus, the collaborative model of working together for a common cause in improving quality of school education was proven successful. Such a model can be replicated anywhere in the world.

It must be realised that mere development of OER and uploading them to the website will not achieve the expected impact. There is a need to create awareness about these resources among the end users. At the same time they need to be convinced that these resources are useful to them. Awareness campaigns and personal contacts are required to spread the movement of OER. It is a fact that dedicated Internet connections are not available in many schools in rural areas. The task of providing this facility should be undertaken on a priority basis. Until such a facility is created digital resources should be made available through CDs and hard discs. The culture of designing and using open educational resources in the country would certainly lead to citizens capable of informed decision-making and sustainable problem solving.

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Appendix: Resources for Students

Primary Level

1. Our Earth
   (a) Day and Night
   (b) Seasons
   (c) Eclipses
   (d) Land and Oceans

2. Our Atmosphere

   (a) Components of atmosphere
   (b) Atmospheric Pressure
   (c) Changes in Atmosphere
   (d) Crops in Different Atmosphere

3. Our Body

   (a) Parts of Our body
   (b) Sense Organs
   (c) Body Coordination
   (d) Caring Our Body

4. Our Food

   (a) Types of food
   (b) Digestion of food
   (c) Balanced Diet
   (d) Preservation of Food

5. Our Material World

   (a) Sates of Matter
   (b) Properties of matter
   (c) Common substances (Water, Oxygen, etc.)
   (d) Natural and man-made substances

6. Our Living World

   (a) Living and nonliving
   (b) Animals
   (c) Plants
   (d) Uses of animals and plants

7. Our World of Work

   (a) Types of energy
   (b) Sources of energy
   (c) Work and Energy
   (d) Simple machines

Upper Primary Level

1. Earth and heavenly bodies

   (a) Our Earth
   (b) Sun and Stars
   (c) Eclipses
   (d) Atmosphere

2. Resources
   (a) Natural resources
   (b) Renewable and non-renewable
   (c) Fossil fuels
   (d) Judicious use of fuels
3. Energy
   (a) Energy sources
   (b) Conversion of energy
   (c) Energy crises
   (d) Fuels
4. Environment
   (a) Biotic and abiotic components
   (b) Environmental degradation
   (c) Pollution control
   (d) Clean environment
5. Matter
   (a) Classification of matter
   (b) Physical and chemical changes
   (c) Metals and non-metals
   (d) Useful compounds
6. Living World
   (a) Living and nonliving
   (b) Plants and animals
   (c) Adaptation of living beings
   (d) Reproduction
7. Health and Hygiene
   (a) Diseases and their control
   (b) Nutrition
   (c) Hygienic practices
   (d) Community health

Secondary Level

1. Living Word
   (a) Cell: Structure and function
   (b) Organisation
   (c) Classification
   (d) Life processes

   (e) Microorganisms
   (f) Evolution
   (g) Adaptation

2. Human body

   (a) Respiratory system
   (b) Excretory system
   (c) Circulatory system
   (d) Reproductive system
   (e) Digestive system
   (f) Nervous system
   (g) Endocrine system
   (h) Lymphatic system

3. Health and Hygiene

   (a) Nutrition, balanced diet
   (b) Deficiency/Over-intake diseases
   (c) Infectious diseases
   (d) Genetic disorders
   (e) Diseases due to malfunctioning of body organs
   (f) Community health
   (g) Hygienic practices

4. Environment

   (a) Biodiversity
   (b) Conservation
   (c) Environmental pollution
   (d) Resources and their conservation
   (e) Ecology/ecosystem
   (f) Climate change
   (g) Sustainable development

5. Agriculture

   (a) Food (production, preservation, spoilage and adulteration)
   (b) Soil and its conservation
   (c) Agricultural management
   (d) Supporting activities (fisheries, sericulture, poultry, etc.)
   (e) Modern agricultural techniques
   (f) Insecticides/pesticides
   (g) Fertilisers

6. Study of Matters

   (a) States of matter
   (b) Classification of matter (elements, compounds and mixtures)
   (c) Methods of separation

(d) Metals, non-metals
(e) Some common substances
(f) Acids, bases and salts
(g) Atomicity of substances

7. Structure of Atom

(a) Dalton's theory of atom
(b) Discovery of atomic particles
(c) Particle distribution in atom
(d) Electronic configuration
(e) Valency and valence electrons
(f) Reactivity and bond formation

8. Elements and their Classification

(a) Idea of elements
(b) Atomic number and atomic weight
(c) Early efforts of classification
(d) Mendeleev's periodic table
(e) Modern periodic table
(f) Relation between periodicity and electronic configuration
(g) Isotopes
(h) Application of periodic classification

9. Chemical reactions and equations

(a) Physical and chemical changes
(b) Types of chemical reactions
(c) Factors affecting rate of reaction
(d) Symbols of elements and formulae of compounds
(e) Chemical equations
(f) Energetics in chemical reaction

10. Solutions

(a) Formation of solution
(b) Types of solutions
(c) Molarity and normality
(d) Neutralisation
(e) Precipitation
(f) Solubility
(g) Electrolytic solutions
(h) Arrhenius theory
(i) Colloidal solutions

11. Metallurgy

(a) Common metallurgical processes
(b) Extraction of metals (Iron, Copper and Aluminium)

(c) Extraction of non-metal (Sulphur)
(d) Study of compounds of metals and non-metals
(e) Alloys
(f) Manifold uses of metals and their alloys

12. Mole Concept and Stoichiometry

(a) Concept of mole
(b) Gas laws
(c) Gas equation
(d) Avagadro's hypothesis
(e) Problems associated with mole
(f) Calculations based on chemical equations

13. Carbon compounds

(a) Characteristics of carbon compounds
(b) Bonding in carbon compounds
(c) Aliphatic hydrocarbons
(d) Aromatic hydrocarbons
(e) Petrochemicals
(f) Common carbon compounds

14. Energy

(a) Sources of energy
(b) Types of energy
(c) Energy conversion
(d) Units of energy
(e) Work
(f) Power
(g) Energy crises

15. Mechanics

(a) Motion and its types
(b) Speed, velocity and displacement
(c) Scalar and vector quantities
(d) Laws of motion
(e) Equations of motion
(f) Forces and their types
(g) Inertia
(h) Momentum and its conservation
(i) Force and pressure

16. Optics

(a) Propagation of light
(b) Scattering of light
(c) Reflection of light

(d) Refraction of light
(e) Dispersion of light
(f) Ray diagrams
(g) Magnification and magnifying power
(h) Optical devices
(i) Human eye
(j) Electromagnetic spectrum

17. Heat

(a) Generation and transmission of heat
(b) Measurement of heat
(c) Temperature and its measurement
(d) Specific heat of substances
(e) Latent heat
(f) Effect of heat (water, metals)
(g) Melting and boiling points
(h) Dew points and moisture

18. Sound

(a) Production of sound
(b) Propagation of sound
(c) Reflection of sound
(d) Echo and its application
(e) Speed of sound
(f) Loudness and pitch
(g) Musical instruments
(h) Hyman ear
(i) Sound pollution

19. Electricity

(a) Static electricity
(b) Electroscopes
(c) Electric charge and field
(d) Current electricity
(e) Electric circuits
(f) Ohms law
(g) Electrical cells
(h) Effect of electricity
(i) Uses of electricity

20. Magnetism

(a) Magnets and their properties
(b) Magnetic field and lines of forces
(c) Electromagnet
(d) Electromagnetic induction

(e) Uses of magnets
(f) DC and AC generators

21. Radioactivity

(a) History of radioactivity
(b) Radioactive substances
(c) Types of radiation
(d) Law of radioactivity
(e) Half-life period
(f) Fission and fusion processes
(g) Nuclear reactions
(h) Atomic energy
(i) Radioactive hazard
(j) Uses of radioactive isotopes

22. Technology and Human Life

(a) Technology and development
(b) Biotechnology
(c) Communication technology
(d) Chemical technology
(e) Nanotechnology
(f) Information technology
(g) Genetic engineering
(h) Space technology

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Chapter 24
Adapting and Customizing Web-based Inquiry Science Environments to Promote Taiwanese Students' Learning of Science

Hsin-Yi Chang, Ying-Shao Hsu and Jung-Yi Hung

Abstract Features of the Web-based Inquiry Science Environment (WISE) such as interactive dynamic visualizations, science inquiry, and online critiquing address educational reform efforts. However, how such reform-based learning environment developed in the US addresses the needs of teachers and students in Taiwan requires investigations. In this chapter, we reviewed research on the customizations and implementations of WISE units in Taiwan to discuss issues including: teacher adaptation from teacher-centered to inquiry-based instruction, the impact of the WISE units on students' learning of science, different instructional approaches to the use of the WISE units and their effects, and the relationship between students' experiences of learning with WISE units and their ability to formulate scientific explanations. We reflected on the issue of the role of the WISE units as replacement for or as supplementary to the conventional textbook instruction. We also discussed the remaining issues for future research.

24.1 Introduction

In this chapter, we synthesized research on the application of the web-based inquiry science environment [WISE] (Linn 2006; Linn and Eylon 2011; Slotta and Linn 2009) in Taiwan. WISE is an open-source, online platform that provides customizable science curriculum materials featuring visualization and inquiry

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activities. WISE curricula are designed based on the knowledge integration perspective (Davis 2004; Davis and Krajcik 2005; Linn 2006; Linn et al. 2004; Linn and Eylon 2006). Research indicates the success of WISE curricula in many teaching and learning contexts in the United States (Lee et al. 2010; Linn et al. 2006). For example, in a cohort comparison study involving 25 teachers and almost 5000 students, the cohort who used WISE curricula outperformed students who experienced typical instruction on the same topic with the same teacher (Linn et al. 2006). Detailed analysis of student learning using WISE curricula has shown the benefits of computer visualizations for developing integrated understanding (Chang and Linn 2013; Ryoo and Linn 2012; Zhang and Linn 2011). These studies raise important questions about the best way to encourage students to explore visualizations with the support from teachers. Meanwhile, it is unknown to what extent these innovative curricula designed for the students in the US changed what students learn in Taiwan.

Curriculum guidelines in both Taiwan and the United States stress the importance of inquiry teaching and learning (Ministry of Education, Taiwan 2008; National Research Council [NRC] 1996, 2007). WISE units scaffold students to explore computer visualizations as part of inquiry science, and take advantage of research showing promising ways to guide students, such as by making digital drawings, critiquing computer visualizations, conducting virtual experiments, and generating online predictions and explanations to make sense of computer visualizations (Linn et al. 2011). However, WISE may place new demands on teachers to guide inquiry and support small groups working together (Chang 2013). Moreover, teachers need to negotiate new norms of scientific inquiry in their classroom culture (Polman and Pea 2001). Implementing inquiry-based instructional materials requires teachers' adaptation of the teaching material. Such adaptation is usually challenging (Marx et al. 1997).

The purpose of this chapter is to synthesize research on adapting, customizing, and implementing three WISE units in Taiwan, to reflect on issues including: teacher adaptation from teacher-centered to inquiry-based instruction, the impact of the WISE units on students' learning of science, different instructional approaches to the use of the WISE units and their effects, the relationship between students' experiences in learning with WISE units and their ability to formulate scientific explanations, and the role of the WISE units as replacement for or as supplementary to the conventional textbook instruction. As revealed in science education frameworks (NRC 2011), it is important to investigate whether new designs of curricula and assessments apply equally well to diverse populations of learners as the community of science education moves toward globalization. While research has shown positive results of how innovative technology features and aligning instructional methods may benefit student learning of science (e.g., Linn et al. 2011), this chapter provides insights into the possibilities and challenges of customizing and adapting technological and curricular innovations to address local and global needs of teachers and students in diverse cultural contexts.

24.2 WISE Units Customized in Taiwan

In collaboration with the Technology Enhanced Learning in Science (TELS) center at the University of California, Berkeley, a research team involving teachers and researchers in Taiwan translated and customized three WISE units. We discuss each unit in the following sections.

24.2.1 Heat and Temperature

This unit was translated from the "Thermodynamics: Probing Your Surroundings" curriculum (Chang and Linn 2013; Clark and Sampson 2007; http://twise.nknu.edu.tw:8888/webapp/vle/preview.html?projectId=99). An analysis of the thermodynamics unit and the curricula guidelines in Taiwan (Ministry of Education, Taiwan 2008) revealed that the unit addressed core content knowledge and basic skills specified in the guidelines. Therefore, no major customization was made except for the wording for reading comprehension.

The unit includes two types of experimental activities. One is hands-on experiments about the measurement of temperature (Fig. 24.1). At the beginning of the hands-on experimental activities, students need to imagine the feeling while touching different objects made of different materials and predict their temperature. Then, they are asked to use a digital temperature probe to measure the temperature.

Fig. 24.1 The heat and temperature unit: the hands-on activity

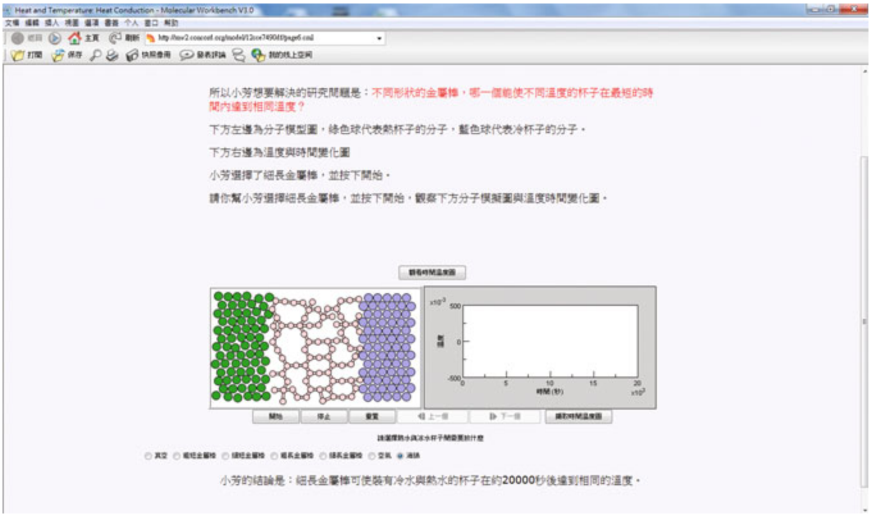

Fig. 24.2 The heat and temperature unit: the virtual experiment activity

After the hands-on practice of measurements, students need to compare their predictions with the real values and explain the results with the pop-up windows of embedded questions. The other type of experiment is virtual experiment activities about thermal conductivity. It involves the molecular visualizations of thermal conductivity which were designed using Molecular Workbench (Xie and Tinker 2006) and embedded questions to guide students to conduct the experiment (Fig. 24.2). The procedures of the two types of experiments are almost the same.

The other activities in the unit incorporated four visualizations made by Flash or Molecular Workbench (Xie and Tinker 2006) to explain the phenomenon of heat transfer. Students are guided to explain why objects made of varied materials at the same or different temperature feel the same or different. The final activity engages students in discussing their principle with peers and reflecting on how to revise their principle of heat and temperature. In general, the unit requires five to six class periods (50 min each) to complete.

24.2.2 Chemical Reaction

This unit was translated and modified from the “Will Gasoline Powered Vehicles Become a Thing of the Past?” curriculum (Zhang and Linn 2011, 2013; http://twise.nknu.edu.tw:8888/webapp/vle/preview.html?projectId=128). An analysis of this unit and the Curricula Guidelines in Taiwan (Ministry of Education, Taiwan 2008) revealed that the unit addressed core content knowledge and basic skills specified in the Guidelines. Minor modifications were made to address the teacher’s needs (Chang and Chang 2011).

Concepts involved in the phenomena of chemical reactions are mostly abstract and at the particulate level. Research indicates student difficulties in learning chemical reactions at the particulate level (Frailich et al. 2009; Krajcik 1991; Tasker and Dalton 2008). The goals of this unit are to facilitate students’ exploration of the phenomenon of chemical reactions by using dynamic visualization to make the concepts accessible for middle school students, and to engage students in using their observations of the visualization and building molecular models as evidence to formulate scientific explanations.

This unit consists of five activities with web-pages, embedded prompting questions, videos, visualization, and drawing tasks. The first and second activities provide a context in which gasoline powered cars are compared with hydrogen fuel cell cars. Students are introduced to the chemical reactions involved in the two types of cars. In the third and fourth activities, students are guided to observe a video of a burning balloon and visualization of hydrogen combustion at the molecular level (Fig. 24.3). They are required to use the drawing tool in WISE to construct their models of the processes of the chemical reaction (Fig. 24.4). After the drawing tasks, students critique their classmates’ models and then revise their own drawing. In the last activity, students are engaged in thinking about their decisions in terms of making the best choice of the type of car. The unit requires about four to five class periods to complete.

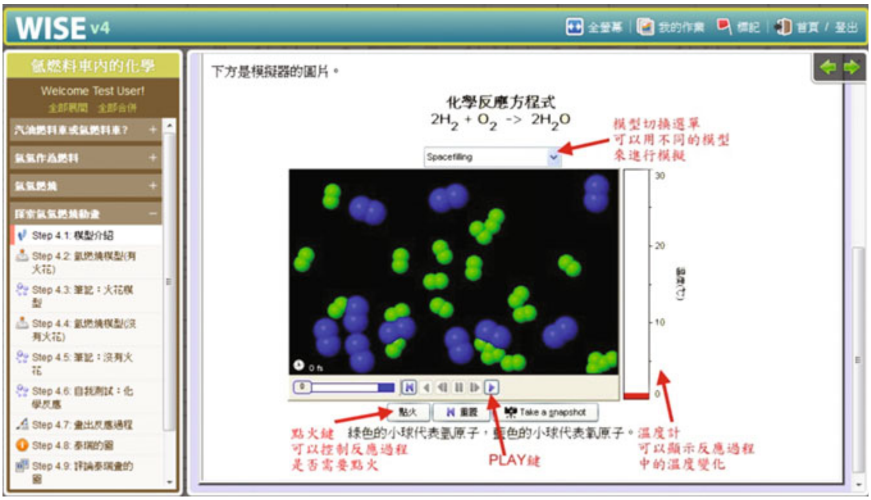

Fig. 24.3 A dynamic visualization showing molecular movement in the chemical reaction of hydrogen combustion

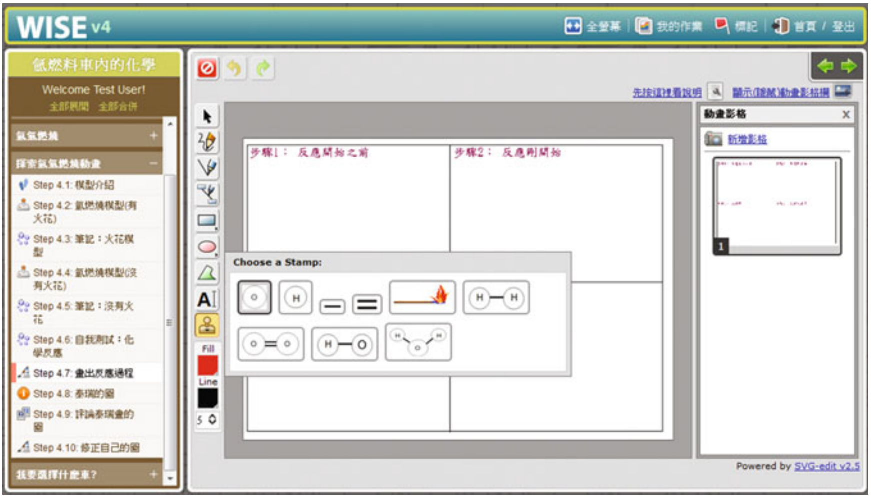

Fig. 24.4 The drawing tool allows students to build their model of the chemical reaction processes

24.2.3 Cell Division

This unit was translated and modified from the "Mitosis and Meiosis" curriculum from the WISE public library at the TELS Center (http://twise.nknu.edu.tw:8888/webapp/vle/preview.html?projectId=127). Modifications were made to address the teacher's needs to align with the biology curriculum the teacher used at a senior high school (Hung et al. 2012). The goals of the curriculum are to facilitate students' understanding and interpretation of the characteristics of every stage of mitosis and meiosis, to promote the connection between the concept of cell division and life experience, and to apply the concept of cell division for life.

This unit consists of four activities with web-pages, embedded prompting questions, videos, as well as, interactive, and static visualizations. In the first activity, students are guided to explore the epistemic aspects and basic definitions of cell division, such as thinking about the purpose and the meaning of cell division and observing the dynamic processes of cell division. In this activity, embedded prompting questions are used to guide the students to focus on the change of the formation of chromosomes during cell division. In the second activity, students are guided to learn the characteristics of the processes of mitosis and to compare the differences of the mitosis processes between plant cells and animal cells. Static images and dynamic visualizations (Fig. 24.5) are used to elicit students' original ideas and to aide their formation of models. In the third activity, students are guided to learn the characteristics of the processes of meiosis and to compare the

Fig. 24.5 Screenshot of the dynamic visualization of cell division

differences of the first meiosis division and the second meiosis division. Students are also guided to conduct inquiry about the mating of virtual organisms, trying to test different results of mating spitfire dragons in this activity. In the fourth activity, students are guided to learn the similarities and differences of meiosis and mitosis and to connect them to their life experiences. The unit requires about four hours to complete.

24.3 WISE Professional Development and Implementation in Taiwan

The deployment of the WISE system, customization of the WISE units, and development of new WISE curricula have been funded by the Ministry of Science and Technology, Taiwan. From 2011 to 2013, we held 15 professional development workshops to recruit science teachers interested in WISE and to help them develop expertise in teaching with WISE. A total of 404 science teachers participated in the professional development activities to learn about WISE. There were 18 implementations following the professional development workshops and 805 high school students were involved in the implementations. We discuss research from these activities in the following sections. We have structured the sections to highlight the research questions, context, methods, findings, and implications for each of the studies.

24.3.1 Teacher Adaptation from Teacher-Centered to Inquiry-Based Instruction

As the role of teachers in the effectiveness of innovative curricula continues to be recognized and acknowledged (Barab and Luehmann 2003), we need to consider what challenges a teacher may face when adapting an innovative curriculum. One case study from the research on WISE in Taiwan investigated how one science teacher, Ms. Ou, adapted the inquiry-based WISE unit on chemical reactions for her own teaching, which was mostly teacher-centered (Chang et al. 2013). The research questions of the study included: How did an in-service teacher customize and implement an inquiry-based, visualization-focused curriculum originally designed for students in the United States to adapt to the needs of her teaching in Taiwan? What are the reflections and possible solutions to facilitate in-service teachers' adaptation of inquiry instruction, based on the results of this customization?

The teacher implemented the chemical reaction unit in four class periods (each 45 min) with a class of 28 eighth-grade students at a public junior high school in southern Taiwan. Researchers collaborated with the teacher during the translation, editing, and planning phases of the curriculum customization. Biweekly meetings were held during the pre-instruction phases to address the teacher's needs and to support her in developing the expertise required to teach the unit. The teacher taught the unit before any classroom instruction on chemical reactions, to replace the regular textbook-based instruction on this topic. She had taught science for five years. She had experience in using technologies such as the interactive whiteboard during her teaching, but this was her first time to teach the WISE unit.

Ms. Ou's customized online curriculum and the classroom videos of her implementation of the chemical reaction unit were collected and analyzed. She was interviewed for about 40 min before and after instruction. During the pre-instruction interview, Ms. Ou was asked about her plans for customization and implementation as well as her views on the visualization and inquiry elements of the curriculum, and the anticipated learning benefits and difficulties. During the post-instruction interview she was asked to reflect on the visualization and inquiry, about whether the outcomes were consistent or inconsistent with her predictions, and about suggestions for curriculum revisions. The data were analyzed qualitatively to understand her adaptation process and generate assertions in terms of reflections on teacher adaptation.

The study found that the teacher made only minor changes to the existing online curriculum. However, she made substantial customization in terms of her regular teaching. This is probably in part due to her expectation of changing the instructional practice using the reform-based unit. In fact, she employed a hybrid approach of teacher-led mini-lectures (30 %) and student-centered inquiry activities (30 %). Overall, the teacher was able to successfully adapt to inquiry teaching with the support from the researchers. However, whether this adaptation lasts depends on the systematic and cultural changes at her school. The teacher thought that the most important thing is for the assessment system to be changed. Three reflections were reported: (1) The in-service teacher's adaptation of a hybrid approach of teacher- and student-centered activities was associated with a tension between science inquiry and school science; (2) A change in school assessment systems can address the greatest concern rooted in the in-service teacher's belief in implementing reform-based curricula; and (3) Significant adaptation occurs during the implementation phase rather than the customization phase.

The study has two implications, one for educational reform and the other for professional development. For educational reform aiming to lead changes to current school systems, the case in the study by Chang et al. (2013) provides evidence that with support that addresses the teacher's needs, teacher adaptation to innovative curriculum materials can be successful. However, sustainability of adaptation requires systemic or contextual supports (Blumenfeld et al. 2000). The case indicates the importance of the assessment system at high schools aligning with the reform calls. For professional development, effective activities for successful adaptation include teachers' actual or pilot teaching of innovative curricula and reflections on the adaptation process.

24.4 The Impact of the WISE Units on Taiwanese Students' Learning of Science

We examined two studies for the impact of the WISE implementations on the Taiwanese students' learning of science. Collectively, innovative curriculum features including hands-on experiments, virtual experiments, dynamic visualizations, drawing, and critiquing activities are examined. In light of learning outcomes, the studies provide evidence that the WISE units had an impact on students' conceptual understanding, experimental ability, learning strategies, and scientific explanation. The studies employed a mixed methods research design (Johnson and Christensen 2008). A quantitative part such as pretests and posttests was conducted to detect the impact of the curriculum on a particular learning outcome. The qualitative part involved the collection and analysis of the learning process data such as classroom videos, teacher and student interviews, and students' responses and interactions during class. The purpose of the qualitative part was to complement and expand our understanding of the curriculum impact, such as the impact of a particular curriculum feature.

24.4.1 Study 1: Combination of Hands-on and Virtual Experiments to Promote Knowledge Integration, Experimental Abilities, and Learning Strategies

The research questions of the study by Tsai and Chang (2011) included: Did the implementation of hands-on and virtual experiments promote knowledge integration? How well did the students demonstrate experimental abilities during the hands-on and virtual experiments, respectively? What learning strategies did the students employ during hands-on and virtual experiments, respectively?

The study used the WISE heat and temperature unit. This unit was implemented by a science teacher for five class periods about 225 min totally. Students worked in dyads with computers. The teacher had taught science for 18 years. He had rich experience of using technologies such as the interactive whiteboard, PPT slides, animations, and simulations during his teaching, but this was his first time to teach the WISE unit.

The first class period started with eliciting students' ideas and the hands-on experiment. The main activities in the second and half of the third class periods were engaging students in learning the concepts of thermal conductivity and equilibrium, particulate representations of the concepts, and connecting to their life experiences. In the next to the fifth class periods the students conducted the virtual experiment to test thermal conductivity in different materials at the particulate level. Finally the students discussed and summarized a scientific principle for heat and temperature based on previously learned lessons.

The study involved the science teacher and 32 eighth-grade students in one class at a middle school in Kaohsiung city. Data collected and analyzed included all students' responses to the pre- and posttests that measured degrees of knowledge integration, embedded assessments that measured experimental abilities, and process videos during the hands-on and virtual experiments that indicated learning strategies demonstrated by the students.

The results of this study indicated that both hands-on and virtual experiments effectively facilitated students' knowledge integration of heat and temperature concepts, with moderate effect sizes. The majority of the students was able to transfer their experimental abilities from hands-on to virtual experiments, including identifying adequate research questions, conducting valid experiments, and explaining the results accordingly. Moreover, the students employed high-level learning strategies such as connecting to their past experience, planning their learning task, reviewing the web-pages to understand the purpose of the task, and monitoring the progress of the task during both of the experiments.

This study identifies difficult areas in both types of experiments that require further curriculum support. It needs to investigate how to guide students to make sense of the virtual experiment context and to develop better questions in the virtual experiment environment. On the other hand, it needs to explore how to guide students to explain the experimental results and connect to the scientific principles in the hands-on experiment environment.

24.4.2 Study 2: Drawing and Critiquing with Dynamic Visualizations to Facilitate Integrated Understanding

The research questions of the study by Chang and Chang (2011) included: What feedback did the students have from their learning experience with the WISE chemical reaction unit? What are the effects of the chemical reaction unit on students' conceptual understanding of chemical reactions?

The study implemented the WISE chemical reaction unit. As a science teacher and also the researcher, S.-Y. Chang implemented this unit for 180 min totally. The study focused on examining four types of inquiry activities, including exploration of a video and a dynamic visualization of a chemical reaction, building models of the chemical reaction, and critiquing the student-generated models, in light of how they promoted the students' integrated understanding of chemical reactions.

The study employed a quasi-experimental design. A total of 28 eighth-grade students in one class at a middle school in Kaohsiung city learned chemical reactions using the WISE chemical reaction unit, as the experimental group. The other class, consisting of 30 students, received the traditional textbook-based instruction on the chemical reaction unit, as the control group. Data collected and analyzed included all students' responses to the pretests and posttests that measured degrees of knowledge integration, and interviews of six randomly selected students from the experimental group.

The chemical reaction unit emphasized the application of chemical reactions to daily life experiences and integrated inquiry activities to help students construct a model of chemical reaction to develop their deep understanding of the concept. Comparing the chemical reaction unit with the chemical reaction section in the middle school textbooks, textbooks place more emphasis on the definition of chemical reactions and balancing the equation of chemical reactions. The WISE chemical reaction curriculum can strengthen and supplement the textbook-based instruction. Nevertheless, only using the WISE chemical reaction unit has a significantly better effect on students' integrated understanding than only using the textbook materials. The students in the experimental group outperformed the control group in their posttest scores measuring knowledge integration, when their prior knowledge (the pretest scores) was controlled. The effect size is 1.69, indicating a large effect by Cohen's definition (Cohen 1988). The results from the student interviews indicated that the students possessed a positive attitude (high motivation and enthusiasm throughout the unit) toward learning with the WISE unit. They needed more guidance when observing the dynamic visualization (cues about which parts of the visualization to pay attention to) and when responding to the reflective prompting questions embedded in the curriculum.

This study provided evidence that the WISE chemical reaction unit can replace the conventional textbook material and in fact has a better effect than the textbook on students' integrated understanding of chemical reactions. In light of professional development, guiding teachers to analyze and refine a new curriculum in a professional development workshop can be a way to facilitate teachers' expertise in implementing the curriculum.

24.5 Different Approaches to Implementing a WISE Unit as a Review Program and Their Long-Term Effects

The research questions of the study by Hung et al. (2012) included: Did implementing the WISE cell division unit as a review program have an effect on high school students' conceptual understanding? Are there different effects in different implementation approaches: student-centered versus teacher-centered?

The study is reported on the implementation of the WISE cell division unit. This unit was implemented for 100 min totally by J.-Y. Hung (the first author of the study) who is also a biology teacher at a senior high school. The WISE curriculum embedded predict-observe-explain (POE) guidance (White and Gunstone 1992) and was designed based on the knowledge integration instructional pattern (Linn 2006) to guide student learning with dynamic visualizations of cell division to help students' knowledge integration of the cell division concepts.

For example, the embedded questions in the unit elicited students' original ideas about the phenomenon of cell division, and then guided students to observe the dynamic visualization. Finally, the unit guided students to explain their observations and to clarify the distinction between ideas. The teacher monitored and evaluated immediately the students' responses for further clarification or discussion.

The study involved 85 12th-grade students attending one of the two treatments: the experimental group (EG), in which students were allowed to explore the curriculum in dyads (the student-centered implementation approach), or the control group (CG), in which the teacher lectured using the curriculum (the teacher-centered implementation approach). Both groups had learned the concept of cell division in their biology course. The WISE unit was used as a review course for both of the groups. Data collected and analyzed included all students' response to pretests, posttest,s and delayed tests that measured students' degrees of knowledge integration of the cell division concepts. There was a five-month interval between the posttests and the delayed tests.

Before the use of the WISE cell division unit as a review program, the high school students' understanding of the process of meiosis and mitosis was rather fragmented, as indicated by their pretests taken before the WISE unit. Both of the groups, EG and CG, demonstrated significant gains of integrated understanding after the unit. The WISE cell division curriculum had moderate effect sizes even on students who had previously learned cell division. Moreover, EG significantly outperformed CG on the delayed tests, despite there being no significant difference between the two groups on the posttests. Analysis of the test items indicates that EG demonstrated better understanding and explanation of the cell division process than CG. The result indicates that implementing the WISE unit in the student-centered approach had a better long-term effect.

Compared to the traditional teacher-centered instructional approach, allowing students to explore dynamic visualizations in small groups has better long-term effects for students' integrated understanding of science concepts. The study results can be used as evidence during teacher professional development that a better way to use these inquiry-based curriculum materials is to allow student inquiry, rather than teacher demonstration of inquiry. A practical concern of teachers is that student inquiry requires more time than teacher lectures. However, such time is well invested considering the educational effect.

24.6 The Effects of Using Multiple WISE Units

The research questions of the study by Lin et al. (2011) included: Which variables, including gender, experience of using computers, experience of using WISE units, and prior knowledge, were significant predictors of the students' ability to generate scientific explanation?

This survey study involved 109 eighth-grade students (56 boys and 53 girls) in four classes at a middle school in Kaohsiung city that has been closely collaborating with our research team to implement multiple WISE units. In terms of the students' computer experience, 34 students frequently used computers to do their homework, and 69 students less frequently used computers to do homework. For their experience of WISE units, 55 students had not used any WISE unit at all, 28 students had learned with one WISE unit (the WISE chemical reaction unit), and 26 students had learned with two WISE units (the WISE chemical reaction and heat and temperature units). All students learned the concepts in their conventional textbook-based curriculum if they did not learn using the WISE unit on the topics.

Data collected included all students' responses to pretests, posttests, and delayed posttests that measured the students' ability to generate scientific explanations on phenomena related to heat and temperature and chemical reactions. The pretests were administered before the heat and temperature and chemical reaction units, and the posttests after the units. The delayed posttests took place one month after the posttests. Background information was also collected such as students' gender, experience of using computers, and experience of using WISE units. This research used stepwise multiple regression to analyze the data. The four predictors included gender, experience of using computers, experience of using WISE units, and pretest scores (as indicator of prior knowledge). The dependent variable is the delayed posttest scores.

When we considered the four predictors, only the students' experience of using WISE units and their prior knowledge were found to be two significant predictors of students' ability to generate scientific explanations; gender and the experience of using computers were not significant predictors. It is common that the pretest score is a significant predictor of students' after-unit performance. More importantly, the study found that when students used more WISE units, their scores on formulating scientific explanations were higher.

This study provides evidence that students' experiences using inquiry-based curriculum materials have effects on their ability to form a scientific explanation. Scientific explanation is an important aspect of scientific literacy (Organisation for Economic Cooperation and Development [OECD] 2013). The inquiry-based science curricula modified from the WISE units can promote Taiwanese students' ability to formulate scientific explanations.

24.7 Concluding Remarks and Future Research

Our research on the impact of adapting, customizing, and implementing the Web-based Inquiry Science Environments in Taiwan can be concluded and has implications in three aspects: student learning, role of curriculum, and teacher instruction and adaptation. In light of student learning, research shows that WISE units benefited the U.S. students' learning of science (Lee et al. 2010; Linn et al. 2006). After customizing and implementing three WISE units for Taiwanese students we also found positive impact of the WISE units. We conducted further investigations to find that the WISE units had both short-term and long-term effects to support the Taiwanese students in developing integrated understanding of the science concepts involved (Chang and Chang 2011; Hung et al. 2012; Tsai and Chang 2011) and their ability to formulate scientific explanations (Lin et al. 2011; Hung et al. 2012; Tsai and Chang 2011). The students who received the WISE instruction outperformed those who received regular textbook-based instruction (Chang and Chang 2011). Moreover, the students who learned with more WISE units outperformed those who had less WISE experience in formulating scientific explanations (Lin et al. 2011).

For the aspect of the role of curriculum, we have investigated different occasions to implement WISE units and their effects, such as using a WISE unit to replace the regular textbook-based curriculum or to supplement the curriculum using a WISE unit as a review program. We found that when instruction based on the WISE unit replaced the regular textbook-based instruction, the students spent more time on small group discussions and inquiry activities, whereas in regular textbook-based instruction the students spent more time on reviewing concepts taught and taking quizzes. As has been revealed in the foregoing sections, the WISE students outperformed the students receiving the textbook-based instruction, providing evidence that inquiry-based instruction can better promote students' knowledge integration (Chang and Chang 2011). Time on student inquiry activities was well invested. WISE units can also be used as review programs for students who had previously learned the concepts. Our research shows that using a WISE unit as a review program could further promote students' integrated understanding even when the students had learned the topic before (Hung et al. 2012).

In terms of teacher instruction and adaptation, we found that WISE units had better effects when they were implemented in alignment with the student-centered, rather than teacher-centered, instructional goals, and approaches (Hung et al. 2012). WISE units were designed based on constructivism that emphasizes student learning of new ideas building on their prior knowledge and ideas. Based on the investigation results, we suggest implementing WISE units using the inquiry-based, student-centered approach. However, in another study some challenges were identified for teachers to adapt to curriculum materials like WISE units (Chang et al. 2013) such as the teacher's reservations to use the WISE unit in the future without researchers' support. The challenges indicate a need for change to the whole school system, in particular a change to the assessment system.

Indeed, the WISE units address the goals of the educational reform in science education in Taiwan (Ministry of Education, Taiwan 2008). However, a gap exists between the instruction and assessment systems at schools and the instruction and assessment goals called by the reform. Cultural studies on systematic changes in science education considering multiple and complex aspects might be needed to take the steps to understand the gaps and propose possible solution directions. In addition, development of new units is underway, with the application of new curriculum design guidelines and patterns (for details, see Hsu et al. 2014), to address Taiwanese teachers' and students' needs. We have shown the effects of the WISE experiences in Taiwan. Future studies include designing and implementing new science curricula within and across countries and regions to promote collaboration and spur discussions on multiple ways to help students around the world to attain science education goals effectively and efficiently.

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Chapter 25
Technology-Enhanced Science Teaching and Learning: Issues and Trends

Tzu Hua Wang and Kai Ti Yang

Abstract This chapter discusses current and future research trends of technology-enhanced science teaching and learning and probes into several new learning technologies, which will highly influence science teaching and learning in the future. These technologies include digital assessment, automatic feedback system, ubiquitous learning (u-Learning), augmented reality (AR) technology, and gesture-based technology. This chapter also conducts literature review and analysis on empirical researches about applying these learning technologies in teaching and learning. It also brings up the research direction future studies can focus on. Based on the "Media Debates" in 1990s and the following development of learning theories, as well as research statements and findings about learning technologies, "the three key elements of effective learning technology implementation" are concluded: nature of ICT, mediation model, and transforming model. This chapter also discusses the three elements and proposes suggestions for following researches on science teaching and learning.

25.1 Introduction

In the past 25 years, the unprecedented growth of the use of Information Communication Technology (ICT) has facilitated teaching and learning (Holliman and Scanlon 2004). ICT applied to assisting learning is called learning technology in recent years. Reviewing the development of ICT in the past decades, the world has experienced a qualitative change in many aspects along with the appearance and use of ICT (Kozma 2003; Yelland 2008).

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Rapid development of ICT accelerates the production of human knowledge and changes the way humans learn. New technologies such as satellite-connected classrooms, high-speed Internet, mass storage device, high-performance personal computers, and smart mobile device seem to have unlimited potential to lead education into a whole new realm (American Association for the Advancement of Science (AAAS) 1998; Linn 2003; Wang 2013). According to AAAS, in the history of American education, the idea that technology is a key component of literacy education has never been so widely accepted as it has today. Educators and the public all desire to see the potential of applying certain technologies to be realized in education. Therefore, following ICT development and policies to foster its use in education, education has entered a new situation. As a result, research exploring the influences of new technologies on learning has quickly thrived. AAAS observed that science learning is increasingly taking place using mature media both inside or outside schools. Linn (2003) looked back at the effects of ICT in science education and concluded that ICT played important roles in five science education realms: “science texts and lectures,” “science discussions and collaboration,” “data collection and representation,” “science visualization,” and “models and simulations.” Based on the evidence of empirical studies, ICT has strongly influenced science education and learning, leading to positive results. Kang and Lundeberg (2010) argued that technology could construct a learning environment in which students actively solved problems they were faced with in life and focused on learning objectives. The learning environment constructed by technology can enhance student understandings about the nature of science and improve their conceptual development (Kang and Lundeberg 2010). Bransford et al. (2000) and Ebenezer et al. (2011) also stated that technology had gradually become part of the way learners construct, manage, and communicate knowledge in classroom. Via recent new technologies, inquiry activities, and interactive visualization are combined to assist learners to develop key scientific concepts and scientific literacy and inquiry skills, abilities called for in international evaluations, such as “PISA 2015 Draft Science Framework” (OECD 2013).

Based on the above, this article reviews current trends in technology-enhanced science teaching and learning, and discuss important issues in technology-enhanced science teaching and learning. This article also discusses key elements about effective ICT implementation in education.

25.2 Current Issues of Technology-Enhanced Science Teaching and Learning

Taiwan’s Ministry of Education (MOE) and National Science Council issued the “White Paper on Science Education” in 2003 (MOE 2003), one of its aims is to “improve inquiry competence, creativity and critical thinking of each student and cultivate good scientific attitude characterizing curiosity and scientific ethics.”

In the United States of America (USA), the National Research Council (NRC 2007) also explicitly suggested ways to improve science education. The goal of science education was re-defined as "*know, use, and interpret scientific explanations of the natural world*," "*generate and evaluate scientific evidence and explanations*," "*understand the nature and development of scientific knowledge*," and "*participate productively in scientific practices and discourse*." In the PISA 2015 Draft Science Framework announced by the Organisation for Economic Co-operation and Development (OECD) in 2013, the framework for assessing scientific literacy in PISA 2015 is to "*explain phenomena scientifically*," "*evaluate and design scientific enquiry*," and "*interpret data and evidence scientifically*." The goals of science education stated above largely shape the development of technology-enhanced science teaching and learning. Songer (2007) identified four aspects of science teaching and learning: "*learners think critically and logically about scientific ideas and compare them with real-life conditions*," "*learners critically evaluate and communicate scientific ideas*," "*learners formulate scientific explanations from evidence,*" and "*learners use appropriate tools to gather, analyze and interpret data*." According to Songer, technology plays an important role in all four aspects of science learning.

Regarding "*learners think critically and logically about scientific ideas and compare them with real-life conditions*," Songer (2007) contended that digital technology tools such as modeling, visualization, and simulation were effective in facilitating science learning. In learning scientific concepts, such as the four seasons and moon phases, volcanoes, earthquakes, and reduction-oxidation, it is impossible for learners to directly observe and manipulate these events due to danger or high costs. In such cases, digital technologies, such as 3D, virtual reality (VR), and augmented reality (AR), can be leveraged to visualize micro worlds or simulate their reality. In this way, learners can learn by manipulating the simulations. Scientific concepts and models can even be constructed in the process of visualization and simulation. Zhang et al. (2014) applied AR smart mobile devices to develop the mobile digital armillary sphere (MDAS) and leveraged it in the teaching of elementary school astronomy. Zhang et al. used the contextual detection function of smart mobile devices, such as digital compass and G-sensor, to detect direction angles and elevation angles of users' handheld smart mobile devices and in turn determine where in the sky the camera lenses of smart mobile devices are pointing at. Then based on the time and the information of direction angle and elevation angle, MDAS provides guides and tools for understanding the region of the sky, such as star signs, the camera lenses are pointing at.

Regarding "*learners critically evaluate and communicate scientific ideas*" and "*learners formulate scientific explanations from evidence*," Songer (2007) argued that digital technology tools supporting online commentary and discussion and online scaffolding tools were effective in facilitating science learning. Many classes offer science learning activities in which learners work together, share their thoughts and work, have discussions in groups, and construct systematic integrated interpretation based on observed phenomenon or gathered evidence. In these activities, technology can be leveraged to construct an environment for online discussion and commentary. This kind of environment is interactive, where learners and their peers are given more opportunities to critically evaluate and communicate scientific thoughts and evidence with each other. Moreover, this kind of open-ended environment is able to increase learners' participation in discussing and commenting activities. By providing written prompts, links, or diagrams, the online system serves as a scaffold to guide student's science learning. In recent years, many researchers have developed online argumentation instruction systems. According to Lu and Zhang (2013), ICT can be used to create external argumentation frames in an online argumentation instruction, which allows users to construct their own argumentation. There are two kinds of argumentation frames, linear, and nonlinear (Lu and Zhang (2013). Lu and Zhang pointed out that linear frames presented argumentations as lists and threaded discussions. This type of argumentation frames is conducted in forums and asynchronous discussion boards. According to Wang (2014a), the argumentation instruction environment constructed by Clark and Sampson (2007), which used Web-based Integrated Science Environment Internet software, is one of this type of argumentation frames. Referring to Toulmin's argumentation model (Toulmin 1958) and suggestions by Erduran et al. (2004), Clark and Sampson planned seven activities for students in performing online argumentation, which includes claim, grounds, rebuttal, support, query, emotive appeal, and off-task comments. Guided by prompts on webpages, learners post the science phenomenon they observed and the data they gathered. They also post their viewpoints and the supporting evidence. The whole argumentation process focuses on discourse of texts. Wang also adopted the linear frames model to develop Web-based Interactive Argumentation System (WIAS) and applied it to the teaching of socio-scientific issues. The theoretical basis of WIAS is the argumentation viewpoints raised by Lakatos' "The Methodology of Scientific Research Programmes" (Lakatos 1978). WIAS provides a scaffold for teachers and learners to perform argumentation teaching activities. Teachers are allowed to configure the timing when each argumentation teaching activity starts. There are four argumentation teaching activities, "announcing personal statements," "reading and criticizing peers' statements," "concluding and announcing personal statements," and "concluding and announcing group statements." Based on teacher's settings, WIAS provides students a scaffold which enables them to know which argumentation teaching activity to perform. Learners can refer to prompts provided by WIAS to present their own viewpoints of the topics and related data, including their statements on a certain issue (i.e., hard core, HC), providing more evidence and data supporting their own statements (i.e., positive heuristic, PH), and offering evidence and data that can prevent their own statements from being refuted by peers (i.e., negative heuristic, NH). They can gradually achieve consensus with other group members. They then announce their consensus as the HC, PH, and NH of the group and perform peer assessment and mutual discussion with other groups in the class. In this way, a consensus of the entire class can finally be achieved. Nonlinear frames present argumentations as graphs, diagrams, and matrices (Lu and Zhang 2013). These visual representations show the logical relation among each element in argumentation in a simplified way. Wang indicated that van Drie et al. (2005) developed the "Virtual Collaborative

Research Institute (VCRI)" to perform argumentation instruction activities. This system can visually present the logical relation of each key element in a user's argumentation. It allows users to represent their own thoughts as nodes and show the relationships among these nodes by connecting lines.

Regarding "*learners use appropriate tools to gather, analyze and interpret data*," Songer (2007) pointed out that digital technologies that could be used for gathering, analyzing, and interpreting data were effective in facilitating science learning. In recent years, along with the development of mobile technologies, small portable computers, and smart mobile devices have been used to gather information and feedback in teaching and learning environments quickly. In some cases, these portable devices are equipped with sensors and detectors, which can be used to assist scientific experiments and collect raw data during experiments. This raw data can also be analyzed and graphed on portable devices. This helps learners interpret the experiments and their raw data. Hwang et al. (2009) developed context-aware ubiquitous learning (u-Learning), which leverages a personal digital assistant (PDA) along with RFID technology so that PDA would be able to detect the user's surroundings. In its instructional expert system and tutoring-strategy knowledge base, users are provided with individualized support and guidance based on their surroundings. The instructional expert system here is an expert knowledge base, which includes bountiful information about the domain specific knowledge. The tutoring-strategy knowledge base includes IF–THEN rules, which helps the system determine user's current operation and their surroundings, and provide users feedback based on the information. Hwang et al. applied the learning environment to guiding researchers who are unfamiliar with single-crystal X-ray diffraction operations to learn, with positive results.

With the rapid development of ICT, cloud computing technology has matured and can be leveraged to enable effective personalized learning. It can also assist in science teaching and learning in a more profound way. In addition to the four aspects identified by Songer (2007), the authors propose a fifth aspect, which is "*providing learners a scaffold that enables learners to perform self-regulated learning*." In this aspect, technology helps provide an integrated digital learning environment; the environment includes teaching and learning strategies, learning contents and assessment that encourage students to do self-regulated learning. Paris and Paris (2001) believed that self-assessment was an effective strategy in helping learners perform self-regulated learning because learners were better able to evaluate their learning conditions if they could assess themselves during the learning process (Wang 2011a, b, 2014b). Technology can be used to develop digital assessment to provide learners with opportunities to do self-assessment and encourage them to perform self-regulated learning. In others words, digital assessment can play the role of a teaching and learning strategy, which enables learners to engage in self-regulated learning behavior during the learning process. Wang (2010, 2011a) proposed "assessment as teaching and learning strategy (ATLS)" and applied the graduated prompt approach proposed by Campione and Brown (1985, 1987) to develop a Web-based dynamic assessment system, "Graduated Prompting Assessment Module of the WATA system

(GPAM-WATA)," based on the framework of Web-based Assessment and Test Analysis system (WATA system) (Wang et al. 2004; Wang et al. 2008). Wang (2010, 2011a) transformed the contents of science instruction into instructional items, which are the test items in dynamic assessment. These instructional items are instructional in that they can guide students to learn and understand the key concepts. Each instructional item has three instructional prompts. When students answer an item incorrectly, the prompts are delivered one-by-one to guide students to learn. The three prompts contain instructional information. Based on the principle of graduated prompt approach, the hints students receive go from general to specific. In the process of taking instructional items and gaining instructional prompts in GPAM-WATA, learners can achieve more (Wang 2010, 2011a). Based on the viewpoint of ATLS, Wang (2014b) further proposed the idea of "assessment-centered e-Learning" and developed the GPAM-WATA e-Learning system (GPAM-WATA_EL), in which assessment scaffolds and guides student's e-Learning. Wang (2014b) adopted Web-based two-tier diagnostic assessment along with Web-based dynamic assessment to develop personalized dynamic assessment. Proper instructional items are automatically selected based on diagnosis results to create dynamic assessment for each student. Students learn in the process of answering instructional items and obtaining instructional prompts. GPAM-WATA_EL further guides students to read personalized and proper digital learning materials. GPAM-WATA_EL is able to scaffold learner's personalized learning and structure science learning tasks so that students can perform effective learning via the system scaffolding and under assessment guidance.

25.3 Future Trends of Technology-Enhanced Science Teaching and Learning

25.3.1 Digital Assessment

Digital assessment has been widely applied in the realm of education and has earned an important role in instructional practice and educational research (Wang 2008, 2010, 2011a, b; Wang et al. 2013). The key advantage of digital assessment is that it can reduce paper consumption and facilitate rapid data collection and analysis. Moreover, digital test items and examination paper make it easier to exchange, preserve, and modify test item resources. These advantages are highly meaningful to both teachers and education researchers. In addition to the advantages above, digital assessment enables machine scoring, which marks examinees' papers immediately after they finish answering all the questions. Thus, examinees know immediately whether their answers are correct and what their scores are. Thanks to this advantage, digital assessment is able to provide examinees with timely feedback, reduce teacher's burdens, facilitate e-Learning, and educate students to perform self-assessment (Wang 2008, 2010, 2011a, b, 2014b).

Digital assessment can be leveraged in two ways: It can evaluate and diagnose student's competence and learning status, and it can serve as a teaching and learning strategy. To evaluate and diagnose student's competence and learning status, summative assessment is administered digitally. Conventional testing theory is used to conduct test analysis and item analysis so that the quality of test items and examination paper and student's learning effectiveness can be known. Based on modern testing theories, such as IRT (item response theory), OT (ordering theory), and Bayesian networks, the teacher uses an adaptive assessment system to accurately evaluate students' competence and to diagnose students' misconceptions and their types.

Digital assessment's role as a teaching and learning strategy is mainly based on the viewpoint of assessment as teaching and learning strategy (ATLS) proposed by Wang (2010, 2011a). Digital assessment is administered to facilitate students in performing formative learning and to creating an assessment-centered learning environment. The spirit of ATLS is to closely combine digital assessment and teaching activities. Test items in digital assessment play the role of instructional items. When students are answering test items in digital assessment, the system can provide them with timely feedback. The feedback contains the teaching information teachers provide. It plays the role of instructional prompts and students can learn in the process of answering test items and receiving timely feedback (Wang 2010, 2011a). Wang applied the graduated prompt approach proposed by Campione and Brown (1985, 1987) to develop a Web-based dynamic assessment system, GPAM-WATA (please see section 25.2 for more introduction). Learners can learn by answering instructional items and receiving instructional prompts in GPAM-WATA. It is found that GPAM-WATA is effective in facilitating science learning, especially for learners with low-level prior knowledge.

For the future development of digital assessment, the idea of "assessment-centered e-Learning (Wang 2014b)," whose basis is the digital learning environment design concept of "assessment as teaching and learning strategy (ATLS)(Wang 2010, 2011a)," is highly recommended. Wang (2011b) believed that whether learners can do self-regulated learning determines the effectiveness of e-Learning (Kauffman 2004). Digital assessment can provide learners opportunities to actively perform self-assessment in an e-Learning environment. This in turn facilitates learners to perform self-regulated learning in an e-Learning environment (Paris and Paris 2001; Wang 2011b). GPAM-WATA_EL developed by Wang (2014b) is an assessment-centered e-Learning system. In GPAM-WATA_EL, digital assessment is carried out by Web-based two-tier diagnostic assessment plus Web-based dynamic assessment. Web-based two-tier diagnostic assessment is used to diagnose learner's learning deficiencies and misconceptions. Then the system automatically constructs Web-based dynamic assessment for learners to answer. Learners can improve their learning deficiencies and misconceptions by answering the dynamic assessment (i.e., instructional items) and receiving hints (i.e., instructional prompt). Based on how they answer test items in the Web-based two-tier diagnostic assessment and Web-based dynamic assessment, the system recommends learners the digital learning materials they need to enhance their learning. According to Wang (2014b), the design can effectively improve student e-Learning effectiveness and address their misconceptions. It is especially effective in assisting learning of students with low-level prior knowledge. Using digital assessment to create assessment-centered e-Learning environment is a topic deserving further investigation of future researches. Web-based learning has gradually become a powerful trend in adult education. In Web-based learning research and development, including Massive Open Online Courses (MOOCs), the idea of “assessment-centered e-Learning” can be leveraged to develop various digital assessment strategies and interactive feedback mechanisms based on the characteristics of different learning contents and individual differences among learners in order to prevent the “disorientation (Brusilovsky 2003; Eklund and Sinclair 2000)” problem and improve students’ e-Learning effectiveness.

For easier machine scoring, current digital assessment mainly consists of multiple choice test items. However, multiple choice test items are always not effective in evaluating learners’ competence in performing problem solving and scientific experiments. Current global evaluations such as TIMSS (Trends in International Mathematics and Science Study) and PISA (The Programme for International Student Assessment) have gradually adopted animation-based test items (Wu et al. 2010). This is because animation is able to create contexts, concretize abstract ideas, describe outlooks, and trigger learning motivation. If these characteristics of animation can be applied to developing test items, it will largely improve quality of test items in current examinations. Students’ scientific abilities it can be used to evaluate will also be more diverse (Kuo and Wu 2013). To evaluate student abilities to perform problem-solving and scientific experiments, the authors developed the Web-based Performance Assessment system (WPA system) and applied animation to develop test items in the WPA system. These animation-based test items are able to simulate real-life situations. By integrating a series of small questions into the animation-based test items, learners can simulate problem solving in real life by moving objects and entering and selecting data. As currently developed, the WPA system can be used to manage animation-based test items and administer online tests containing these items. The system can also record examinees’ operations on the animation-based test items and score each step of the operations automatically. The recorded information can be leveraged by examinees and teachers to reproduce how examinees operated certain animation-based test items. In this way, the whole process of operating an animation-based test item is completely recorded and scored and the item are therefore made most effective in evaluating examinees’ competence in conducting scientific experiment and problem solving. Future researchers may focus on how teachers apply the WPA system to assist in the teaching of scientific experiment. Teachers can develop animation-based test items and deliver the examination via the WPA system. By recording a complete operation history of how learners answer animation-based test items, the difficulties students face in conducting scientific experiments can be understood. Based on the records, remedial teaching can also be delivered and instruction can be improved. In addition, learners can rely on the WPA system to perform self-assessment. In addition to identifying their own learning deficiencies, they can also reflect on how to improve their competence in conducting scientific experiments by reviewing their own operation history of answering the animation-based test items.

25.3.2 Automatic Feedback System

Meaningful feedback plays an important role in both teaching and learning. Generally speaking, there are timely feedback and delayed feedback, and timely feedback is effective in facilitating student learning. Learners can leverage the timely feedback to correct their deficiencies in learning and thinking, and perform learning transfer (Bransford et al. 2000; Wang 2011a). However, delayed feedback has negative influences on learners with lower learning motivation or struggling with learning difficulties (Shute 2008). In traditional teaching environment, it is difficult for teachers to provide each student with timely feedback. With the help of ICT, the timely feedback mechanism can be realized.

Wang (2013) developed the Instant Questioning-Answering system (iQA system), which allows learners to use any smart mobile devices to ask questions online when they have questions in learning contents but fail to ask their teachers or outstanding peers at the moment. They can therefore gain different levels of timely feedback and get assisted in their learning. The iQA system provides a chat room for learners to log in and chat with the Answering Robot by entering texts. iQA system also comes with the "question and answer database (QA database)" and the "question group tracking database (QGT database)." The former contains answers to various kinds of questions and advanced reference learning resources while the latter is a technology to track student's questions. In traditional teaching environment, the interaction of asking and answering questions between teachers and students often involve answering and asking a series related questions. Referring to the related questions students have asked, it can be predicted what following questions they may ask and require more learning resources on. By monitoring student's question history with the iQA system, the following questions they may ask and possible learning difficulties they may experience can be understood. If references and learning resources can be provided in advance, students are less likely to experience frustration in learning. The iQA system supports various technologies for comparing phrase strings with questions in the QA database when students ask questions. It also provides answers and a rich variety of advanced references and learning resources to the students.

With the advent of cloud computing technology, smart mobile devices have gradually become widespread. Smart mobile devices can get online anytime using Wifi, 3G, or 4G. This further drives the advancement of cloud computing technology. Ubiquitous learning (u-Learning) will be a future learning trend. Researchers focusing on e-Learning should explore how cloud computing technology can be used to develop online Answering Robot technology to help teachers preliminarily answer students' questions in real time and solve their questions by enriching the contents of QA databases and its question analysis and matching technologies.

25.3.3 Ubiquitous Learning (U-Learning)

With the prevalence of smart mobile devices, learning anytime, and anywhere has become a new learning trend. Ubiquitous learning (u-Learning) is a type of e-Learning which applies smart mobile devices in teaching and learning. Smart mobile devices can be taken as the extension of personal computers. Assisted by cloud computing technology, complicated computing can be carried out without pricey hardware. Moreover, current smart mobile devices are capable of processing images, video, and audio and equipped with built-in environmental sensors, such as GPS, digital compass, and G-sensor. Smart mobile devices offer contextual awareness, which is the most important advantage of applying smart mobile devices in education. According to the "situated learning theory" proposed by Lave and Wenger (1990), learners can achieve effective learning when learning knowledge in contexts, which means they learn in the authentic context containing concepts and knowledge they are about to learn. In recent years, there have been many studies on u-Learning. They have found that this type of e-Learning has positive influences on teaching and learning. Wu et al. (2012) developed a context-aware mobile learning system for use as a nursing skills training system. Used with smart mobile devices, it allows nursing school students to perform physical assessment on dummies. It is found that the system is effective in improving learner's clinical skills and relevant knowledge. Hwang et al. (2011) applied the interactive concept map-oriented approach to creating u-Learning environment and then applied the environment to outdoor nature science teaching. Students learn in an authentic learning environment (butterfly ecology garden) using smart mobile devices. It is found that it can improve student's learning attitudes and learning achievements. In addition to designing u-Learning systems catering to the needs of authentic learning environments, the advancement of software and hardware technologies on smart mobile devices and the maturation of mobile application (i.e., APP) development technologies and constant renewal of development tools have lead developers to create many APPs for teaching and learning applications. Many of these APPs have great potential for improving teaching and learning effectiveness (e.g., "Sky Map Davs" for Android, "Chemist" for iOS). Future researchers should explore integrating these APPs into a conventional classroom teaching environment to develop effective teaching strategies and activities. In recent years, several researches have investigated the factors influencing u-Learning, such as Liu et al. (2012) and Chu (2014). They contended that learning effectiveness of learners in u-Learning environment was influenced by the cognitive load they encountered when completing learning tasks (Paas et al. 2003; Sweller et al. 1998; Wang and Yang 2015). Cognitive load may come from learner's background and environmental context (Paas and van Merriënboer 1994; Paas, van Merriënboer, and Adam 1994). This issue deserves deeper follow-up investigation because learners in the u-Learning environment constantly switch between learning in the real environment and learning in a digital environment. In other words, both sides generate a cognitive load (Wang and Yang 2015). If learners are not familiar with the operation of system software and hardware, the effectiveness of u-Learning may be further degraded. Therefore, developing learning strategies or learning assistive tools and providing them to learners in a proper way can allow learners to perform effective learning in an u-Learning environment. This is also a topic worthing deeper investigation in the future.

25.3.4 Multimedia Technologies: Augmented Reality (AR) Technology and Gesture-Based Technology

The digital teaching materials designed by adopting multimedia animation have been widely applied to assisting teachers to teach and students to learn (Bowman 2012; Yang et al. 2012; Yang et al. 2015). According to Dancy and Beichner (2006), Wu et al. (2010) and Wouters et al. (2008), animation is effective in constructing situational context, concertizing abstract ideas, depicting outlook, and triggering learning motivation. In addition to the already mature VR technology, multimedia technologies which have received attention in recent years and provided application value in science education include AR technology and gesture-based technology.

AR technology refers to technology which integrates images and videos of the real environment with digital virtual objects for real-time presentation. It thus projects digital materials onto real-world objects (Cuendet et al. 2013). These technologies were developed as early as the 1990s, but their uses are limited due to the fact that AR devices are not yet prevalent. In recent years, along with the development and prevalence of smart mobile devices, AR technology has become more widely leveraged. When applied in education, the advantage of AR technology is that it combines digital resources with traditional teaching environment and can lead to positive affective and cognitive learning outcomes (Ibáñez et al. 2014). Recent researches focuses on the application of AR technology. Cheng and Tsai (2014) used AR technology to develop AR picture books and investigate the reading behavioral patterns of side-by-side reading between parents and children and their relationship with children's cognitive attainment. Ibáñez et al. applied AR technology to senior high school student's learning of basic principles of electromagnetism, investigating its influences on learner's level of enjoyment and learning effectiveness. Empirical research into applying AR technology to education has found that AR technology has positive effects on learners. However, much remains to be investigated. AR-based learning is a kind of personalized learning model. Learners can easily encounter the problems of "disorientation (Eklund and Sinclair 2000; Brusilovsky 2003)" and "cognitive load (Paas and van Merriënboer 1994;

Paas et al. 1994; Sweller et al. 1998)," which they may face in Web-based learning. Therefore, two meaningful research topics include: (1) how to apply AR technology and learners can avoid disorientation and (2) how to decrease cognitive load during AR-based learning so as to effectively assist learners. Moreover, AR-based learning is a new way of learning for most learners. Learner's conceptions of AR-based learning may also affect their learning behaviors and learning achievements (Cheng and Tsai 2014), a topic worth investigating. As Cuendet et al. stated, "*a system that is pedagogically efficient is not enough to be used in a classroom*." Therefore, there are two other issues deserving follow-up researches: (1) how to apply AR technology to developing teaching materials and designing teaching activities so that it can be effectively integrated with traditional classroom environments and (2) how to do in-service and pre-service teacher training and professional development so that the effectiveness of AR technology in facilitating teaching and learning can be improved.

Gesture-based technology has been widely applied in video games, such as Microsoft Kinet for XBOX. For education, gesture-based technology provides authentic interactive learning scenarios and can be used to design dynamic in game activities (Homer et al. 2014) so as to improve learner participation and learning interest in game-based learning. The Horizon Report (Johnson et al. 2011) identified gesture-based computing as an emerging technology that has a great potential to influence education in the near future by providing a novel form of interaction, expression, and activity (Ozcelik and Sengul 2012). This proves the value and potential of gesture-based technology when applied in education. According to Barsalou (2010), knowledge representations in cognition are grounded in multiple ways, including simulations, situated action, and bodily states (Chang et al. 2013). The main characteristic of gesture-based technology is that it can extend digital environments to real environments and allow users in real environments to directly operate digital environment via physical actions and interact with objects in digital environment. This characteristic provides teachers and learners opportunities to apply physical actions to operating and interacting with digital teaching materials, which may improve learner's learning effectiveness. It also has the potential to facilitate learning of complicated and abstract scientific concepts. For example, it can show the micro world via digital technology, allowing learners to interact with the micro world presented digitally using gesture-based technology. These ways of interaction are largely different from the interaction using the mouse or touch screen. They require learners to do particular physical actions, including raising hands, crouching, dodging, etc. This makes them feel like they are physically in the digital environment, enhancing their understanding of abstract concepts. Although gesture-based technology appears to have great potential, few researches have focused on applying gesture-based technology to education (Ozcelik and Sengul 2012). This is mainly because of the technology limitation, which is the accuracy of user movement detection. However, this problem has been mostly solved in 2013 because "Kinet for XBOX One" announced by Microsoft largely improved the accuracy. Implementation of gesture-based learning in science education should be an important research topic in the near future.

25.4 Conclusion and Suggestions

The unprecedented development of ICT technology gives birth to knowledge economy and informationizes the whole world. Based on the current and future trend of technology-enhanced science teaching and learning stated above, ICT provides greater flexibility and possibility, develops more innovative teaching strategies, and is playing an increasingly important role in science teaching and learning (Table 25.1). For example, based on the viewpoint of assessment as teaching and learning strategy (ATLS) (Wang 2010, 2011a), along with the maturing of online database and interactive technology, digital assessment can be used to facilitate learners to do self-assessment and in turn perform self-regulated learning in an e-Learning environment. Effective assessment-centered e-Learning environment (e.g., Wang 2014b) can also be developed to assist science teaching and learning. Moreover, multimedia animation can be used to develop test items which simulate situational contexts in real life. These animation-based items can be administered online and the operation and answering history of the item can be scored and recorded. After the examination, teachers and students can replay the operation and answering history of a certain item. They can understand and reflect on learning deficiencies based on the replay so that teaching and learning effectiveness can be improved. Based on cloud computing technology, a timely feedback system can be developed, with which learners can raise questions online using any smart mobile devices when they have questions about learning contents but fail to ask teachers or outstanding peers. They will immediately get different levels of feedback to assist their learning (e.g., Wang 2013).

Along with the prevalence of smart mobile devices and maturation of mobile computing technology, developing ubiquitous learning (u-Learning) environments to enable learners to learn in authentic contexts (e.g., Hwang et al. 2011) has now

Table 25.1 Trends of technology-enhanced science teaching and learning

Implementation of technology in science teaching and learning	Related information communication technology (ICT)
Learners think critically and logically about scientific ideas and compare them with real-life conditions (Songer 2007)	• 3D Virtual Reality • Augmented reality (AR) • Gesture-based technology
Learners critically evaluate and communicate scientific ideas (Songer 2007)	• Online discussion and forum • Online chat room
Learners formulate scientific explanations from evidence (Songer 2007)	• Online scaffolding tools
Learners use appropriate tools to gather, analyze and interpret data (Songer 2007)	• Smart mobile device (Ubiquitous learning, u-Learning)
Providing learners a scaffold that enables learners to perform self-regulated learning	• Digital assessment • Automatic feedback system • Smart mobile device (u-Learning)

become an important trend in science education. Development technology of mobile application (APP) has also matured and APPs are commonplace recently. APPs can be used with smart mobile devices to perform effective teaching in a physical classroom teaching environment. Moreover, along with the maturation of multimedia animation technology, AR technology, and gesture-based technology can be applied to science teaching and learning to create AR-based learning (e.g., Cheng and Tsai 2014) and gesture-based learning (e.g., Chang et al. 2013). Integrating these emerging technologies into teaching creates educational contexts different from those of conventional teaching. That is why they may influence the situational context of conventional teaching and in turn teacher's teaching and student's learning when integrated into teaching. It may also influence teaching and learning paradigms and current education theories as evidence from empirical research continues to accumulate. In the future, it is also possible to develop specific theories on technology-enhanced teaching and learning.

However, although technology has greatly advanced from teaching video tapes, computer-based instruction (CBI), computer-assisted instruction (CAI), and computer-assisted learning (CAL) to the latest ICT, the topic of how technology influences learning continues to be debated (Wellington 2005). Ross (1994) stated that '*the issue in the "media effects" debate, therefore, is not a trivial one, but one with important implications for how researchers and practitioners think about media applications*.' Similarly, in the heated technology trend, education researchers and practitioners need to think about how to make technology pedagogically and practically effective in improving teaching effectiveness and student learning effectiveness. The debates over technology's influences on learning can be dated back to the arguments between R.E. Clark and R.B. Kozma. Clark and Kozma analyzed media-related research from different angles and used the results as evidence for their own viewpoints (e.g., Clark 1994, 1983; Kozma 1991, 1994). They argued over whether "media" or "teaching methods" are the key factor in influencing learning. Based on meta-analysis and research results about media attributes, Clark emphasized that teaching methods are the key to support learning. Kozma examined how different media and media attributes contribute to constructing, forming, modifying, and elaborating learner's mental models. He contended that media attributes complement the learning process. However, the revolution in learning psychology in the 1990s, from behaviorism to cognitivism, objectivism to cognitivism, and instructionism to constructivism, again focused on the role of learners in the learning process (Jonassen et al. 1994). But Clark's insistence on teaching methods and Kozma's statements on media attributes both make the media debates overly focused on the concepts of instructionism; they both neglected the idea that in a learning environment scaffolded by technology, learners are still the subject of learning (Jonassen et al. 1994).

Many media researchers have followed the development of learning psychology to shift research focus from comparison between media approaches to examining the relation between teaching methods and media using the knowledge-constructed cognition and society process (e.g., Kozma 1994), taking teaching methods as the key of media teaching (e.g., Clark 1994) and the viewpoint of learners as the center of the media learning environment (e.g., Jonassen et al. 1994). According to Kozma (1991), an effective design integrating media into teaching is aimed at consolidating the media with teaching methods, and the two influence teaching by influencing each other. Mayer (2003) also observed that technology did not influence learning itself. Instead, it could assist learner's learning only when used with effective teaching strategies and designs. Taking individual cognitive process suggested by cognitive science research about the nature of human learning as the starting point, based on the three assumptions of "dual channels," "limited capacity," "active learning," and related empirical studies, Mayer proposed the "cognitive theory of multimedia learning," which explains how human learns via multimedia. The theory emphasizes the importance of how learners select, organize, and integrate pictures, texts and visual-audio messages in the process of multimedia learning. Based on the work of Kozma, Clark, and Mayer, it is found that to apply technology to construct an environment which can effectively assist learners to perform science learning, in addition to considering technology attributes, related instructional strategies and methods, the learner's characteristics should also be taken into consideration. In this way, learners can be assisted by the technology to achieve the richest learning in the way most suitable for their characteristics and maximize technology effectiveness in facilitating science learning. This means that to make technology effectively facilitate science learning, technology attributes, related instructional strategies and methods, and learner's characteristics should all be taken into consideration.

The development of ICT creates new opportunities for innovative application to the realm of science teaching and learning. Following the mainstream education paradigm turning from teacher-centered to student-centered teaching, names of these technologies have changed from educational technology to learning technology. In this article, many learning technologies which can be successfully applied to assisting science teaching and learning have been discussed. There are shared elements in these technologies. This article proposes "the three key elements of effective learning technology implementation:" nature of ICT, mediation model, transforming model (Fig. 25.1). "Nature of ICT" is that it is equipped with the technology to digitally process messages (texts, images, videos, and sounds) and to communicate. This makes message exchange more efficient and is able to keep, reproduce, deliver, revise, and create innovative messages. The "mediation model" represents the media attributes of technology, which can also be called the presentation type, meaning the ways digital messages are presented and exchanged. There are two main types: visual presentation type and auditory presentation type. The "transforming model" is the transformation approach of instructional information, which includes transformation of teaching material contents, teaching strategies, learning strategies, assessment strategies, etc. This transformation makes instructional information effective to perform teaching and learning activities based on the "nature of ICT" and "mediation model" of a certain learning technology. The "transforming model" is the key to the connection between ICT and pedagogy. A successful learning technology needs to come with a successful transforming model. There are two kinds of transforming model: internal and external. The internal transforming model refers to the hardware and software features of learning

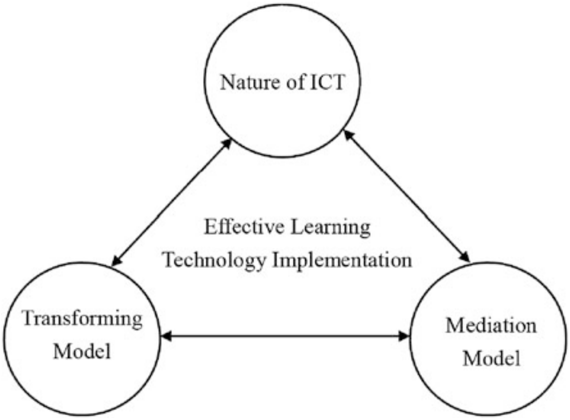

Fig. 25.1 Three key elements of effective learning technology implementation

technology that assist teachers to successfully transform teaching materials, teaching strategies, learning strategies and assessment strategies, and then construct technology-enhanced teaching and learning activities. For example, AR technology requires related hardware and software to transform instructional information into various multimedia objects and messages in an AR-based learning environment to perform teaching activities. These related hardware and software are internal transforming model of AR technology. The external transforming model includes the factors influencing how teachers leverage learning technology, including environmental factors, such as school and government education policies, school organization culture, teacher professional development courses, etc., teacher factors, such as teaching beliefs, teaching styles, self-efficacy,etc., and student factors, such as learning styles, cognitive styles, prior knowledge, cognitive load, and other individual differences. Regarding environmental factors, school and government education policies about promoting and supporting learning technology and the ways and strategies they promote it will determine how teachers use learning technology and in turn the transformation model of instructional information. School organization culture, including the attitudes toward applying learning technology to teaching, acceptance of new learning technology,etc., can influence the ways teachers leverage learning technology. Teacher professional development courses refer to the workshops and courses which help teachers learn to use learning technology. How these courses are held also influences teacher's skills and ability to use learning technology and their attitudes toward using learning technology in their teaching activities. Teacher and student factors interact with each other to influence the way teachers use learning technology and in turn the way instructional information transforms. For example, if a teacher's teaching belief is student-centered and his/her students in the technology-enhanced learning environment prefer "a kinesthetic learning style (Fleming 2001)." The transformation model of instructional information tends to be teaching activities which increase student's actual operation. This article suggests that in the future the implementation of all emerging learning technology in education should deeply investigate these three key elements:

nature of ICT, mediation model, and transforming model to understand how to make learning technology pedagogically and practically effective in improving teaching effectiveness and student learning effectiveness.

How to understand student learning in science learning environment in more proper methodology and get more empirical evidence so as to understand student learning effectiveness in the environment are also important for following researches on technology-enhanced science teaching and learning. Clark (1994) refuted the possibility of media-assisted learning using the evidence from meta-analysis of media comparison. Due to the methodological deficiencies of early research on media comparisons and dependence on achievement test scores, Kozma (1994) indicated that several researches lacked understanding of learning and descriptions about situations and contexts. The role of current technology-enhanced learning not only focuses on learning of scientific concepts but also includes facilitating students to actively investigate phenomena, master science practices, and develop inquiry competence and their views on the nature of science (Kang and Lundeberg 2010; Krajcik and Czerniak 2007; Linn 2003). These cannot be measured by simple achievement tests and their effectiveness cannot be explained by meta-analysis.

Although the effect size from meta-analysis is presented as an obvious quantified number, descriptions of the contexts where learning happens are missing. What situations does effectiveness comes from? What are the learning strategies and what are the learners these strategies happen to? A qualitative viewpoint is definitely required (Kozma 1994; Ullmer 1994). Although quantitative researches are inferential, their simplified situation contextual descriptions and neglect toward special cases make the reference and application value of pure quantitative research findings quite limited. But if the qualitative methodology, including investigation on research context and emphasis on individual cases, are adopted along with quantitative methodology, research findings on how technology influences learning will have more reference and application value. In addition, along with the development of technology and neurophysiology, more new research methodologies and instruments, such as eye tracking (e.g., Yang et al. 2013), emerge. These can be further adopted as research methodologies in the realm of technology-enhanced science teaching and learning, and leveraged to understand more about the mechanism and effectiveness of technology-enhanced teaching and learning.

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Chapter 26
Commentary: Innovative Curriculum Materials: Development, Pilot-Testing, and Scaling-Up

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Abstract This summary reviews the four chapters dealing with the development and implementation of innovative curriculum materials. These chapters provide a snapshot of diverse innovative curriculum materials to promote student teaching and learning in Science in Asia. Education for sustainable development (ESD) has been the central theme of two closely related curriculum reform movements in the history of Science education: Environmental education and Science-Technology-Society (STS) education. Innovative education resources, particularly digital ones, are becoming available at an unprecedented pace; one essential issue is integration of digital recourses into teachers' current curriculum. Teacher professional development courses must consider the process of innovation adoption. In addition, the effect of integrating digital recourses must be evaluated. No matter how effective innovative curriculum materials may prove to be during its development and evaluation stages, scaling up innovative curriculum materials is a totally different and new challenge. In Asia, countries have a history of placing strong emphasis on disciplinary structures and cross-grade progression, while Western countries have a history of placing strong emphasis on cross-disciplinary nature of Science; there is much to be learned between the Asia countries and Western countries themselves.

The four chapters in this section deal with development and implementation of innovative curriculum materials. Specifically, Chap. 21 reports the development of sample high school chemistry lessons to implement the UNESCO's Education for Sustainable Development (ESD) agenda. Results from trial uses in select classes in Japan and South Korea suggest that the lessons can develop students' abilities to make informed judgements about important socio-scientific issues, such as bio-fuels, bio-resources, and metal resources, and at the same time develop their knowledge and understanding of key scientific concepts. Chapter 22 reports a national project in India to develop online open educational resources to support reformed school science teaching and learning. Resources for students, teachers as

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well as parents were developed. Feedback received from field testing of the resources showed that students, teachers, and parents were quite positive about the potential value and impact of the open educational resources. Chapter 23 reviews a series of studies on adapting the Web-based Inquiry Science Environment (WISE) curriculum units for teaching and learning in Taiwanese classrooms. The findings suggest that WISE units had a positive impact on developing students' integrated understanding of science concepts and abilities to formulate scientific explanations, and such a positive effect was both short-term and long-term. The final chapter, Chap. 24, reviews literature on technology-enhanced science teaching and learning and identifies trends. The review proposes three key elements of effective learning technology implementation: nature of Information Communication Technology (i.e. , digitally process and communicate messages), mediation model (i.e., the forms digital messages are presented and exchanged), and transformation model (i.e., the pedagogy to transform digital messages for teaching and learning). Together, the four chapters provide a snapshot of diverse innovative curriculum materials to promote student teaching and learning in science in Asia.

ESD has been a central theme of two closely related curriculum reform movements in the history of science education: environmental education and Science-Technology-Society (STS) education. Despite of much progress in both theories and practices in environmental education and STS, ESD has not become an explicit and core vision in science curriculum reform documents of many countries with the exception of Canada (Council of Ministers of Education of Canada [CMEC] 1997). In the Pan-Canadian science curriculum framework, Science, Technology, Society, and the Environment (STSE) is one of four foundations for science literacy. One main reason for the lack of progress in making ESD a core vision in science curriculum reform documents is lack of agreement on the relationship between ESD and other components of science literacy. Given the continuing driving force of science literacy in current science education reforms around the global, how to conceptualize ESD as part of science literacy remains theoretically important and practically imperative. The chemistry lessons incorporating ESD reported in Chap. 21 provide a good example on how to integrate ESD into current science curriculums that primarily aim at science literacy. As it has shown in the trial implementation, the lessons can not only develop student knowledge and understanding of key science concepts, but also develop student reasoning abilities in making sound judgements on complex issues such as bio-fuels and bio-resources.

However, just developing students' knowledge, understanding, and reasoning is not enough for promoting ESD. Aikenhead et al. (2011) proposes a vision called *Science-Technology-knowing-in-Action*, or *ST-knowing-in-action*. *ST-knowing-in-action* values not only knowledge, understanding, and reasoning but also the capacity of citizens to deal with ST-related situations in their everyday lives. Actions can take place in many forms. For example, given that current ST-related issues are often complex involving social, cultural, political, and environmental aspects, citizens with *ST-knowing-in-action* are capable of participating in dialogs with others of different views. Participation in dialogs with people of various perspectives is also called science engagement (Liu 2009). Actions may also be in the form of collaboration on community projects between scientists and students (Roth 2002; Roth and Calabrese 2004; Roth and Lee 2004). Following Hodson (2003), Bencze and Carter (2011) propose an activist science and technology education program based on principles of holism, altruism, realism, egalitarianism, and dualism. Taking actions is central to this program, and examples of actions include educating others about issues, developing better products and systems, lobbying "power-brokers," boycotting harmful products/services, protesting against sources of issues, disrupting socio-enviro problem situations, and changing one's own practices (Bencze and Carter 2011).

ESD is consistent with a distinct research and education program called socio-scientific issues (SSI) (Zeidler 1984; Zeidler and Sadler 2011; Zeidler et al. 2005). SSI provides contexts for science learning by involving students in decision making regarding current social issues with a purpose to develop moral reasoning, ethical consideration, and character development. SSI is grounded in both cognitive and social-cultural learning theories; it has shown much promise to promote student learning by facilitating science knowledge acquisition and understanding of key science concepts, improving understanding of nature of science, developing argumentation skills, and increasing interest and motivation (Sadler and Dawson 2012).

Innovative education resources, particularly digital ones, are becoming available at an unprecedented pace; open educational resources (OER), and Web-based inquiry science environment (WISE) curriculum units reported in Chaps. 22 and 23 are good examples. As a result of the flattened world, governments and NGOs around the world have been investing heavily in developing digital education resources. In developing countries such as India, making OER available can help equalize opportunities to learn among students because of the wide disparity among students of different geographic regions and social-economic backgrounds. Adapting open curriculum resources developed in other countries, particularly the US, other countries can benefit. No matter who developed digital resources, one essential issue is integration of digital recourses into teachers' current curriculums. This integration is no simple task. One important consideration is teacher beliefs in and knowledge about uses of digital resources. Because various teacher beliefs and knowledge, the effect of a digital resource on student learning in the classroom is often unpredictable. Thus, teacher professional development is a key. "The best educational reforms and the most sophisticated curricula—even if well matched to an assessment regime—are likely to prove fruitless unless reforms and matched implementation of new curriculum are accompanied by adequate teacher professional development" (Coll and Taylor 2012, p. 774). In the case of the development of OER in India, teacher professional development is only at the beginning. In the case of WISE adaptation in Taiwan, comprehensive teacher professional development took place.

Teacher professional development must consider the process of innovation adoption. Hall and Hord (2001) define an innovation as a program or process being implemented. The innovation can be a specific product, such as a new textbook or curriculum, or a process, such as incorporating a different approach to a concept or different instructional practices. There are various levels of innovation adoption with each level associated with different knowledge of innovation and different ways of acquiring information, sharing, assessing, planning, status reporting, and performing. According to Hall and Hord (2001), “levels of use, or how teachers are using an innovation, are specific input for the facilitator in determining how to help teachers become increasingly successful and effective in using the innovation” (p. 14). As teachers increase levels of uses, their concerns changes from about themselves to about learning tasks to about impacts on students.

In addition to teacher professional development, the effect of integrating digital recourses must be evaluated. Coll and Taylor (2012) point out that, typically little curriculum evaluation has been conducted on new curriculums and assessment typically lags behind curriculum development by nearly 10 years. Often outdated assessment methods (e.g., standardized tests) are used to evaluate student-centered constructivist curriculum and instruction. The alignment between evaluation measures and the intention of the digital resources is demonstrated by the studies on adaption of WISE curriculum units in Taiwan as reported in Chap. 23. Chapter 23 also alludes to the potential incompatibility between the intention of digital recourses and the current school culture such as external test-based accountability.

Making best uses of open curriculum resources is a major challenge in both developed and developing countries. Addressing such a major challenge requires a systemic thinking about the role of technology in science teaching and learning, and Chap. 24 provides a useful conceptual framework on this. As reviewed in the chapter, education technology can facilitate student learning in thinking critically and logically about scientific ideas and comparing them with real-life conditions, evaluating and communicating scientific ideas, formulating scientific explanation from evidence, and using tools to gather, analyze, and interpret data (Songer 2007). Therefore, teacher professional development on integrating open education resources into science teaching and learning needs to keep the above functions of technology in mind and to help teachers decide the best function open education resources may perform. In addition, evaluation of the effectiveness of open education resources for science teaching and learning should avoid the pitfalls of media comparison approaches, because media do not function alone, and comparing one medium with another without taking other aspects of a teaching and learning system into consideration is not meaningful. That is, evaluation should consider open education resources as one component of a learning system in which teachers and students interact with the aid of open education resources to construct meanings and common knowledge (Kozma 2003).

No matter how effective innovative curriculum materials may prove to be during its development and evaluation stages, scaling-up innovative curriculum materials is a totally different new challenge. There have been various theories about scaling-up educational innovations. Successful scaling up must achieve outcomes on four interrelated dimensions: (a) depth—making a deep and lasting change in classroom practices, (b) spread—implementation to a large number of classrooms and schools, (c) sustainability—lasting long after pilot-testing and promotion, (d) shift in ownership—becoming internal to teachers, schools and districts (Coburn 2003). Scaling up is essentially about “extending the reach of an exemplary intervention to produce similarly positive effects in different settings to reach a greater number of students, teachers and setting" (McDonald et al. 2006, p. 16). Successful scaling up requires dynamic alignment and coordination of various activity systems of students, teachers, and researchers, such as close partnership between researchers and school district educators, recognition that the success of any intervention is determined by the pervasive policy climate of the powerful school system, quality of assessment feedback and other information that both permit and drive scale-up decisions, and well-organized research agenda to systematically introduce new curriculum materials to teachers (Lynch 2012).

There is currently a trend toward science education globalization (Chiu and Duit 2011). While there may be different challenges in Asia and in western countries, there is also a great deal of complementarity in approaches to science education between Asia and western countries (Liang, Liu & Fulmer, in press). Specifically for curriculum materials, Asian countries have a history of placing strong emphasis on disciplinary structures and cross-grade progression, while Western countries have a history of placing strong emphasis on cross-disciplinary nature of science; there is much to be learned from each other between Asian countries and western countries.

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Part V
Teacher Professional Development and Informal Science Learning in Science Education

Chapter 27
Professional Development of Science High School Teachers in Israel

Rachel Mamlok-Naaman, Dvora Katchevich and Avi Hofstein

Abstract Becoming an effective science teacher is a continuous process that stretches from pre-service experiences in undergraduate years to the end of a professional career. Science has a rapidly changing knowledge base, and long-term, continuous professional development (CPD) is essential for school science teaching to become more meaningful, more inquiry-based, more educationally effective, and better aligned with the twenty-first century science and its related socio-scientific issues. Therefore, accomplished teaching of science can be defined in terms of the knowledge that teachers use in their teaching. Any sustainable change of substantial character asks for long-term strategies including the connection towards practical experiences and multiple exchanges between practitioners and researchers in the specific educational domain. The implementation of new content and pedagogical standards in science education in Israel as well as in other countries necessitates intensive, life-long, professional development of science teachers. In the following chapter, we will describe four models that were developed in Israel: (1) leadership workshops for teachers, (2) action research, (3) evidence-based professional development, and (4) teachers as curriculum developers.

The *National Science Education Standards* (NRC 1996, 2011) present a vision of learning and teaching science in which all students have the opportunity to become scientifically literate. In this vision, teachers of science are professionals responsible for their own professional development and for the maintenance of the teaching profession. The standards provide criteria for making judgments about the quality of the professional development opportunities that teachers of science will need to implement. Professional development for teachers should be analogous to professional development for other professionals, since teachers are the critical link and are key in determining the quality and the standards of education in general and science education in particular. Each teacher would encounter a large number of pupils over the years of working in the educational system, thus teachers have a major impact on the Science

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and Technology education of pupils at all levels. In the past, conventional methods of conducting preservice and in-service education and professional development have not always proved to be adequate for attaining such demanding goals. In-service workshops conducted all over the world have been usually too short and sporadic to foster a change in teachers' classroom practice. In order to meet the challenges of reform in science education, we need to help schools and other educational institutions that are involved this reform to meet the challenges of the times. One of the ways to attain these goals is to treat teachers as equal partners in decision making. In other words, teachers have to play a greater role in providing key leadership at all levels of the educational system. Thus, by attending continuous development workshops, teachers will: (1) get acquainted with developments in science and with innovative curricular materials and innovative teaching strategies, (2) undergo a proper professional preparation in order to implement new curricular materials, and (3) continue to get the needed guidance and support while implementing new curricular materials.

27.1 Theoretical Background

The critical role of teachers in attaining the goal of quality education in the sciences is highlighted in the research literature on education. A recent international policy document written by Osborne and Dillon (2008) reflects a consensus on the importance of good quality teachers:

> Good quality teachers with up-to-date knowledge and skills are the foundation of any system of formal science education. Systems to ensure the recruitment, retention, and continuous professional training of those individuals must be a policy priority in Europe. (p. 25)

Teachers repeatedly had been described to be the key for any sustainable innovation in educational practices (Eilks et al. 2007). There is a variety of teacher professional development models/courses. Some of them are single contact courses and traditional top-down models of in-service teacher training. The single contact courses sr critically viewed by a few science educators and researchers (e.g. Smith and Neale 1989; Tobin and Dawson 1992). That is why long-term, extensive, and dynamic professional development of science teachers is recommended in the framework of reform in science education, and (National Research Council 1996; Loucks-Horsley and Matsumoto 1999) that will allow teachers' sustainable learning (Anderson and Helms 2001). Within such a framework, teachers need to receive guidance and support throughout the various stages for implementing changes in the curriculum or in their teaching methods (Harrison and Globman 1988). Any change of substantial character in science education, should consist of long-term professional development programs, (Huberman 1993). Under these circumstances, it has been noted that teachers, in general, are excellent learners, and are interested in trying to teach new curricula, as well as improving and enriching their teaching methods (Joyce and Showers 1983).

Effective CPD needs to provide an opportunity for teachers to reflect and learn about how new practices can evolve or be modified based on existing classroom practice (Harrison et al. 2008). Teachers need to familiarize themselves with new ideas and also understand the implications for themselves as teachers and for their students in the classroom before they adopt and adapt them. Previous research highlighted important features that characterize effective CPD programs (Loucks-Horsley et al. 1998), such as:

- Engaging teachers in collaborative long-term inquiries on teaching practice and student learning;
- introducing these inquiries to problem-based contexts that consider content as central and integrate them with pedagogical issues;
- enabling teachers to approach teaching-learning issues, embedded in real classroom contexts, through reflections and discussions of each other's teaching and/or examination of students' work;
- focusing on the specific content or curriculum teachers will be implementing so that teachers will be given time to determine what and how they need to adapt what they already do.

Science has a rapidly changing knowledge base and long-term, continuous professional development (CPD) is essential for school science teaching to become more meaningful, more inquiry-based, more educationally effective, and better aligned with the twenty-first century science and its related socio-scientific issues. Thus, accomplished teaching of science can be defined in terms of the content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK), that teachers use in their teaching (Magnusson et al. 1999; Shulman 1987). Teachers who will feel confident in their PCK will also be able to develop a sense of ownership toward their educational profession (Mamlok-Naaman et al. 2007).

27.2 Models of Professional Development Programs in Israel

The implementation of new content and pedagogical standards in science education in Israel as well as in other countries necessitates intensive, life-long professional development of science teachers. In Israel, in 1992, the Ministry of Education initiated a reform in science education (Tomorrow 98: Report of the superior committee on science mathematics and technology in Israel 1992). The report, which refers to the reform, includes 43 educational and structural recommendations for special projects, changes, and improvements in the areas of curriculum development and implementation, pedagogy of science and mathematics, as well as directions and actions to be taken in the professional development of science and mathematics teachers. More specifically, the report recommends:

- Providing science teachers with the opportunity to engage in life-long learning.
- Creating an environment of collegiality and collaboration among teachers who teach the same or related subjects, an environment that encourages reflection on their work in the classroom.
- Incorporating the process of change into professional development (support for these goals can be found in Loucks-Horsley et al. 1998).

In order to attain these goals, national and regional centers for the professional development of science and mathematics teachers were established (for more details, see Hofstein and Even 2001; Hofstein et al. 2003). The national centers specialize in the CPD for leading science teachers. The centers are directed by experienced staff scientists of the department, and act as the academic and practical home centrally (such as national conferences), the centers support and counsel regional professional development programs, develop and provide resource materials, and evaluate the outcomes. The centers are supported financially by the Ministry of Education that funds nationally one national teacher center per scientific discipline, except for mathematics. In the following chapter, we will describe four models that were developed in Israel:

- Leadership workshops for teachers
- Action Research
- Evidence-based professional development
- Teachers as curriculum developers

1. Developing leadership among chemistry teachers

Leadership in the context of science education was defined as the ability of a person to bring about changes among teachers and teaching. An innovative program, whose aim was to improve the pedagogy of chemistry education in the Israeli educational system, developed in Israel (at The *National Center for Chemistry Teachers*, The Weizmann Institute of Science). It focuses on a model aimed at the professional development of chemistry teacher-leaders. Israel has a centralized education system. The syllabi and curricula are regulated by the Ministry of Education. Since the 1960s, the Ministry of Education has provided for the long-term and dynamic development of science curricula and its implementation. These initiatives were usually accompanied by short courses (summer schools) for science teachers in general and for chemistry teachers in particular, intended to introduce them to the new approach and its related scientific background.

The program was planned with the assumption that the participants (chemistry teachers) are thoughtful learners; that they are prepared to be professional teacher-leaders; that after completion of the program the teachers will develop creative strategies for initiating reform in the way chemistry is taught, and in professionalizing other chemistry teachers.

Consequently, it was decided to design the program around the following three components:

- Developing teachers' understanding on the current trends of chemistry teaching and learning to include both the content and pedagogy of chemistry learning and teaching; for example, with the current trend to make chemistry more relevant, it is suggested that new programs in chemistry should also include its societal and personal applications, technological manifestations, and those components that could be characterized as historical and nature of chemistry in addition to the conceptual approach and the process of chemistry (Kempa 1983).
- Providing teachers with opportunities to develop *personally*, *professionally*, and *socially* (Bell and Gilbert 1994).
- Developing leadership among these teachers and enhancing their ability to work with other chemistry teachers.

The structure of the program is presented in Fig. 27.1.

The program extended over a period of two academic years, totaling 450 h, conducted 1 day a week, in an effort to allow for the gradual development and growth of the participants' conceptions, beliefs, and changes in behavior. In other words, to allow enough time for the development of teachers *personally*, *professionally*, and *socially*. The first year of the program was mainly devoted to the development of the teachers' *CK* in various topics in chemistry that were

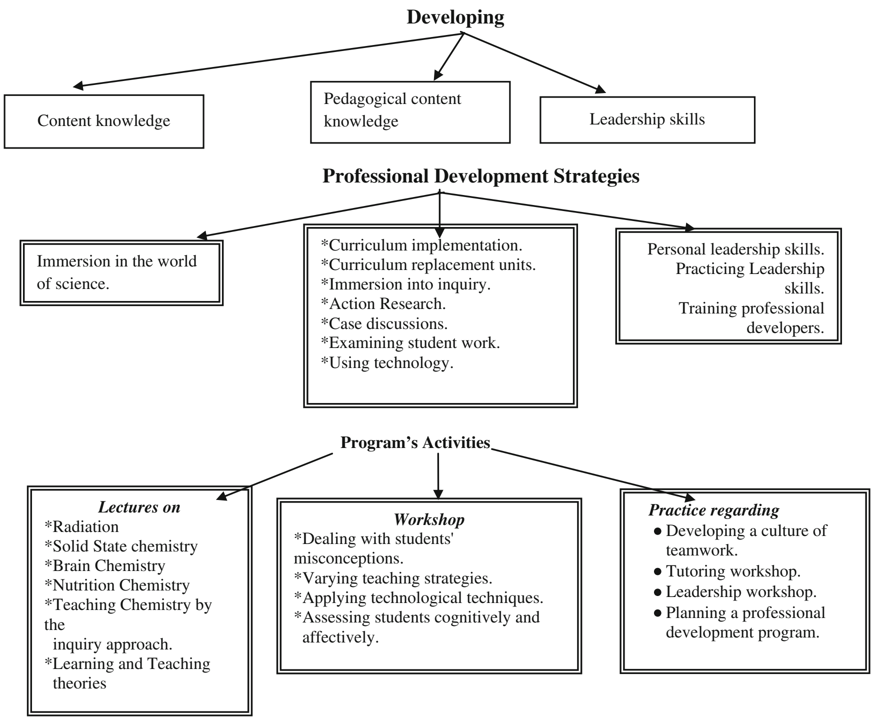

Fig. 27.1 Structure of the leadership course

characterized as relevant to the learners, possess a historical background, and also have a technological ramification and application. Among these topics are: forensic chemistry, solid-state chemistry, the chemistry of nutrition, and selected topics in the area of interaction between radiation and matter. In addition, a large segment of this year was devoted to the development of the chemistry teachers' *PCK*. The second year was mainly devoted to the development of skills in the area of leadership. The various abilities and skills were developed using many of the strategies for professional development suggested by Loucks-Horsley et al. (1998) and are presented in Fig. 27.1.

The program for chemistry teacher-leaders was designed to include all the necessary components that are comprised of the life-long professional development of science teachers, and also those components that are unique to the development of leadership among chemistry teachers.

2. Action research

Accomplished teaching should always occur simultaneously with reflection in order to improve the teaching strategy. It should be followed by protocols assembled in a portfolio, which can be used to demonstrate evidence-based accomplished practice in science teaching, in an effort to achieve more effective teaching. The portfolio should document the activities, interactions, and behavior in the chemistry laboratory where inquiry-type experiments are implemented. It can be viewed as a systematic and organized collection of evidence used to monitor the growth of a learner's knowledge, skills, and attitudes in a specific content area.

One set of medium to long-term strategies to connect research and practice, researchers and practitioners is the wide variety of methods of Action Research (e.g. Feldman 1996; Parke and Coble 1997; Bencze and Hodson 1999; Eilks and Ralle 2002), or related strategies such as *Content Focussed Coaching* (Staub et al. 2003), *Teachers Learning Communities* (Putnam and Borko 2000), and *Knowledge-Creating Schools* (McIntyre 2005). All these models have a different focus and a different strategy. But, all of them also include strong bottom-up and teacher-centered components. The differentiation among these strategies often lies in (i) the researcher-practitioner relationship and (ii) the degree of whether the approach is thought to implement a pre-thought concept efficiently versus helping practitioners to ask their own questions and to develop their practice following own needs (see, e.g., Eilks and Ralle 2002; Eilks 2003; Eilks et al. 2010). In this span, Action Research is thought to be an inquiry of the teachers regarding their work and their students' learning in the classroom oriented on the needs of the practitioners (Feldman and Minstrel 2000) or the development of new teaching strategies oriented on the deficits or interests of the teachers and their students (Eilks and Ralle 2002). Within this research, according to Feldman (1996), the primary goal of Action Research is not to generate new knowledge, whether more local or universal, but to improve and change classroom practices. Nevertheless, this point can be viewed differently depending on the Action Research mode chosen and the objectives negotiated within the group where the development of the individual practice and the generation of results of general interest can be seen as two sides of the same coin and with equal importance (Eilks and Ralle 2002).

Along the large amount of examples in science education and beyond, Action Research also became a more and more widely accepted tool for the professional development of teachers in all stages of their career, including the preservice preparation of teachers (e.g. Korthagen 1985; Gore and Zeichner 1991; Gipe and Richards 1992). Loucks-Horsley et al. (1998) claim that the strength of Action Research as a professional development strategy is that teachers either define the research questions or contribute to defining them in a meaningful way, and are actively involved in the research process (Parke and Coble 1997). The use of action research as a strategy for professional development is based on the following assumption (Loucks-Horsley et al. 1998):

> Teachers are intelligent, inquiring individuals with important expertise and experiences that are central to the improvement of education practice. By contributing to or formulating their own questions and by
> collecting data to answer these questions, teachers grow professionally. Teachers are motivated to use more effective practices when they are
> continuously investigating the results of their action in the classroom. (p. 97)

In order for Action Research to be an effective means for helping teachers to reflect on their practice, we must provide them with opportunities to engage in life-long professional development. These opportunities should provide them with an environment of support, collegiality, and collaboration with professional researchers and other teachers who teach the same or related subjects, an environment that encourages reflection on their classroom practice and the results of their research efforts. According to Holly (1991), collaboration is now seen as a major form of professional development. Indeed, this collaborative inquiry should be conducted by professionals acting as reflective practitioners (Schön 1983). When teachers reflect critically on their experiences, they critically examine them and improve their ability to teach and understand their students' learning difficulties useful for the development of promising teaching and learning scenarios (Obaya 2003).

The following workshop, which was conducted in Israel, will serve as an action research model of professional development. This project (e.g., Dass et al. 2008) focused mainly on allowing teachers to develop their own individual practices by enabling them to conduct small-scale action research studies in their schools. Therefore, a workshop structure was established to build the teachers' confidence in the area of conducting action research as a part of their professional development. The course developed for this purpose was part of a wider educational program for Chemistry teachers. Action research was selected as a topic within this program in order to (1) provide teachers with a powerful tool for enhancing their professional expertise by performing small-scale research projects in their local environments, (2) improve opportunities to practice the technique in the teachers' schools, and (3) create a professional community of connected, collaborating chemistry teachers. While planning the program, it was assumed that the teachers needed to improve their CK, PCK, and leadership skills in order to become professionals. Action research was assumed to offer potential solutions for reaching all of these goals using a joint approach. The action research segment of the program was structured around a series of workshops teaching the methodology and research tools necessary for data collection and evaluation. This was carried out by coupling workshop phases with action research activities performed directly in the teachers' regular school environments. In between the workshops, the teachers were asked to both discuss the content of the workshop with their school colleagues and to apply the learned strategies and methods to several aspects of their own practice, including specific research questions involving different domains: pedagogical, affective, behavioral, and cognitive.

A total of 22 teachers participated in the professional development program for Israeli high school Chemistry coordinators. All participants were experienced secondary school teachers. Each person had at least 10 years of experience teaching high school chemistry (grades 10–12), including preparing their students for Israeli matriculation examinations. All of the teachers had at least a Bachelor of Science degree in Chemistry; 12 held more advanced degrees. In addition, several teachers had backgrounds in academic science research. The teachers participating in the workshop had been recommended by their principals and regional tutors. They had also been classified as highly motivated teachers, who would be able to implement changes in the way Chemistry is taught in their schools. They were identified as potential candidates for becoming chemistry coordinators. The program involved weekly meetings and consisted of a total of 450 h at the National Center for Chemistry Teachers, located in the Science Teaching Department of the Weizmann Institute of Science. The action research course was included in the program and consisted of eight meetings focusing on, among other things, the development of the teachers' PCK. The workshop syllabus had been planned based on the fact that: (1) the participants were experienced teachers with backgrounds in both Chemistry content and pedagogy and (2) they nevertheless lacked experience in performing educational research and were not well-acquainted with qualitative research paradigms in general and action research in particular.

The action research meetings dealt specifically with the following topics and activities: (1) action research principles, (2) the qualitative research approach, (3) methodology (the rationale for choosing a subject for research, defining good research questions, types of research tools and data collection, methods of data analysis), (4) self-reflection during each of these stages, and (5) the presentation of reports. During the first four meetings, the workshop leaders would present the theoretical framework and issues. The meetings that followed were then devoted to discussing the various stages of classroom-based action research: (1) identifying general problems and teachers' own research question; (2) planning the research, including the development of research tools; (3) data collection and analysis; (4) implementation; (5) further data collection and analysis; and (6) evaluation and reflection of the results (Fig. 27.2).

After each meeting, the participants were asked to meet with their colleagues at school and share with them the topics and subjects discussed at the workshops. In

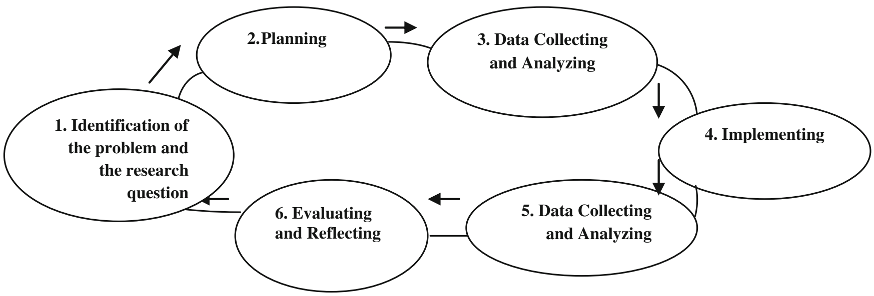

Fig. 27.2 The various stages of action research

this way, it was aimed that the teachers would involve their school's entire Chemistry staff in the action research process. During the course meetings, participants reported on their work, discussed the difficulties that had arisen from their teamwork, and received comments, clarification, and support from other participants and the facilitators. The participants were advised to choose research questions relevant to their work in school and in their classrooms. The questions formulated by the teachers covered various aspects of their environment. Some teachers were interested in their students' understanding of the subject (Mamlok-Naaman et al. 2003). Others were interested in pupils' behavior or motivation. Several of the teachers were interested in their own teaching and how it functioned in the classroom. Each of the teachers focused on a different topic, thus enabling the workshop participants to be involved in a wide range of research issues.

The workshop was accompanied by a study about its effects (Mamlok-Naaman et al. 2004, 2005). The main goal of the study was to discover how the action research workshop influenced the professional development of the participants. Ten female teachers were chosen to participate in this study. All ten of these teachers taught chemistry in schools that were located in the central part of Israel and attended mainly by middle-class students. Three sources of data were used for evaluation: (1) an opinion questionnaire administered after the course, (2) follow-up interviews (30 min each) employing open-ended questions given 1 year later, and (3) self-reported stories provided by the participating teachers (Lawrenz 2001). The attitude questionnaire used the Likert format and was administered to the ten teachers after the completion of the workshop. The Likert items used a scale of 1–4 (in which 4 stands for "fully agree" and 1 for "do not agree"). They included seven items assessing the teachers' opinions regarding the extent to which the workshop had contributed to both their professional development and to their ability to continue using action research methods in their teaching practice. Table 27.1 summarizes the questionnaire and presents the participants' answers regarding how the action research workshop contributed positively to their work.

From the questionnaire, we see that most of the teachers expressed satisfaction with the workshop. This was particularly true with respect to their personal interest

Table 27.1 Teachers' attitudes regarding how the action research workshop contributed to their work (n = 10)

Statements related to the action research workshop	x	SD
It increased my interest in integrating action research into my own class	3.80	0.42
It encouraged me to strengthen my relationship with science teaching experts	3.70	0.48
It improved my teaching strategies	2.80	0.92
It improved my ability to reflect upon my work	3.70	0.48
I became part of a community of practice	3.80	0.42
I would be happy to participate in a continuing workshop on action research	3.60	0.52
I would recommend that my friends participate in a similar workshop	3.90	0.32

in conducting action research in their own classrooms and in becoming part of a community of practice. Some participants did not feel that the workshop had broadened their teaching strategies. However, since our candidates were all experienced teachers, we assume that most of them already possessed a large repertoire of teaching strategies. From the interviews, three categories emerged by applying grounded theory (Glaser and Strauss 1967): (1) enactment followed by reflection, (2) membership in a community of practice, and (3) contact with science teaching experts. In the analysis, seven participants out of the ten interviewed stressed the fact that they had learned the importance of reflecting upon their work using the methods learned during the action research process.

Some of them continued conducting interviews with their students, stating that their pupils raised very good points that contributed to their work. Almost all the teachers claimed that they felt like members of a team during the workshop meetings and that they continued to exchange ideas over a year later. During the action research workshop, the teachers established closer contact with the academic staff on a professional basis and could contact the experts and consult with them whenever they needed to.

One example of self-reporting deserves brief discussion at this point. Lia, one of the participants, wrote that she had begun teaching a tenth grade chemistry class in a new school. The working atmosphere and overall environment in the new class disturbed her greatly. When asked to choose a subject for her action research project, Lia described the cooperation problems in her tenth grade class, which was composed of 28 students. She wanted to enhance her pupils' ability to collaborate with one another and openly share ideas during the lessons. She hoped that this would improve the learning environment. Lia decided to integrate computer work into her lesson plans, while also introducing group work. Accordingly, her research question asked: "What impact does integration through group work and the use of technological learning tools have on the classroom environment?" Lia divided her students into small groups and added computers as part of her teaching strategy. This enabled each group to progress at its own speed, using a variety of auxiliary materials including software, web quests, Internet sites, and various literature sources. As research tools, Lia incorporated pre- and post-lesson questionnaires and classroom observations, as well as holding informal discussions with her students. She also discussed the entire process with her colleagues and advisors during the workshop. From her students' reactions, Lia concluded that the action research workshop had directly influenced her work and teaching. She reported that these changes had become an integral part of her work, so that she no longer could teach in a "regular" fashion. The follow-up study revealed that Lia's process of change included two additional phases: She worked closely with the teaching team in her school, sharing the principles of action research with her colleagues. She also became head of a project named "Learning from Success" (reflective practice). Her target was identifying problems in school and finding project-based solutions which were perceived as successes. Together with the teaching team, she integrated action research principles as a tool for implementing changes.

Analysis of the interviews and questionnaires revealed that the action research workshop had helped the participants to both reflect on their personal practices and make appropriate changes. More specifically, teachers started investigating their own work and systematically exploring how their students were learning subject matter as a core element of developing personal PCK (see dimensions 4 and 5 outlined by Magnusson et al. 1999 above). As Joyce and Showers (1983) have suggested, teachers are generally interested in improving and enriching their personal teaching methods. Action research in particular proved itself to be a new and rewarding experience for this group of teachers.

A further objective of the workshop was to enhance the chances of creating a professional community of Chemistry teachers. It has already been suggested (Hofstein et al. 2003) that teachers need to have a strong and solid professional foundation in order for them to develop socially. The participants in our group had many opportunities to enhance their social skills through collaboration and cooperation with their peers. They shared ideas, consulted with each other, and maintained good social and professional relations with the others. The workshop meetings enabled them to consult with each other and exchange information and ideas as often as they wish. The cooperation among the teachers in the group was fruitful and helped in promoting their teaching strategies. It became a major developmental source of their knowledge on teaching in the sense intended by Appleton and Kind (1999), but in this instance appeared in a reflected form. The participants reported that they had become a team of active, professional teachers. In fact, they maintained contact and exchanged information with one another in the year after completion of the workshop. They even met a couple extra times and worked together. From the beginning, the approach chosen for this study was believed to be able to promote emancipatory action research as described by Grundy (1982). The creation of the above-mentioned, independent learning communities among teachers is a clear indicator that Grundy's processes of participation and emancipation as mentioned in his three-mode developmental model of action research (Eilks et al. 2010; Eilks and Markic 2011) had begun to take root.

Another central objective of the workshop was the establishment of a team of lead teachers. These leaders would perform action research with other colleagues as the ultimate stage of the emancipatory process. The action research project described here enabled the participants to develop and enhance their own social abilities and gather experience as leader figures. Such leaders serve as catalysts for change and as supporters of reforms (Hofstein 2001). This action research program helped our teachers develop necessary leadership skills. The participants reported that they had directly shared the methodology of action research with their colleagues and had also become independent of their peers when it came to their personal abilities and research interests.

We can conclude that the program presented here fulfilled its objectives. By integrating action research into their work, teachers can learn to better understand their students and how they think and learn. They can also increase their professional esteem and directly share their experiences with their colleagues. Both action research-based critical reflection upon one's own experiences and exchanges between trusted colleagues provide a promising environment for strengthening teachers' professional repertoire.

3. Evidence-based professional development

In Israel, the inquiry laboratory was integrated into the teaching and learning of high school chemistry (Hofstein et al. 2005). An evidence-based model for the CPD of chemistry teachers was developed and implemented (Taitelbaum et al. 2008). Using the CPD model enables the teachers to gain the unique PCK needed, so they will be good guides for their students. During the learning process in class, teachers should try to recognize the way students think in order to help them construct their understanding and create rich and meaningful interactions in the classroom. However, to use the inquiry approach, teachers will need to undergo an intensive process of professional development, so that they will experience the same skills, knowledge, experience, and thinking habits as their own students (Winscihtl 2003). In order to be effective guides for their students, teachers should be able to gain skills such as the ability to organize collaborative teamwork and promote students' questioning skills, keeping the classroom–laboratory workplace safe, and properly assessing students' work.

The model was developed during an evidence-based CPD program, which was part of a more comprehensive project (between Kings' College, London and the Weizmann Institute of Science) (Hofstein and Mamlok-Naaman 2004), conducted in the Chemistry Teachers' National Center located in the Department of Science Teaching at the Weizmann Institute of Science. The main goal of the project was to develop, through collaborative research with teachers, a CPD program that focuses on a set of characteristics and protocols assembled in a portfolio, which can be used to demonstrate evidence-based practice in teaching chemistry in the classroom-laboratory using inquiry-type experiments. The key objective of the CPD program was to develop teachers' knowledge and pedagogy, through a design-based approach, so that they will be able to scaffold their students in acquiring the inquiry skills (Fortus et al. 2004). The CPD program was designed and implemented throughout the period of three years. The first year focused mainly on developing a teacher's guide and planning a summer induction course. In

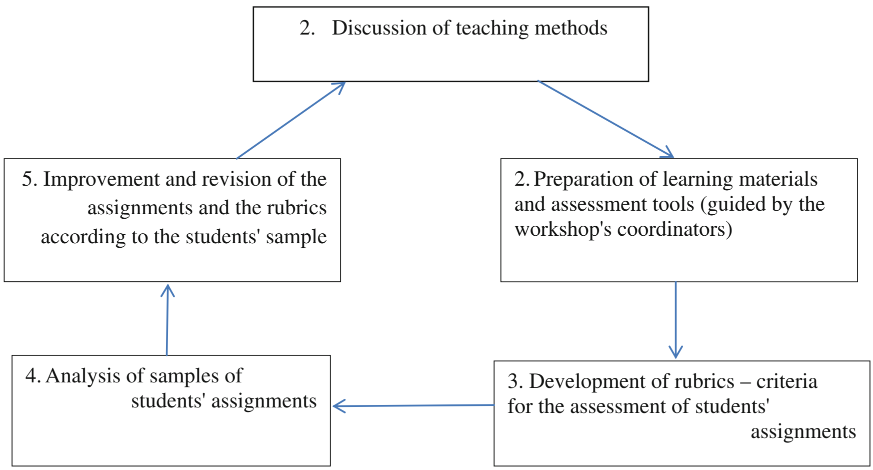

Fig. 27.3 The different components of the workshop

the second and third years, program was implemented, and modified between the second and the third year. Seven high school chemistry teachers participated in this program each year. They were novices in teaching the inquiry approach in chemistry laboratories, but most of them had several years of experience in teaching chemistry. In this paper, we will refer to the second and third year. Figure 27.3 is a schematic representation of the final CPD model that was implemented. The model consisted of three phases: (1) Development of the CPD components, (2) Summer induction course, and (3) A workshop, which included preparation of evidence-based portfolio and videotaped observations and discussions related to the school-laboratory. The workshop was accompanied by a study, which demonstrated the changes the two teachers who participated in the workshop underwent in terms of their professional behavior related to the inquiry program.

Based on the findings and observations, the authors suggested that teachers who teach chemistry according to the inquiry approach should develop a novel approach regarding their CK and PK. In order to provide students with guidance and support, teachers themselves need to develop many of the above-mentioned inquiry skills. A CPD model was developed to achieve these objectives. The model developed and implemented in this study was time consuming and very intensive. We presented a model in which the teachers developed some of the needed skills. We also presented few examples of how they developed a new pedagogical approach. The change in the method used in grouping the students, the change in managing the laboratories' lessons, (for example, student-centered as opposed to the teacher-centered), and the change in phrasing and posing an inquiry question, serve as examples for teachers' changes. The study was aimed at understanding some of the unique teaching strategies that teachers have to adopt while teaching inquiry approach in their classes and how these are developed and enriched throughout their various experiences. The study was based on teachers' point of views, for example, the different opportunities for reflections, and was supported by looking into their practice, e.g., the observations. Although we observed various teaching strategies in the classroom-laboratory, we decided to focus on group work since literature points out the importance of it in achieving the goals of teaching and learning (Shachar and Sharan 1994; Sharan and Sharan 1992; Slavin 1990). Results of the study indicated that even a minor change in the pedagogy, such as grouping of students can influence teachers' self-confidence. Reflecting upon the preparations and the enactment of the inquiry activity helped them in understanding their professional improvement and progress.

The results also indicated that a change in CK such as phrasing inquiry questions is not immediate, and participating in a summer induction course is not enough for this change to happen. It is suggested that involving teachers in a reflective-type process accompanied with continuous support and scaffolding can promote the necessary professional development to include both CK and PK. In addition, once teachers have acquired this knowledge, they could use it explicitly as they guide and provide support to their students, and thus make their guidance effective and meaningful.

It is suggested that during the CPD initiative, teachers had gained more self-confidence in critiquing their own work, understanding their teaching strategies in leading and tutoring students who work in small collaborative groups, and developing the investigative skills of students, e.g., discussing the types of questions posed, the nature of the hypotheses raised, the questions selected for further investigation, and the process of planning more experiments (Davis and Honan 1998).

Teaching sing the inquiry approach is much more complex and different from traditional classroom teaching. It demands different kinds of skills and a high level of expertise among teachers (Crawford 2000). This is why teaching inquiry approach puts a lot of stress on teachers, and it takes time for teachers to become familiar with and comfortable in teaching it. It is possible to develop PK and CK just through classroom experiences, but as we learned from this research study, the professional development of teachers could be faster and much more meaningful if it is done through teachers' participation in a CPD program similar to the one described in this paper.

Introducing evidence from the classroom-laboratory was not a trivial task, but the fact that the teachers were encouraged to document their work, together with the process of investigating their work during classroom-laboratory (reflecting and watching the videos), significantly contributed to their work. Among the benefits, the teachers mentioned the exchange of ideas, as well as getting relevant feedback and support. The model implemented in this study could be adopted effectively for other instructional techniques and pedagogical interventions used by science teachers in general and by chemistry teachers in particular.

As mentioned above, teachers need to receive guidance and support throughout the various stages of their career (Harrison and Globman 1988), and especially during their first years of teaching (Feiman-Nemser et al. 2000). Novice teachers should participate in long-term workshops and experience different models of CPD in order to become professionals as soon as possible. The model described below will serve as an example for a professional development course in which experienced teachers participated with novice teachers in a course that aimed at supporting novice teachers. The first working years of novice teachers are a critical stage in their success and long-term survival in the system (Feiman-Nemser et al. 2000). Supporting novice teachers is a key in the professional development of both novice and experienced training teachers (Elliott and Calderhead 1995; Kajs 2002). From the experienced teachers' viewpoint, the course empowered them and formed a significant stage in their professional development. They received recognition from the course coordinators for their ability to mentor the new generation of teachers. The novice teachers, who participate in this type of course, received support in the areas of CK, PK, and PCK, as well as in the affective field.

The course consisted of 60 h over 1 year. It takes place once every 2 weeks (15 meetings) consisting 12 face to face sessions and three online sessions. Fifteen high school chemistry teachers participated in the course, including ten novice teachers (with 1–5 years of experience) and five experienced teachers (with at least 20 years of experience). The experienced teachers had a lot of experience in preparing their students for the final (matriculation) examinations, as well as in evaluating these examinations. They were selected by the course coordinators due to their capabilities and interpersonal communication skills. The activities of the course included:

(a) Impartation by an experienced teacher

The activities were structured by the experienced teachers according to the needs of the novice teachers. During the course, the novice teaches functioned as students and the experienced teachers as teachers. In the course feedback, the experienced teachers indicated that they had gained something from this activity since they had to prepare the subject, which they presented to the group of the novice teachers. In addition, the novice teachers helped them to refer to different points of view and questions which they had not considered before.

> Together with my group, we selected the subject… While discussing and analyzing the subject, we created a detailed sequence of each subject. It caused me to organize the whole subject and the materials that I hand out to the students. I received ideas from the new teachers and we integrated them into the subject. (An experienced teacher)
> The group work with the experienced teachers contributed very much – Practical suggestions for teaching sequence and the small group involved personal relating of each experienced teacher. Another advantage – Rotation of the groups, each time it was possible to discuss another teaching subject. (A novice teacher)

(b) Designing lesson plans

After we had structured a template for writing up the lesson plan in the course, the new teachers were asked to prepare a lesson/lessons plan on the subject that they had learned from the experienced teachers and to present it in the course forum. The remaining participants, both experienced and new teachers, were asked to provide feedback to the lesson plan. A productive discussion around the lesson plans was held in the forum. In some instances, the new teachers activated the lesson plans and returned to the course with new insights after the implementation in class.

> Very important for both sides; it provides feedback for the new teachers and generated renewed thinking about the subject by the experienced. (An experienced teacher)
> It is important for the new teachers to prepare lesson plan and get feedback on them… When a number of teachers in the field share plans, this is positive. There is an exchange of information between the teachers, enrichment of other teachers, and a look at the different teaching/studying directions of the teachers. (A novice teacher)

(c) Presentation and analysis of teaching cases

Teaching case studies is an important component in the practical training period of novice teacher (Carter 1988). In the course, a teaching case was defined as a happening in class in which the teacher had to respond to a question or idea raised by a student relating to both the content and in the context of conducting the lesson. The first teaching case was presented by the staff in order to demonstrate to the teachers what a teaching case is. During the course, both experienced and new teachers were asked to upload two teaching cases to the course forum and provide feedback on the cases of their colleagues. According to instructions given to the teachers, the document that records the teaching case had to include the background of the case, the lesson subject, and the teacher's reflections on the teaching case, which should include his/her recommendations for handing the case in the future. Some of the teaching cases were selected by the staff and presented by the teachers and analyzed in the plenum. The discussions around the teaching events were productive. Both experienced and new teachers recommended methods for handling the events. The atmosphere in the course created a secure environment for the teachers to share difficulties and receive reinforcing feedback.

The teaching events were presented by both experienced and new teachers. The latent message is that, at any stage, teachers are likely to face surprises and some of the skills required of teachers are functioning in uncertain situations, an ability to improvise, and an awareness of the fact that the lesson plan is a basic program that changes according to need. While most of the teaching cases related to content, surprising questions raised by the students, some related to the students' grades, tests *and copying*.

> It is important for new teachers to discuss teaching cases that occur in class and receive feedback about them. There is cooperation amongst the teachers regarding teaching methods… New teachers can learn from both new and experienced teachers' mistakes; they can be assisted by strategies on how to respond when, I, as a teacher, do not know the answer and how to cope with disciplinary problems and awarding grades. (A novice teacher)

(d) Writing assessment tasks

A number of sessions were dedicated to the correct writing of assessment tasks. The course staff lectured on the principles for constructing a test. The lecture was integrated with a workshop that included correcting questions presented by the staff, and writing new questions: closed, open and unseen questions. There was at least one experienced teacher in each work group in this workshop. New teachers chose the subject for writing the questions. The workshop outcomes were questions/exams/test/, which included detailed answers sheets according to the new teachers' needs.

> The workshop for writing question and tests, I would do more (An experienced teacher)
> The activity in writing tests and questions in groups in cooperation with the experienced teachers contributed much to me. (A novice teacher)

Based on the above feedbacks, we may conclude that support for novice teachers in the affective aspect is no less important than support in the content and pedagogical fields. Teachers cope within the period of specialization with difficulties stemming from their being part of a new system. Some of the difficulties stem from the fact that the teachers become members of a new organization with a certain culture. Teachers require an attentive ear and a platform for presenting their problems (Huling-Austin 1992). The open and inclusive atmosphere that prevailed during the course enabled teachers to share without fear of receiving any criticism.

> The atmosphere during the course was excellent, an atmosphere of no criticism and full cooperation. (An experienced teacher)

The main platform for presenting difficulties was presenting teaching cases, which related to content as well as to conducting the lesson and the communications between teachers in the staff and between teachers and students. However, we found it proper to assist the new teachers in finding points of light during this difficult period. Each session commenced with a number of minutes during which one of the teachers shared something good that it happened to him/her at school. This activity assisted the teachers in gaining a more optimistic view.

> The points of light were most important. This creates proximity, breaks formality and generates a pleasant atmosphere. (A novice teacher)

To sum-up, as mentioned before, the professional development course achieved its goals in relation to new and experienced teachers alike. The new teachers felt that they had a supportive environment that answered their needs regarding CK, pedagogy and the effective aspects. The experienced teachers felt that they not only contributed, but also gained a lot of insights. They were glad to re-experience the energies of the new and younger teachers.

> I was happy to be both a contributor and gainer during the course. I contribute from the knowledge and experience of many years of teaching. During the course tasks were given, which I could use in order to contribute optimally. I also gained from the new teachers, introducing creative and innovative ideas and knowledge from the academic field. (An experienced teacher)
> The course was interesting and very enriching. I was happy to participate and get to know senior and new teachers. This is an interesting and pleasant learning method. I could raise any problem thanks to the attention and warm personal attitudes. (A novice teacher)

In summary, supporting teachers (novice as well as experienced) continuously, has the potential of enhancing teachers' professional practice in our attempt to attain newer and higher pedagogical standards.

4. Science teachers as curriculum developers

In the framework of reform in science education, an extensive, dynamic, and long-term professional development of the science teachers should take place (Loucks-Horsley and Matsumoto 1999; National Research Council 1996). Teachers need to receive guidance and support throughout the various teaching and implementation stages that involved changes in the curriculum (Harrison and Globman 1988; Loucks-Horsley and Matsumoto 1999). On the one hand, although teachers are excellent learners, and are interested in trying to adopt new curricula, as well as in improving and enriching their teaching methods, it is not easy for teachers to undergo modifications that include changes in content and in the ways they teach, (Joyce and Showers 1983). An integrated science curriculum differs from a traditional science curriculum. Science teachers usually receive good preparation in teaching the traditional science curriculum—One or two science disciplines, but not integrated science. However, they need to learn the knowledge, skills, attitudes, and teaching skills to teach such an interdisciplinary topic (Bybee and Loucks-Horsley 2000). They should be encouraged to expand their repertoire of student assessment strategies to include techniques such as observation checklists, portfolios, and rubrics (Wiggins and McTighe s1998).

For example, one of the ways to overcome teachers' anxiety regarding reforms such as Science, Technology, and Society, requires their active involvement in the development of learning materials, instructional techniques, and related assessment tools (Loucks-Horsley et al. 1998; Parke and Coble 1997). Similarly, Sabar and Shafriri (1982) claimed that "Participation in curriculum development, which is a protracted process, is likely to take the teacher from a conscious phase to one of greater autonomy and internalization phase." (p. 310). It is generally believed that involving teachers in the process of curriculum development leads to a wide variety of pedagogical ideas regarding instructional techniques and their related tools (Connelly and Ben-Peretz 1980).

Based on this rationale, we designed a workshop for science teachers to implement learning materials and to develop assessment tools for a "Science for All" program. The following described workshop was accompanied by evaluation procedures, in order to determine whether the objectives of the STS were accomplished. The workshop participants met eight times, 4 h every other week. Two science education researchers conducted the STS workshop and the research associated with it. They were experts in curriculum development and in the professional development of teachers. The workshop was initiated to address the teachers' questions: "what strategies should we use in teaching STS-type modules, and how should we assess the students who are studying such modules?"

The workshop participants consisted of 10 science teachers from 10 different high schools in Israel. Each taught the "Science for All" program in one class and had at least 10 years of high school science teaching experience, mainly in grades 10–12. All of them had already participated in several in-service professional development workshops. Their scientific backgrounds differed, and included areas such as chemistry, biology, agriculture, nutrition, technology, and physics. The teachers had already taught the "Science for All" modules previously mentioned but had difficulties in using a variety of teaching strategies in general, and in grading and assessing their students in particular. Each of the teachers who participated in the workshop had taught at least one of the "Science for All" modules in one class consisting of about 30 students. The workshop coordinators focused on guiding the participating teachers in using a variety of teaching strategies, and in the development of auxiliary assignments used in this workshop consisted of detailed checklists (rubrics) and rating scales.

In the first three meetings, the participating teachers were exposed to lectures and activities related to alternative assessment tools and methods, and especially to the way in which they should get used to working with rubrics. Each teacher prepared the assignments for his or her students, followed by assessment tools. The assessment tools included tests, quizzes, assessment guides for carrying out mini-projects, essays writing, and critical reading of scientific articles. All the assignments were developed in stages, each of which required consideration and an analysis of assessment criteria as well as scoring. These assignments were administered stage-by-stage at school. Students were involved in the assessment methods and their respective weights. The students learned how to be aware of the alternative assessment method, the weight percentage for the each of the assessment components, and the final grade. This continuous assessment provided them with more control over their achievements since they were. At each stage, students would submit their papers to the teacher for comments, clarification, and assessment. They would meet the teachers before and after school for extra instruction and consultation. The detailed checklist given to each student after each assignment compelled them to address the comments with the greatest seriousness if, of course, they wanted to improve their grade.

The students reflected on their work and ideas at each stage, and followed their teacher comments on a detailed checklist and corrected them accordingly. Thus, they were able to improve their grades. The teachers revised the rubrics related to the assignments at each stage. Samples of the student assignments were brought to the workshop for further analysis and the process involved both the coordinators and their colleagues—the participating teachers. The group discussed the revision of the rubrics, and agreed on the percentage (weight) allocated to each of the assignment components. They also agreed on the criteria for levels of performance, in order to grade the students as objectively as possible. The different components of the workshop are presented in Fig. 27.2, specifically (1) discussions of the teaching methods, (2) preparation of learning and auxiliary materials and assessment tools, (3) development of rubrics—criteria for the assessment of the assignments, (4) analysis of samples of student assignments, and (5) improvement and revision of the rubrics according to samples of the student assignments. At the end of the year, the students of each class presented their assignments to an audience consisting of their peers from parallel classes, their parents, science teachers, and the school principal.

The goal of the study which followed the workshop was to find out whether the objectives of the workshop were attained. The researchers used self-report questionnaires and interviews of teachers. This decision was based on the literature

(Lawrenz 2001); claiming that such instruments could be regarded as valid and reliable if they were administered and the data were collected at times when a person's almost immediate response can be obtained.

Regarding the students, the researchers focused on the affective aspects of learning and not on the cognitive ones, since one of the main objectives of the reform in Israel was to make science an integral part of the education of all citizens (Tomorrow 98: Report of the superior committee on science mathematics and technology in Israel 1992). Changing the attitudes of non-science-oriented students toward science is one of the main objectives of the reform in Israel. Four sources of data were used: (1) an attitude questionnaire administered to participating teachers, (2) semi-structured interviews with the teachers, (3) minutes of the meetings, (4) an attitude questionnaire administered to the students, and (5) structured interviews with students. The analysis of the interviews and the minutes was done according to basic methods of qualitative data analysis (Glaser and Strauss 1967; Tobin 1990).

The findings revealed that the teachers who participated in the workshop gained self-confidence in the teaching and assessment methods of this new interdisciplinary curriculum and were motivated to try new content and teaching strategies. Moreover, they could better understand the advantages of the alternative assessment methods and were better prepared to use them. They were satisfied with their work and their accomplishments and feel pride in their work.

Teachers' knowledge of science is based on previous experiences (von Glaserfeld 1989) and on doing and experiencing (Gilmer et al. 1996). Moreover, it was shown that personal involvement helps in reducing their anxiety in teaching an unfamiliar subject (Joyce and Showers 1983). Therefore, teachers who actually develop the teaching strategies and assessment materials get a better understanding of how it should be taught and experience some kind of I involvement: they are part of the curricular process (Parke and Coble 1997), feel pride in their work, and become producers rather than consumers (Sabar and Shafriri 1982). The new curriculum materials also appeared to be effective vehicles for teachers' learning (Bybee and Loucks-Horsley 2000). They were involved in the development of learning materials as well as the teaching strategies and assessment tools, which must be tailored adequately to the students' cognitive and affective characteristics, as mentioned by Ben-Peretz (1990). Hopefully, in the future, these teachers will serve as leaders and coordinators for similar workshops, and support those who will teach the STS module and use the alternative assessment method.

The active learning for which we strive in order to stimulate and motivate our student also stimulates and motivates the teachers. They understand better that the traditional paper and pencil assessment tools frequently used in science courses are inadequate for such an interdisciplinary program that is accompanied by a wide range of pedagogical interventions. As a result, the interest of these teachers' students in the process of learning increased. Moreover, the students were more satisfied regarding the learning materials, the learning strategies, the assessment methods, and the ongoing dialog with their teachers.

The teachers who participated in the workshop were aware of the difficulties that could arise regarding the validity and reliability of the assessment tools. Thus, they made great efforts to improve and revise the assignments and rubrics according to the students assignments. In fact, their anxiety about the alternative assessment methods gradually diminished when they realized that the continuous assessment of students' progress and achievements, consisting of detailed and clear assessment instructions, could present a broad, valid, and reliable picture of their students' knowledge and abilities. To attain a wide range of assessment models, clearly time is needed in order to construct a supporting framework for science teachers (Westerlund et al. 2002). Indeed, the teachers in the workshop were continuously supported and assisted by the workshop coordinators.

In summary, teachers who implement a new curriculum should receive sustained support in order to gain knowledge of different teaching strategies and assessment skills. This can be done by attending professional development workshops that deal with those topics, which will consequently stimulate their creativity and diversify their instructional strategies in the classroom. Such skills should improve their ability to teach and understand their students' learning difficulties. Since they will better understand the goals, strategies, and rationale of the curriculum, they will feel more qualified to modify the curriculum as needed. We believe that such workshops help more teachers become producers rather than just consumers, and to gain a sense of ownership (Hofstein et al. 2012). Such efforts and reform in the way students are assessed (school-based assessment) necessitate approval and support from other people not directly connected to the program, namely school headmasters, science coordinators, and government regional consultants (Krajcik et al. 2001).

27.3 Summary

The education system in Israel is centralized. In this system, the Syllabi, and students' final examinations (matriculation) in the sciences are controlled by the Ministry of Education. However, the way in which science is taught—its contents and pedagogy, is often controlled by science education centers, such as departments of science teaching (e.g., the Department of Science Teaching of at the Weizmann Institute of Science), and national centers for science teachers (as mentioned above). Over the last decade, in these institutions, science teachers were involved in many CPD initiatives, aligning the teaching to various students' needs and abilities, as well as to their professional and social development. However, Israel is a multicultural state. In some cultures, lecturing by the teacher is the prevalent method: The students are passive receivers of knowledge, and construction or transformation of that knowledge is not an essential part of their learning (Dkeidek et al. 2011). Therefore, in this paper, we choose to describe four models of professional development that over the years were implemented in the national centers for science teachers. Each of the models is unique, has its own educational goals and addresses different kinds of teacher population.

The first model (leadership workshops for teachers), is aimed explicitly for future teacher leaders in science education. It consists of four phases: The teacher as a learner (getting acquainted with the CK); the teacher as a teacher (experiencing new pedagogies and teaching strategies); the teacher as a reflective practitioner (getting used to structured self- reflections); the teacher as a leader (leading innovations and changes in the educational system).

The following three models (action research, evidence-based professional development, and Teachers as curriculum developers) present long-term strategies to connect research and practice, as well as researchers and practitioners (Mamlok-Naaman and Eilks 2012). They include bottom-up initiatives (e.g., teachers who develop their own learning materials and assessment tools); reflection strategies; inquiry skills, etc. By attending these professional development workshops, teachers felt that they gradually become part of a community of practice, developed a sense of ownership toward the projects which they attended. Some of these teachers developed a high level of sense of ownership so that they became leading teachers namely providing leadership for future CPD initiatives. It should be noted that one of the difficulties regarding implementation of new learning materials, modules, or pedagogies is the need to provide teachers with continuous support. These leading teachers are expected to help in these initiatives.

We also referred to an exemplary CPD workshop in which experienced teachers shared their experiences with novice teachers. We tried to show how such a workshop contributed to the experienced teachers as well as the novice teachers. The support which the novice teachers got reduced their anxiety and strengthened their PCK. Regarding the experienced teachers, it was a significant stage in their professional development as they received recognition from the course coordinators for their ability to mentor the new generation of teachers.

We may conclude that becoming an effective science teacher is a continuous process that stretches from preservice experiences in the undergraduate years to the end of a professional career. Teachers develop socially; learn how to collaborate with their colleagues in new ways, and how to receive support and feedback from them (Bell and Gilbert 1994; Mamlok-Naaman et al. 2013). There are various models of professional development, and teachers may choose the ones which match their needs at a certain stage in their career and in alignment with the educational system demand.

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Chapter 28
How Have Japanese *Rika* (School Science) Teachers Traditionally Formed Their Own Cultures and Improved Their Teaching Competencies Through Research and Practice?

Tetsuo Isozaki

Abstract How have Japanese '*Rika*' (school science) teachers traditionally formed their own cultures and improved their teaching competencies through research and practice? I investigated two historical contexts which may provide keys to illuminate this question: the nation's attitudes towards education and the teaching profession, and the professional cultures of science teachers. For the latter, I focused that how professional cultures, in the case of science teachers, have been formed since the late nineteenth century in Japan through analyzing three factors which have helped to form Japan's professional culture: the contribution of teacher training in higher education institutions, the role of learned societies, and the practice of 'Lesson Study'. And then, I analyzed a case study of science education in the 1960s and 1970s in Japan. Finally, I concluded that in Japan, within the framework of the administrative guidance and control provided by the Ministry of Education, teachers have traditionally and determinedly performed both research and practice. Professional cultures have been traditionally formed as a result of the intellectual claims of educators that they are keen to improve not only their teaching competencies but also pupils' learning. Therefore, we must not ignore science teachers' traditionally accumulated wisdom and expertise based on their enthusiasm and reflective practices as professional cultures in our own country.

28.1 Introduction

In international comparisons such as Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS), Japanese children, along with those from the 'Four Tigers' of South East

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Asia—Taiwan, Hong Kong, South Korea and Singapore (Morley and Robin 1995, p. 173), usually succeed in getting higher scores. There appear to be multiple factors contributing to the success and it is not easy to identify the most important reasons. For example, Green (1997a) stated that 'the high achieving countries appear to have an 'inclusive learning culture' which is characterized by the high premium which society places on *learning for all group*s' (p. 128, italics in original). Green also pointed out that 'it exists as a historical sediment, visible in the cultural norms and institutional practices of the 'learning society' (1997b, p. 297). However, some questions remain: 'Who created such a learning culture in Japan?' and 'How was it created?' These issues have interested a number of policy-makers and researchers.

The publication of *The Teaching Gap* (Stigler and Hiebert 1999), based on the TIMSS Video Study in Japan, Germany and the U.S.A., led to an interest in 'Lesson Study' for many scholars in and outside of Japan and also provided a good opportunity to reconsider its importance for professional development and for establishing a learning culture of teachers for Japanese educators themselves. What is 'Lesson Study' and why are teachers encouraged to engage in it? Is it a traditional professional culture in Japan?

In this chapter, I will investigate two historical contexts which may provide keys to illuminate the issues mentioned above: the nation's attitudes towards education and the teaching profession in Japan, and the professional cultures of *rika* (school science) teachers. Japan has a well-developed educational system in which structure and function have some points in common with Western countries and the 'Four Tigers'. In the tradition and culture of Japan, and in its social context, however, it is possible to identify some characteristics that are particular to the Japanese education system. For example, schools in Japan historically have offered a statutory common curriculum for all pupils under a single-track system. One of the aims in establishing a statutory common curriculum is 'to raise the quality of science teaching in schools and to enhance the accountability of the educational service' (Donnelly and Jenkins 2001, p. 155), and making a common curriculum cannot avoid taking account of teachers' practice. The centralized government, the Ministry of Education, has historically reorganized such a system as it has evolved with social changes, while on the other hand, Japanese 'teachers have created their own occupational culture in the process of innovation of their educational activities at their schools' (Kimura and Iwata 2007, p. 38). In Japan, the culture of teaching, which is regarded as one of the characteristics of Japanese education has been explored by a number of Japanese researchers (e.g. Shimahara and Sasaki 1992; Kudomi 1994; Inagaki and Kudomi 1994; Kimura and Iwata 2007). Unfortunately, however, cultural issues among Japanese science teachers have not been well investigated and very little literature can be found on the topic (e.g. Ogawa 2002, 2014). In particular, Ogawa (2014) identified occupational culture as a means of professional development. However, Ogawa analyzed pre-service teacher training rather than in-service teacher training from a historical perspective. The historical relationship between the central government and teachers is a key point for understanding how Japanese science teachers form their own cultures and improve their teaching competencies. This is the reason why I identified the two historical contexts mentioned above.

In Japanese, '*rika*' means 'school science' or sometimes simply 'science'. Yet, '*rika*' and 'school science' still differ somewhat in meaning and characteristics (e.g. Ogawa 2011; Isozaki 2014). In this chapter, however, I will use 'science' not '*rika*' unless otherwise noted in order to avoid confusion for readers and use the term 'professional' culture in the same meaning as 'occupational' culture. In Japan, elementary school teachers are generally classroom teachers who teach all subjects rather than being subject specialists. In this chapter, nevertheless, the term 'science teachers' includes both elementary and secondary school teachers.

A simplified history of education in Japan was included in the appendix section of this paper to help readers better understand the context of Japanese school culture development.

28.2 The Role of the Japanese Government in Education and the Teaching Profession

28.2.1 The Role of the Japanese Government in Education

Japan is one of those rare nations that modernized rapidly in a short period of the time. In the second half of the nineteenth century, the new Meiji government's intervention was as strong and effective in education as it was in other areas [such as in the economy, civil service and the armed forces (e.g. Shipman 1971)]. Japan became a developing nation using education as a vehicle for state formation. Modernization in Japan, however, was not simply a conflation with Westernization (e.g. Cummings 1980; Marshall 1994; Isozaki 2014).

Per the request of the General Headquarters, which controlled the country at the end of World War II (WWII), the U.S. Education Mission came to Japan to present reports on educational reform. Subsequently, Japan's post-war education reform was carried out based on the mission's recommendations. For example, the centralized control of education was weakened and power decentralized with the hope of achieving a democratic society. However, just after the return of sovereignty in 1952, the democratic educational system was changed. Mizuhara (2011) pointed out that it was 'a return to traditional Japanese education [more] than democratization' (p. 144), but the Ministry of Education (1980) articulated a different view saying that 'some aspects of the democratic education system introduced during the Occupation period were not suited for the Japanese situation with its own particular culture and tradition' (p. 265). As a result, the Ministry of Education re-examined the prefectural and municipal board of education system which had been established in the Occupation period and strengthened the vertical relationship linking the Ministry (central) with those Boards (local or regional) in 1956. The Ministry of Education revised the Course of Study, the national curriculum or standards (which describe the objectives and contents that teachers *must* teach) in 1958. All textbooks from elementary school to upper secondary school now have to reflect the Course of Study, which is based on the recommendations of the Central Council for Education (a body that carries out research and deliberations on important matters related to the promotion of education and other matters in response to requests from the Minister of Education, and which makes proposals to the Minister), and must be authorized by the Ministry of Education for school use.

Green (1997a) argues that ‘these societies [Germany, France, Japan and Singapore] place an exceptionally high value on education both for its potential contribution towards national development and for its enhancement of individual opportunities’ (p. 118). Green also argued that ‘generally, […] national government control over education [not] been weakened by international changes in state forms’ (p. 180). Traditionally, education has been regarded as a vehicle for human development and nation development, e.g. in establishing a modern society in the second half of the nineteenth century and after WWII, and, more recently, in response to globalization.

Jenkins (1997) analyzed policy-makers’ and science teachers’ attitudes to the Attainment Target: Science 1 (scientific investigation) in a former version of the National Curriculum for Science in England and Wales, and concluded that in the absence of clear and authoritative guidelines, it was left to science teachers to turn policy into practice by ‘continuously drawing upon their professional experience and “teacherly knowledge”’ (p. 126). In contrast, however, the Course of Study in Japan describes the aims and objectives of the subject, the content which teachers must teach and the practical work in which pupils should engage. We can say that the Course of Study appears to be constructed as ‘a body of well-defined authoritative knowledge’ (Donnelly and Jenkins 2001, p. 118) to be taught with implications for teaching methods and activities. After the Course of Study is announced, a detailed ‘interpretive document’, edited by the Ministry of Education, is published for educators. Even the so-called *interpretive document*, despite its title, unavoidably carries the authority of official advice. Educators would then interpret the meanings of the aims and objectives prescribed into classroom practice. Of course, when they make this interpretation, they make the most use of their professional experience and professional knowledge base.

28.2.2 ‘Teachers’ and the Teaching Profession in Japan

Andy Hargreaves (2000) traced the history of professionalism and categorized it into four ages: ‘the pre-professional age’, ‘the age of the autonomous professional’, ‘the age of the collegial professional’ and the fourth age ‘post-professional or postmodern?’ These categories, however, may not necessarily apply in Japan. As mentioned above, the historical relationship between central government and teachers in Japan is different from those of ‘Anglophone cultures’ (Hargreaves 2000, p. 153).

The concept of the term ‘teacher’ is complicated in Japan. There are three words that mean ‘teacher’: *sensei*, *kyoushi* and *kyouin*. The first one is used for a person whom people usually look up to, e.g. a medical doctor and a lawyer, but sometimes is sarcastically used. The second term, *kyoushi*, may be a similar concept to the word 'teacher' in English. The final term, *kyouin*, or with the same meanings *kyouyu*, has been used primarily as a legal term. To locate the meaning of teacher, teaching profession and professionalism in Japan is not easy as there have been controversial debates about the issue and various models that described teachers and teaching cultures have been proposed since the late nineteenth century (e.g. Kumura and Iwahashi 1967; Kudomi 1994; Inagaki and Kudomi 1994; Shimahara 1998: Kimura and Iwata 2007). These models of 'profession' may not be completely or exactly correlated with the Western concept of 'profession'.

Before WWII, there was a controversy around secondary school teachers involving professionalism and academism (Isozaki 2001). A 'professional' teacher graduated from a higher normal school (later by universities of letters and sciences established in 1929) and learned pedagogical knowledge and content knowledge, whereas an 'academic' teacher graduated from an imperial university in the main and learned only to deepen content knowledge while ignoring pedagogical development. 'Professional' teachers were criticized for their lack of deep content knowledge, and 'academic' teachers were criticized for their lack of pedagogical knowledge. The two types of teachers were sometimes antagonistic. On the other hand, elementary school teachers were trained only in prefectural normal schools, which was said to be a 'closed system'. Teachers who graduated from normal schools and partially graduated from higher normal schools were derided as 'normal school types' and were criticized for 'hypocrisy, formalism, unadaptability and indecision' (Kumura and Iwahashi 1967, p. 82). Based on the suggestions of the U. S. Education Mission in the Occupation period and the reflection on the 'closed system' of teacher training, the government decided to adopt an 'open system' that was a university-based teacher training system. The Education Reform Commission insisted that teacher training should be carried on in universities and not in normal schools because many of the members of that commission had graduated from imperial universities and not normal schools, higher normal schools or universities of letters and sciences (Miyoshi 1979). As a result of these suggestions and recommendations, the Ministry of Education decided that in every prefecture there should be one national university with a faculty or department devoted to teacher preparation (Ministry of Education 1980, p. 251). However, under the 'open system', many upper secondary school science teachers graduated from science faculties in universities instead of the education faculties, having only studied professional subjects focusing on pedagogical knowledge and pedagogical content knowledge within the minimum requirements of the law. Consequently, these teachers knew far less about teaching than those who graduated from educational faculties. It can be said that teacher training reform for upper secondary school teachers after WWII was strongly affected by the academism and 'intellectualism' (Kimura and Iwata 2007, p. 26) of the pre-war period.

Within the framework of the administrative guidance and control provided by the Ministry of Education, Japan's teachers have traditionally and determinedly performed both research and practice. This was a kind of 'licensed' autonomy

(Dale 1988). Andy Hargreaves (2000) pointed out that 'Many influences have forged it [a professional culture of collaboration] into existence' (p. 163) since the later 1980s. As we will observe later, however, this 'professional culture of collaboration' emerged earlier.

28.3 Professional Cultures in Japan

David Hargreaves (1982) defines the culture of teaching as follows:

> Most jobs, in other words, are located within an 'occupational culture' with which we must come to terms – a set of beliefs, habits, traditions, way of thinking and feeling and relating to others that are shared and understood by those already in the occupation. This occupational – culture, so obvious and taken for granted by the initiated members, is often obscure, mysterious and difficult to learn to the tiro. (pp. 192–193).

Andy Hargreaves (1992) asserts that within the cultures of teaching there are two notions: contents and form:

> The *content* of teacher cultures consists of substantive attitudes, values, beliefs, habits, assumptions and ways of doing things that are shared within a particular teacher group, or among the wider teacher community […]
> The *form* of teacher cultures, rather, consists of characteristic *patterns of relationship* and *forms of association* between members of those cultures.
>
> (Hargreaves 1992, p. 219, italics in original)

There seem to be two key points for thinking about the professional cultures of teachers: the first one posits teaching as a profession having its own culture, the second one suggests that novice teachers need to have an opportunity to be mentored by experienced teachers or colleagues to learn the explicit and hidden norms of a professional community. Why and how have teachers organized their relationships within professional communities or schools? In this section, I will investigate how professional cultures, in the case of science teachers, have been formed since the late nineteenth century in Japan through analyzing three factors which have helped to form Japan's professional culture: the contribution of teacher training in higher education institutions, the role of learned societies, and the practice of 'Lesson Study'.

28.3.1 The Contribution of Teacher Training in Higher Education Institutions for Forming Professional Cultures

In 1929, universities of letters and sciences with two faculties were established and attached to each Higher Normal School in Tokyo and Hiroshima in order to educate secondary school teachers and academic researchers.

Educators of the Tokyo and Hiroshima Higher Normal Schools and their attached secondary and elementary schools had contributed to developing professional cultures before WWII. For example, Gentaro Tanahashi (1869–1961) and Chinji Ohshima (1874–1960), both graduates of the Tokyo Higher Normal School and studied in the West during their careers, introduced Western ideas and methods of science teaching into Japanese schools. They were distinguished leaders and practitioners of science education before WWII.

The most important historical contribution of Tanahashi and Ohshima was their introduction of the heuristic method by British scientist Henry E. Armstrong (1848–1937). Having thoroughly studied the heuristic method, they published some important science teaching books for teachers involving heuristic methods (e.g. Tanahashi 1913; Ohshima 1922). When the Ministry of Education organized a committee to draft a physics and a chemistry syllabus that included experiments for boys' secondary schools and normal schools, in September 1917, Tanahashi, whose academic back ground was natural history, played the most important role within that committee. Notably, other members of the committee were also well-reputed physics and chemistry educators of Tokyo Higher Normal School and Tokyo Higher Normal School for Women. In contrast, Ohshima worked at Hiroshima Higher Normal School at that time, and was engaged in promoting laboratory work based on the heuristic method through workshops, editing textbooks and lecturing (see, for example, Terakawa and Brock 1978; Kataoka and Isozaki 2003). In the immediate years that followed the end of WWII, professors who graduated from Tokyo Higher Normal School and/or Tokyo University of Letters and Sciences (Now the University of Tsukuba) played important roles for the founding of learned societies promoting science education.

On the other hand, elementary and secondary schools attached to normal schools in every prefecture and higher normal schools played important roles in the formation of professional cultures. Higher normal schools, and normal schools, and also their attached schools, organized subject study groups and published educational periodicals in order to convey research results that were based on their classroom practices, timely educational topics, and their opinions or research perspectives to their counterparts either in their particular region or across Japan.

The departments of science of higher normal schools organized study groups (physics and chemistry, natural history, and science as a whole) to support research and practice on science teaching. They edited and published secondary school science textbooks authorized by the Ministry of Education. The secondary school attached to Tokyo Higher Normal School edited a journal *'Chuutou rika kyouiku'* (it later changed its name to '*Rika kyouiku kenkyuu*'—*Secondary Science Education*). According to the preface of the first issue, the department of science organized study groups: physics and chemistry, and natural history, and held meetings every week for more than 10 years. At the meetings, one teacher would present his research and discussed with his colleagues on how to improve their teaching competencies (Rika kenkyuu-kai 1933, p. 1). Every issue of this journal included research papers on teaching materials and teaching methods based on teacher practices and ideas. It also included the records of research lesson plans given by teachers and reports of reflective meeting/conferences. Attached schools to normal schools and higher normal schools provided an opportunity for teachers to take part in open-house Lesson Study and exchange information on education including science.

Additionally, normal schools and higher normal schools in general, organized their own alumni associations. These associations played the role of a learning community for their graduates through publishing bulletins to share and exchange ideas and information on education. On the other hand, school nepotism among graduates was ‘an obstacle to resolving disputes about the teaching profession’ (Miyoshi 1979, p. 29).

Since the Meiji era, normal schools and higher normal schools and their attached schools (before WWII), and educational faculties and universities of education (after WWII) have played a significant roles in improving science education and their graduates formed professional cultures.

28.3.2 The Role of Learned Societies (Academic Associations and Voluntary Educational Research Organization) for Forming Professional Cultures

Learned societies in Japan may be divided into three categories: academic associations, voluntary research organizations and others. The academic association or society is an organization that aims to promote an academic discipline or profession. Many of these associations have been designated as academic learned societies by the Science Council of Japan. Their activities normally include regular conferences or meetings for presentations, discussions and workshops of members’ research results and editing periodicals and books in their discipline. There are several associations relating to science education, e.g. the Society of Japan Science Teaching (founded in 1952), the Japan Society for Science Education (1977), the Physics Education Society of Japan (1952), the Society of Biological Sciences of Japan (1947) and the Japan Society of Earth Science Education (1948). The Chemical Society of Japan (founded in 1878) has a long history of chemistry education as well as other societies mentioned above. The origin of pan-Japan learned societies established by science teaches for science teachers dates back to 1918 for elementary school teachers and 1926 for secondary school physics and chemistry teachers. Those pre-war associations’ activities were similar to those of contemporary academic associations, including discussing and advising on matters brought forth by the Ministry of Education as well as making proposals to the Ministry. The pan-Japan learned society ‘*Dai Nippon kyouikukai*’ (Pan-Japan Education Society) was established by educators for educators in 1883. Both pan-Japan science education associations and regional science education groups were organized by science teachers. Science teachers were also engaged in self-improvement of their teaching competencies through taking part in such learned societies before WWII.

Table 28.1 The strands of the annual meeting of SJST in 2013

A: Science teacher education	H: Environmental education, STS and Integrated studies
B: Science education in the world	I: Physics teaching and materials development
C: Science curriculum and curriculum development	J: Chemistry teaching and materials development
D: Ideas and history of science education	K: Biology teaching and materials development
E: Research lessons and instruction	L: Earth science teaching and materials development
F: Learning psychology and assessment	
G: ICT	

Table 28.1 shows the general strands of the annual meeting of the Society of Japan Science Teaching (SJST) in 2013. The strands cover the whole area of science education. These strands have changed little since the 1980s.

On the other hand, there are also voluntary educational research organizations that are sometimes called ‘Circles’, in which teachers and university researchers are considered as equals. These organizations are not designated as academic learned societies by the Science Council of Japan. There are many types of organizations, ranging from regional to national organizations. While some of them have criticized the Course of Study, others have been informally connected with the Ministry of Education and local Boards of Edducation. For example, *Kagaku kyouiku kyougikai* (Association of Science Education: ASE) (established in 1954), *Shotou rika kyouiku kenkyuukai* (Association of Elementary Science Education: AESE) (1961) are both pan-Japan learned societies and their activities are basically similar to academic associations. However, one of their activities, which differed from academic associations, is that they give one or 2-day seminars including Lesson Study, forming what can be called ‘a community of practice’. Shigekazu Takemura (1936–), who was a former elementary school science inspector of the Ministry of Education and strongly committed to the AESE, identified the important role of the AESE as follows:

> The AESE had originally developed voluntary educational research (in Japanese *Minkan kenkyuu undou*) without being affected by the American educational movement based on academism, and had accumulated practical wisdom of every teacher. By taking elementary teachers’ the ideas of their own science lessons into consideration, we had developed the tradition where elementary teachers focused on and engaged in studying a specific lesson. When analyzing those data, we did not employ high-order statistical analysis, but focused on case studies instead. By recording every child’s learning processes and based on the child’s characteristic self-description, we had improved reflectively our own teaching and education as a whole. We had explored how experiences and ideas of different kinds of children affected their learning and how it was deepened. Teachers had improved children’s learning by a kind of virtuosic improvisation without designing a lesson plan.
>
> (Takemura 2009, p. 205: translated by the author)

This range of research topics was not unique to AESE; the ASE took a similar approach as the following quote indicates, even though their stances towards the Ministry of Education and the Course of Study were adversarial:

> In the 1950s, teachers made use of actual lesson records and analyzed two kinds of situations: situations where children did not understand the matters considered by the teacher to have been taught well, and situations where children understood well when the teacher thought the children could not understand. In addition, studies that identified the mechanism of children's errors and cognitive processes were already presented in this period.
> (Suda and Ohno 2011, p. 62)

Both of the quotations above indicate that research on children's cognitive processes and on conceptual change had already been started in the 1950s and 1960s by educators in Japan. These empirical research studies, conducted within voluntary educational research organizations, are not only on children's cognitive processes but also on researching and developing teaching materials, and teaching methods as well. Unfortunately, reports of the research were not written in English and are not known outside Japan.

There have been other organizations that have aimed to promote science education through supporting science teachers. For example, *Zenkoku Shougakkou Rika Kenkyuu Kyougikai* (All Japan Research Council for Elementary School Science) and *Zenkoku Chuugakkou Kenkyuu Kyougikai* (All Japan Research Council for Lower Secondary School Science), both of which involve cooperation between every prefectural science education group and administrative organization. They hold an annual meeting including Lesson Study and a lecture by the science inspector of the Ministry of Education. Some private enterprises have founded an educational organization to support science education, e.g. SONY and MAZDA.

Most of the above-mentioned associations and organizations, which I call the factors, commonly provide teachers with learning opportunities as follows: (1) holding an annual meeting to present research results, exchange information and knowledge, and discuss science teaching and other educational issues, (2) editing and publishing periodicals and books consisting of academic and practical-based papers by teachers and researchers, (3) delivering special lectures by scientists, educators, school inspectors or senior specialists on the science curriculum of the Ministry of Education and others and (4) providing Lesson Study. Historically, Japanese science teachers have taken part in these activities formally or informally. They have also formed a professional culture of collaboration through the wide range of professional communities to develop a common purpose, and have improved their own teaching competencies.

Finally, I have to refer to another factor promoting science education in Japan. This factor can be called 'a professional culture of publication', whereas learned societies have published their own periodicals and books for members and the public, many private publishers have traditionally edited magazines for teachers and children and published large numbers of books ranging from academic research to manuals for science teaching since the late nineteenth century. Traditionally, science teachers have got a lot of significant information and knowledge aimed at improving their competencies through not only reading these publications but also through professional networks such as professional communities.

Through analyzing the history of the Association for Science Education in England, Layton (1984) pointed out that 'a profession can be interpreted as a means of controlling an occupation' (p. iii). To borrow that discourse, I would state that 'a profession can be interpreted as a means of forming cultures in Japan'.

28.3.3 The Practice of Lesson Study as a Professional Culture

The most popular venue for doing Lesson Study is commonly known as *Kenshū.* Horio (1988) described '*Kenshū* (in-service teacher training) as a legally constituted term. It is a construction of *kenkyū* (research) and *shūyoū* (training or cultivation)' (p. 270). The term 'Lesson Study' is a literal translation of the Japanese term *jyugyou kenkyuu* (or *kenkyū*) which is composed of two words: *jyugyou,* which means lesson*, kenkyuu,* which means research or study.

Historically in Japan, Lesson Study has been a routine practice of the teaching profession—used in both in-service teacher training and also pre-service teacher training. The origin of Lesson Study can be traced back to the Meiji era (1868–1912), particularly the 1870s and the 1880s following the Meiji Restoration. Lesson Study is culturally and historically embedded and is ingrained in Japanese teachers' professional identity. Nakano (2011), who explored the 1960s situation of education and movement of Lesson Study, stated that 'there is the professional ethics of teachers and researchers as educators in it [Lesson Study]' (p. iv).

In general Lesson Study may typically be divided into three parts: a preparation phase, a research lesson and a reflective meeting/conference.

In initial teacher training, an example of the Lesson Study process takes place during teaching practice in school. Student–teachers are encouraged to learn many things, e.g. what teaching involves, what the teaching profession is, how to make a lesson plan and a scheme of work, and how to do *kyouzai kenkyuu* (research and develop teaching materials) and to do practice within a professional community. Trainee teachers experience some aspects of Lesson Study with other student–teachers during their teaching practice. Through this process, student–teachers gradually become familiar with the processes of Lesson Study including *kyouzai kenkyuu*.

Since the Meiji era Lesson Study in in-service teacher training has been conducted in a number of ways and varies by provider (such as central and local governments, and learned societies). Science teachers in secondary schools often engage in researching and developing new teaching materials for a research lesson during the preparation phase. Their intention is to try to find new and appealing teaching materials focusing on the scientific investigation using practical activities. Elementary school teachers often tend to focus on problem-solving processes. The teacher who will give the research lesson makes and revises a lesson plan based on discussions with colleagues and advisors. In general, a Japanese lesson plan provides the teacher and observers with a platform that includes the scientific and educational values implicit and explicit within the lesson. One of the science teachers would give the research lesson in the laboratory based on the revised lesson plan. Other teachers, including other subjects teachers in his/her school and other schools' teachers outside his/her school, use the revised lesson plan as a guide for comment and critique and collecting data, taking notes and observing the focus on the teaching and learning. Many science teachers in secondary schools who give a research lesson are eager to employ the inquiry-based approach: encouraging students to make a prediction or hypothesize, conduct experiment, obtain data and induce a law or principle from those data. A reflective meeting is based on the evidence collected during the research lesson. Sharing the results of Lesson Study can be done in several ways including writing a report or a school bulletin. Through these processes, science teachers acquire a sense of identity and of belonging to a professional community with shared norms (Isozaki 2015, p. 616). Japanese science teachers cannot be considered merely in terms of their individual performance in their specialty, but should rather be considered in terms of their collegiality.

Lesson Study can build an effective collegial relationship within or across a school and should be one of the keys to solve real problems in classrooms, and the results of Lesson Study can be reflected in everyone's teaching. Through Lesson Study, collaboration within a professional community can be seen as a useful vehicle for teachers to improve their teaching competencies. Lesson Study helps to build a learning community or professional community and, therefore, it may help in the formation of a professional culture that provides opportunities to share the dominant values of science education. However, there are both benefits and disadvantages in Lesson Study, e.g. while Lesson Study is a useful vehicle to spread an ideal model of teaching science so that many science teachers may utilize it, science lessons may become more fixed, standardized and rigidified, and the values shared by science teachers sometimes lag behind the latest research trends (Isozaki 2015, pp. 617–618).

Lesson Study is a traditionally embedded culture of teachers and may provide significant opportunities for not only novice science teachers but also experienced science teachers, because they can reflectively learn something new that he/she wishes to acquire from colleagues and others. Of course, professional growth is naturally embraced by teachers and is encouraged not only through Lesson Study, but also other learning activities taking place in the daily life of the school and through reflective conversations. These are important traditional features based on a culture of an effective professional community (Isozaki 2015, p. 618).

It is noteworthy that in Japan, especially in secondary schools, science teachers belong to a subject department and are also organized into grade units cutting across subject boundaries to deal with common issues and tasks pertaining to a particular grade level, and they also have other responsibilities in school such as school management, research promotion, student counselling, school sports club instruction and communication with people in school community. Therefore, science teachers in secondary school can understand students' characteristics as a whole, not only through their performance in science lessons but also through other school activities such as pastoral care and tutoring classroom students (Isozaki and Isozaki 2011, p. 37).

28.4 A Case Study of Science Education in the 1960s and 1970s

The 1960s and 1970s formed one of the most important ages in the history of science education in Japan. We can observe many unique phenomena that may be not similar to other countries.

The mid-1950s to the 1980s is known as a period of 'curriculum reform' (e.g. Bybee 1993; DeBoer 1991) in the U.S.A., 'curriculum innovation' (Waring 1979), 'curriculum development' (Ingle and Jennings 1981) and the 'Nuffield Science Teaching Project' in the U.K. However, in Japan, the expression used was '*Rika kyouiku no gendaika*', which means 'modernization in science education'.

The Ministry of Education adopted three ways of improving science education in the 1960s and the 1970s: revising the Course of Study for science from elementary school to upper secondary school; supporting in-service teacher training programmes and the establishment of prefectural science education centers; and, establishing a special budget for scientific research, including science education.

The Ministry of Education revised the Course of Study for elementary and lower secondary schools in 1958 and for upper secondary school in 1960, based on the criticisms by teachers of the previous version. Just after the revisions, the Western 'education reform movement' had a significant influence on secondary science education in Japan. After planning changes for 10 years, the Ministry of Education revised the Course of Study for lower secondary school science in 1969 and for upper secondary school science in 1970 focusing on the logical structure of the disciplines and the processes of science. The key word in the Course of Study was 'inquiry'. In contrast, we can scarcely observe such influence on the revised Course of Study for elementary school science in 1968 and, the key word of the Course of Study for elementary school was 'problem-solving'.

Second, the 'Science Education Promotion Law' was enacted in 1953. As a result, all schools that wanted to improve their scientific facilities to satisfy national criteria could apply for a national subsidy that would meet part or all of the costs to do so. By the order of this law, the Science Education Council was organized within the Ministry of Education. The council often submitted proposals and reports concerning the promotion of science education in the mid-1950s and the 1960s. As a result of these proposals, science education centers, which aimed to give in-service teacher training programs including Lesson Study for science teachers in every prefecture, were established with financial support from the Ministry of Education after 1960. Staff members of science education centers were school science teachers called 'consultant teachers', who would work for several years in the center before returning to schools and play important roles in improving science education in their regions. The centers had three roles: providing in-service teacher training programs, researching science teaching, e.g. researching and developing teaching materials and teaching methods, and spreading ideas and the results of research through publishing bulletins. Also, the Ministry of Education established the 'Science Education Center' in 1972 within the National Institute for Educational Research (now National Institute for Educational Policy Research). They organized an effective network called the 'National Science Education Center Council' and held a meeting every 2 years that included presentations of science teachers' research and practice, discussions and the exchange of information on science education. These activities were an effective element in the continuing professional development of science teachers. Advised by the Science Education Council, the Ministry of Education and Prefecture Boards of Education had managed the '*Rika kyouiku gendaika kouza*', which means 'course of the modernization in science education', since 1968 for in-service teacher training that enhanced and extended the previous courses focusing on practical work.

Finally, advised by the Science Education Council that scientists and educators cooperate in carrying out a systematic research on science education (Ohashi 1980, p. 19), the Ministry of Education budgeted for special scientific research on science and mathematics education.

As mentioned above, the Ministry of Education backed up these initiatives on science education with enthusiasm and financial support in the 1960s and the 1970s.

The curriculum reform and development from the mid-1950s to the 1980s had been an initiative of groups of scientists with financial backing of the U.S. National Science Foundation (DeBoer 1991, p. 147). By contrast, in the U.K., the Nuffield Science Teaching Project work was carried out 'by teachers for teachers' (Ingle and Jennings 1981, p. 24). Like other non-Western countries, Japanese science educators had not developed its own science curriculum such as those in the U.S.A. and the U.K. in the 1960s and the 1970s. Educators and scientists had translated the U.S.A. and U.K. curriculum materials into Japanese and they carried out practical work using textbooks and laboratory manuals aimed at adapting to Japanese science classes. According to Kurita (1981), Japanese science educational associations and other organizations invited members of the U.S.A. (Physical Science Study Committee, Chemical Bond Approach, Biological Sciences Curriculum Study, Chemical Education Material Study, Earth Science Curriculum Project, Introductory Physical Science and Intermediate Science Curriculum Study) and the U.K. (Nuffield Physics) projects in order to provide seminars to educators and scientists. Those seminars were held over several days and included not only lectures but also demonstrations, practical work and discussions (Kurita 1981, p. 77). In Japan, the '*Rika kyouiku no gendaika*' (the modernization of science education) was strongly promoted via cooperation between the Ministry of Education and educators including teachers.

Ganiel (1995) highlights the Israeli experience in the 1960s and the 1970s which offered valuable lessons:

> adaptation of a course from a different country, different culture, and different educational system is generally not a very useful practice. Certainly it makes good sense to learn from

colleagues in other countries, and it would be foolish not to build on accumulated wisdom and expertise. But simple translation is not the way to go. (p. 38)

It is noteworthy that the influence of the U.S.A. and U.K. projects on the Course of Study for elementary school science was quite limited in comparison to their influence on the Course of Study for upper secondary school science (e.g. Takemura 2009, p. 211; Kurita 1981, pp. 81–82). Of course, the Ministry of Education and educators did not ignore Western projects aimed at elementary school science. Elementary school teachers, however, have traditionally accumulated wisdom and expertise based on their enthusiasm and reflective practices as part of their professional culture. In the 1960s and 1970s the Japanese term equivalent to modernization was ‘*gendaika*’, but it did not mean the same as ‘reform’ or ‘innovation’, indicating that perhaps the Japanese may have not deepley reflected the true meaning of the curriculum reform or innovation as implemented in Western cultures.

Figure 28.1 shows teachers’ roles and organizations which control and support teachers.

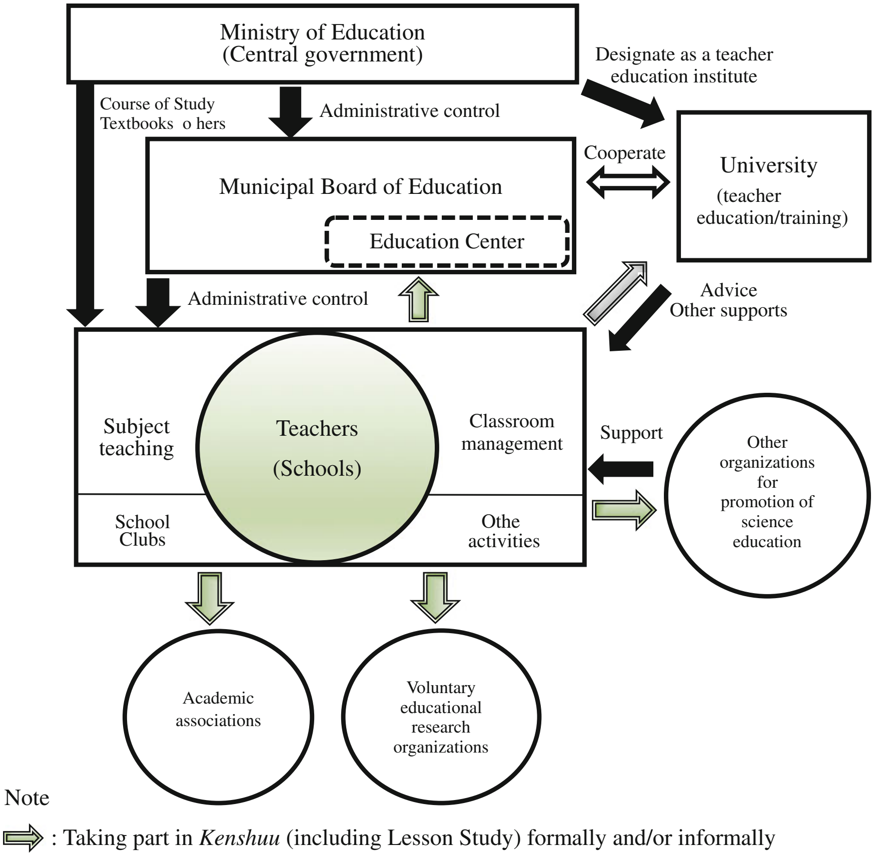

Fig. 28.1 Teachers’ roles and the relations between teachers and organizations which support and control them after WWII

28.5 Conclusion: *Challenge and Opportunity for the Globalization of Science Education*

What is the modern social circumstance for the teaching profession? Andy Hargreaves (2000) has argued that the postmodern is driven by two major developments in economics and communications (p. 167). One of the key words is 'globalization'. There is no doubt that education can be ranked among the chief concerns of nations as it can play many roles in preparing children for the future in globalization. In recent years, Japan's central government has produced action plans in response to globalization from elementary education to higher education, e.g. enhancing and improving English education in elementary and secondary schools.

What is 'globalization' and is it definable? The word 'globalization' may be often used as little more than a vague fashionable term without a concrete meaning. There are several discourses on the definition of globalization, e.g. Giddens (1990), Featherstone (1990), Tomlinson (1991, 1999) and Green (1997a). However, to correctly define globalization is quite difficult because 'globalists are still controversial and speculative' (Green 1997a, p. 156). Tomlinson (1999) critically reviewed many discourses of globalization from the perspectives of economics, politics and culture. Green analyses globalization from the perspective of education, and criticizes discourses of globalization and postmodernity. Finally Green concludes:

> For all the postmodern protestations to the contrary, and despite the effect of globalizing trends, governments across the world still exercise considerable control over their national education systems and still seek to use them to achieve national goals. […] in the majority of countries government still see education as a process of national-building which involves both economic and social objectives.
>
> (Green 1997a, p. 181)

According to Green's notion (1997a), some of Japan's action programs mentioned above may be categorized into 'internationalization' not globalization. If there is one common approach for analyzing globalization between Tomlinson (1999) and Green (1997a), it may be 'historical'. Tomlinson makes an important point in that 'the key to understand the cultural globalization which Japan is currently experiencing is the deeper portion of a move that Japan has built the distinct form of non-Western modernity since the Meiji era' (Tomlinson 1999 transalted into Japanese by Kataoka 2000, p. 9).

There are other important points employed in discourses on cultural globalization in order to understand the non-Western modernity of Japan. For example, Morley and Robin (1995) argued that 'every culture has, in fact, ingested foreign elements from exogenous sources, with the various elements gradually becoming "naturalised" within it' (pp. 129–130). Tomlinson (1999) pointed out that culture simply does not transfer in a unilinear way, and cultural movement includes interpretation, translation, mutation, adaptation and 'indigenization' (p. 84). Through analyzing the early history of *science* education in Japan (Isozaki 2014) and developments in the 1960s and the 1970s in this chapter, the notion of 'recontextualization' (Brannen 1992, 2004; Isozaki 2014) may be more suited for the case of *science education* in

Japan rather than the notion of 'naturalization' and 'indigenization'. Science teachers in Japan have been affected by the Ministry of Education and prefectural and municipal Boards of Education to which they belong, but they have traditionally, formally and informally, formed their own professional cultures through educational activities that included Lesson Study in schools and learned societies since the second half of the nineteenth century. The responsible attitudes of the Ministry of Education and Japanese teachers' professional cultures within licensed autonomy were able to build *rika* independent of Western science education.

In response to globalization, how Japanese science teachers have developed their teaching competencies within the professional cultures that teachers have traditionally formed, may be a good example for non-Western countries to reflect on their research and practice on science education within their cultural context for their continuing professional development.

However, as Andy Hargreaves (2000) points out 'Market principles have become embraced so strongly by many governments, that schools (like many other public institutions) have been rationalized, […] set in competition against one another for "clients"' (p. 168), and Japan is no exception. 'The neo-liberalistic trend of educational reform since the mid-1980s is gradually modifying the traditional culture of teachers such as their social status and occupational roles, based on people's criticism of teachers' (Kimura and Iwata 2007, p. 39). As a result, the collegiality shared among teachers based on traditional professional cultures has been gradually diminished by such influences. Japanese secondary teachers, who have multiple-characteristics, e.g. subject teacher, instructor of school club and counselor, are so busy due to assessment criteria, the revised Course of Study and paper trails of accountability, therefore it is more difficult for them to find time to conduct research than before, especially when compared to the 1960s and 1970s. Additionally, science teachers have faced the crucial problem that the international comparisons clearly show that Japanese children's attitude towards science are always very negative like some of the 'Four Tigers'. The struggle to solve these problems and to improve teaching competencies for both themselves and children's learning is a mantle of responsibility that falls on all educators.

Professional cultures have been traditionally formed as a result of the intellectual claims of educators that they are keen to improve not only their teaching competencies but also pupils' learning. The professional cultures of science teachers are characteristic of science education as a domain of human activity. They should be adapted or modified taking into account of any changes in the social context that may require a different set of knowledge and competencies compared to those fostered by the existing Course of Study and political demands for accountability. Nevertheless, professional cultures should not be ignored, because they have been enthusiastically and traditionally formed by teachers. Whereas we need to learn from other countries in order to solve such problems and get information on research trends, and we should also correctly and carefully understand not only contents and methods written in documents but also the philosophy and sometimes the hidden meanings or messages of foreign science projects as a whole. However, the case study of science education in the 1960s and the 1970s in Japan described in this chapter shows that we must not ignore science teachers' traditionally accumulated wisdom and expertise based on their enthusiasm and reflective practices as professional cultures in our own country.

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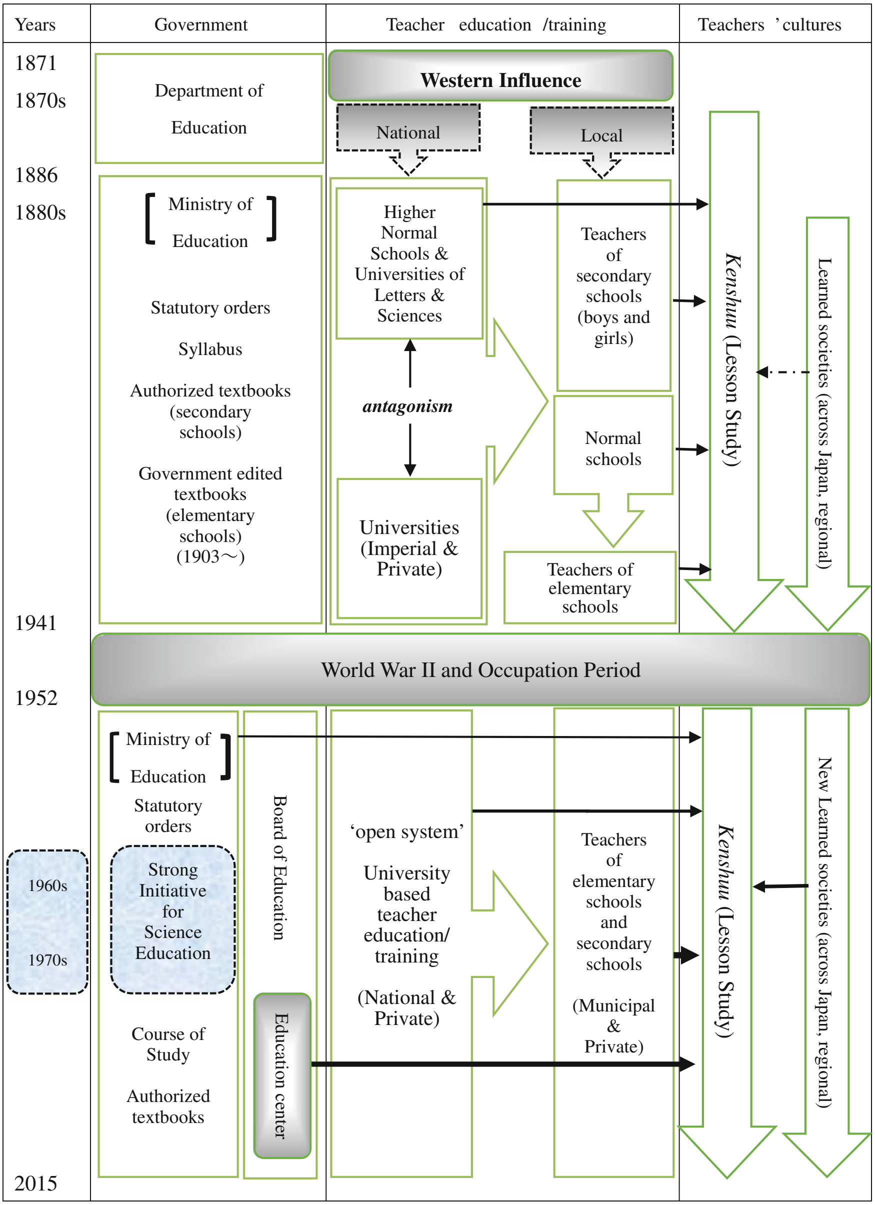
Appendix



Figurer: A simplified chronology of science education and professional development in Japan

A simplified chronology of science education and professional development in Japan

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Chapter 29
From Schools to Nature: Bridging Learning Environments in Israel

Tali Tal

Abstract This chapter portrays the history of out-of-school education in Israel from the early 1900 to the 2000, and the changes from ideological natural history education to modern science-education. Historical documents are presented that show the unique blend of romantic views with progressive education thought and how this blend had an impact on Israeli outdoor education for decades. In 1960, the new science curriculum shifted at least part of the out-of-school learning into more inquiry-learning oriented. In parallel, teachers became less engaged in their students' out-of-school learning, while informal science and environmental organizations offer their services to the education system. This trend discourages teachers from being more involved and acting as mediators between their students and professional guides and between the school and the out-of-school learning environments. This historical interpretation of the place of out-of-school learning in Israel could be relevant to other places in which accountability considerations become more central now-a-days.

> The school year at Netaim School began yesterday. We are on our way back from our first field trip with the first-graders and their parents. We started out in the dunes near Ashdod in the afternoon, without the parents, and we spent the entire night in the dunes, after the students got their "route pin" and after they each signed the school's convention. This is how they experience the unique spirit of the school (M., the Principal, *Facebook*).
>
> Second grade is taking care of Yossi today – the biggest African elephant in captivity. First, we spread out food and enrichment objects (toys etc.) for him in the yard before he went out, and after he went out, we cleaned his sleeping area - a real pleasure! All I had to do was convince the students to abandon all the work tools, and just clean his droppings with their hands (wearing gloves). What a joy! (M., Principal, *Facebook*).
>
> "Netaim Elementary School (grades 1-8) has a school-based curriculum that is focused on environmental education. The students go on several field trips per year, and the principal's belief is that outdoor activity in general, and in the countryside in particular, contributes to her students in the cognitive, affective, and social aspects. The school makes use of local

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> resources: the biggest zoo in the country, and a natural history museum, both of which are in walking distance, and an educative agricultural farm. The school yard is designed as an ecological garden. Teachers can get a teaching job in Netaim, only if they like to be in, and teach in, natural environments" (interview with M., the Principal).

These short vignettes of a school principal represent an atypical school, and an atypical principal who holds clear ideas on how field trips should be integrated, and how students should be engaged. This principal bases her beliefs on the history of field trips in Israel and the way they have contributed to education.

This chapter will begin with a description of this unique history and then will continue with the history of research on outdoor education. Finally, I will describe current research on bridging school learning with learning in natural environments.

29.1 History of Out-of-School Learning in Israel

The history of out-of-school learning in Israel is as long as the history of the Hebrew school. Unlike field trips in other countries, they have a strong national value, in addition to other more common international aims. In Israel, the field trip became a central means to creating a new nation. It was influenced by trends that were developed in Germany in the nineteenth century as part of a romantic youth movement ideology, and by progressive educators who immigrated to the country from Russia and other Eastern European countries during the early 1900s.

In 1903, the first meeting of the Hebrew Teacher's Union took place in the village of Zichron Yaakov. The keynote speaker who addressed the program of a rural school was Haim Vilkomich, a teacher from the Galilee region. He began with the physical structure of the school, but mainly described how the school yard is used for leisure and physical activity. He described the school garden, in which students and teachers work together, and added that while working hard and strengthening their muscles, the students acquire moral values. Then he talked about the out-of-school learning experience:

> For the benefit of physical and moral education, we will have field trips as well. Once or twice a month, the teachers will walk to one of the towns or the villages. While walking, they will climb mountains and cross valleys, run, sing and laugh. Their muscles will get used to the long walks, their eyes will adapt to recognize everything from a distance, their vision will improve and their blood will be purified by the clear, clean mountain air. They will come back from the field trip tired but happy and admire everything they saw and learned … (free translation from Gertel 2010).

Vilkomich then ties everything to one theoretical perspective, influenced by natural pedagogy.

> In this progressive school, natural pedagogy is employed that leads from the simple to the complex, from the easy to the more difficult, from concrete to abstract, and from the particular to the general. Let's take, for example, the plant sciences. It is obvious that school is not the right place to learn, but rather the yard with all its trees, and the gardens of the village. The teacher does not begin with the roots that are hidden, but rather, from the

> branches, foliage and flowers. The teacher picks leaves, mixes them, and then asks his students to identify and compare them … if only one out of ten or twenty students will answer, if the teacher discusses properly with them, he will make all the students observe and identify size, color and pattern, which is the target and the essence. After such a discussion and activity, the teacher does not need to ask them to memorize. With no further requirements, they will continue thinking and learning wherever there are plants.

Although not all teachers attending the meeting in 1903 agreed with this vision, some because of the belief that field trips waste too much time, and others because of inadequate natural history knowledge, this very early integration of school and out-of-school learning has further developed as a backbone of the developing Hebrew and Zionist education (Stahl 1981, in Hebrew). Part of this education was inspired by the vision of creating a new version of the Israeli Jew who differs from his ancestors who were detached from the land and nature while in exile.

Already in 1907, the Teachers' Center of the Teachers' Union, which was established 4 years earlier, defined three types of field trip which were to be adopted in schools: "science field trips" in the school's local environment, to teach concepts related to the curriculum; six "pleasure field trips" to more distance places, also related to what is being taught in school; and one "annual field trip" of a few days, to learn about the regions of the land of Israel (Dror 2011, in Hebrew). National values were central to the philosophy of these field trips, as reflected in the writings of the teacher and naturalist, J. Margolin (1877–1947):

> We, the nation that has been torn from its land and nature for two thousand years; we walk in this abundance and happiness as foreigners and dreamers with a lack of orientation and habit of observation, and lack of knowledge. Knowledge which is acquired while out in the wild for hundreds of generations and hereditary from father to son. Therefore, we are obliged to seek and find the way of nature around us and get to know it, because occasional field trips, or even life itself in nature, are not enough to provide clear and accurate knowledge of the flora and fauna and to create feelings of connection to them (from the introduction to *Education for Nature, the Theory of Margolin* 1957).

Again, the field trip to natural environments is viewed as a way of learning (about the flora and fauna), but more so, as a transition from European urban life to living in harmony with nature and becoming attached to the land. Margolin was not only teaching; he established the first professional development (PD) programs for teachers in biology education—then natural history education—and in 1930, he functioned as a teacher-educator who traveled from one school to another to support the teachers. Equipped with a microscope and a little lab, he spent one week in each village or kibbutz. The morning hours were dedicated to field trips and biology education in the schools, and the evenings were dedicated to teaching agricultural botany to the adults. Friday evenings were spent in Sabbath social gatherings, when people sang about nature in the land of Israel.

As evident in the above quotes, the field trip became not only a central means to teach about the environment, but also to develop new set of values which were influenced by the natural pedagogy on the one hand, and by national-Zionist thought on the other hand. Apparently, these two motives still shape the current policy of the Israel Ministry of Education regarding field trips. However, the two sources of influence existed long before the State of Israel was established in 1948, and before any formal policy was formulated. An interesting example of an attempt to design an 8-year sequence of field trips is described by Gertel (2010, in Hebrew) from a program published in Tel Aviv in 1931. This sequence from 1st to 8th grades is characterized by the increased distance from school and by the natural history and national topics. Only in 8th grade did the students visit the desert and probably learned about archeology too. In the mid-1930s, the first policy documents appeared. These documents clearly stated that the field trip program cannot be separated from the school curriculum and that field trips should be educative as well providing opportunity for social interaction and esthetic experiences.

A more modern science education orientation can be found in the writing of another teacher-educator, Menachem Zaharoni. Although Zaharoni (1970) uses some of the older national narrative, he refers to educational theory in supporting outdoor education.

> Only through direct observation can one construct correct and clear concepts. One who does not know his land and does not construct correct conceptual understanding through observing its life and nature, cannot understand the world. Meaningful learning is possible only through critical observation using all the senses, analyzing and examining the sensual information in a critical way. Accumulation of controlled observations allows generalization… through investigating the students' environment – the natural history and the land of Israel – geographical images and conceptions are developed, which are a prerequisite for understanding other countries.

This quote could be seen as a transition from focusing on nationality and romantic reasoning to an approach that examines how outdoor education contributes to meaningful learning, understanding complex phenomena, and developing thinking skills.

29.2 From Nature Education to Science Education

Until the 1960s, nature education was the leading theme, especially in elementary schools. Although the main goal specified in the "nature and agriculture curriculum" was: "students will recognize laws and order of natural phenomena and will acquire methods of observation and scientific thought", which no science educator would criticize today, the objectives which would probably not be acceptable nowadays were:

- provide students with knowledge and the ability to work in agriculture
- nurture an intimate relationship with the land, and the desire to work in agriculture, in terms of pioneering fulfillment, creation of the homeland, and protecting the State of Israel
- instill in students the recognition that agriculture is the primary foundation of our nation's economy, and it is one of the main means in the revival of a healthy nation upon its land.

During the 1960s, two processes made a substantial impact in Israel: first, a national education reform that cut the schools into elementary (grades 1–6); lower secondary (junior high school: grades 7–9); and upper secondary (grades 10–12). Secondary school teachers were required to specialize in specific disciplines and to hold a university bachelor's degree and a teaching certificate. Second, changes in the science curricula in the USA that promoted inquiry-based learning and bringing in scientists to make an impact on the curriculum, strongly influenced the curriculum, which shifted from nature education to science education. One example, provided by Gotlib (2002), who was for many years the chief superintendent of science education at the Ministry of Education, is how the structure of the scientific disciplines became the organizer, and how suddenly first-graders were taught about the black moth (rather than on cows or sheep), and older students were taught about the fly as a biological model (rather than learning about taxonomy). Opponents argued that the social and esthetic values were missing, and proponents responded that models are required to teach pure science.

In 1965, a leading educator and novelist, Eliezer Smoli (1965) published his criticism of the "scientific curriculum" in the Biology Teachers' Journal of the time, arguing that now every teacher had to present science at its utmost, so in order to teach about germination of a reddish seed, "he has to move the planets, address the 'theory of ancient fog', make chaos again, erupt lava from volcanos, and teach about thunder and lightning storms. Then the bell sounds and the poor student is left with nothing. Not even with some particles of soil for the little seed." In the past, Smoli argues, the teacher would go out to the yard, put some soil in a test tube, add water and shake the beaker to demonstrate how the bigger particles sink first, then the sand, and finally the silt and clay, to explain how soil in which reddish seeds germinate forms. His main argument was, that while attempting to teach pure science to immigrant youth in rural communities, we lose thousands of students who fail the transition to the secondary school. Smoli continued by arguing that the integration of the outdoor environment and the real and relevant context of agriculture would better suit this youth. Unlike the earlier ideologists and educators, Smoli's arguments were pedagogical. He raised the argument that simple out-of-class activities support more meaningful learning of scientific ideas.

However, despite the shift in the 1960s toward teaching value free science based on the structure of scientific disciplines and scientific methods, out-of-school science education did not disappear; it only changed its form. School field trips continued, but some separation appeared between what Avissar (2011, in Hebrew) called the "ideological field trip", the "expressive field trip", and the "educative field trip" that aimed at teaching and demonstrating natural phenomena. The latter included also designed environments such as museums, archeological parks, and other sites that did not require long hiking.

29.3 Research in Science and Natural History Museums

I begin this section with a personal memory:

Many years ago, at the age of ten, I visited a small natural history exhibit in a kibbutz. At that time, many kibbutzim had their own little museums in which they exhibited local stuffed animals, skeletons, and remains of ancient cultures, including prehistoric humans; and each little museum reflected the kibbutz environment and wildlife. My most vivid memory from my visit was a series of bowls filled with formaldehyde in which animal and human embryos were kept, and one particularly exciting bowl with a two-headed calf. Decades afterwards, I remember the smell of dust and chemicals and my fascination with the snakes, lizards, and embryos in these glass bowls. Many years later, I revisited the place, which had since been much better designed. There were nice exhibits, but I didn't feel the same thrill.

These small museums became locations for educational field trips for local schools even with no interactive or hands-on exhibits. Only decades afterwards, bigger, modern science centers appeared in the big cities, which attract thousands of students every year. These museums' main visitors are school students in organized activities, which have become an acknowledged part of science education. Pedretti (2002) describes a few periods in the development of science museums: from places where scientific collections were kept for researchers eyes only, to places in which collections were presented behind glass according to scientific criteria, and finally, to places in which the public is engaged with phenomena, processes and thought. In Israel, only now the home of the national natural history collection is being built, adjacent to Tel Aviv University, for the preservation and exposition of valuable 150-year-old collections that were kept in the university's basements up until now. But those early kibbutz museums at least provided the "behind glass" approach to specimens. Furthermore, they exhibited the local flora and fauna and allowed visitors to learn more about their specific environment.

In our own research group's studies of four natural history museums and a science museum in the mid-2000s, we tried to reveal what types of learning occur, how the scientific information is being communicated, how engaged students are, and what is the role of school teachers in the museum visit. We found that most of the guides at the museums used a didactic approach, telling the students about the exhibits, teaching concepts, and doing their best to deliver knowledge. Most of the questions asked by the guides were either rhetorical or required students only to recall knowledge. Only a small number of questions required higher order thinking or addressed students' own experiences. A great number of scientific concepts were presented, but only a minority was properly explained and demonstrated (Tal and Morag 2007). The idea that informal learning environments have the potential to allow free-choice learning (Falk 2001) brought us to look at what type of choice is provided to students, and to find the relationship between choice and meaningful learning. We found that what we termed *limited choice*—where students are guided by learning tasks that give them some freedom to select exhibits or topics—yielded more meaningful learning than complete free-choice visits on the one hand, or complete structured activity on the other hand (Bamberger and Tal 2007). Following the literature that points to learning outcomes other than cognitive ones (Falk and Dierking 2000), we identified a variety of outcomes of the museum visit. Students gained new knowledge, but the museum visit allowed them to connect this knowledge to what they learn in school or to their everyday knowledge and experiences. The museum visit allows many opportunities for social interactions which are associated by the students with learning. They indicated sharing knowledge, debating, and convincing each other. We found that affective outcomes such as motivation and enjoyment were no less important to the students (Bamberger and Tal 2008b). The museum learning experience has long term effects as well. Students remembered meaningful experiences 16 months after the visit, and connected ideas learned at the museum to the science they learned in school *after* the museum visit (Bamberger and Tal 2008a).

Despite all these advantages, a major impediment to implementing meaningful school visits to museums is insufficient communication and collaboration between the museum educators and teachers. In two studies, we pointed out the common practice of teachers functioning as chaperones rather than as mediators between their students, the museum guides, and the scientific ideas demonstrated at the museum. The majority of teachers had little impact on the visit program: most of them did not visit the museum prior to taking their students out, and their expectations from the visit were stated in a very general manner (Tal and Steiner 2006; Tal et al. 2005). (I will come back to this issue later in this chapter.) This pattern is known elsewhere as well, and there are many examples from around the world that indicate a similar reality (i.e. Kisiel 2014). Kisiel (2014) argues that the way to challenge the gaps between informal science institutions and schools is by acknowledging that teachers and informal educators represent different communities of practice that have to establish proper bridges in order to improve the school visit experience.

29.4 Research on Outdoor Environments

Despite the great importance attributed to field trips in Israel, as reflected earlier, very little research has been conducted on this unique phenomenon. A few studies were published, in Hebrew only, that focused on the socio-historical aspects of the field trip as a means to building a national identity and an appreciation of nature. In one article, Milner (2001, in Hebrew) argues that there is a huge difference between the guides' and the students' world views. The guides continually deliver messages that degrade the students' world. "When the guides ask the students to avoid littering by burning their toilet paper after use", Milner says, "a student asks if they need to burn their feces, too." Human waste is seen as litter by the guides, while animal feces are a thing to show, break up and touch, and it is something educative. When students find it hard to accept such an attitude, it is hard for them to adopt the naturalistic view as well. Milner also refutes the myth that in order to learn, students need to hike. She asks if students in the US or Europe are taken on long, challenging and sometimes dangerous hikes, too. Her argument is that this myth of "knowing by hiking" has developed because of the history of the country, as described earlier, and because of its small size.

Orion, in the 1990s, was the first to focus on learning science in the outdoors. He studied how to use the outdoors to better teach scientific ideas, mainly in Earth science (Orion 1993; Orion and Hofstein 1994). For the first time in Israel, he did not take for granted that students learn just because they are outside, because they hike, or because they are fascinated by the views of the countryside. He built on the idea of "novelty space" (Kubota and Olstad 1991), suggested how to reduce it, and then how to bridge the learning that occurs in school prior to and after the field trip with what is done during the field trip. Orion argued that students should explore and investigate the outdoors, and that these investigations should be such that they cannot be brought into the classroom.

One innovation that became obligatory in the Israeli matriculation exam system, was an outdoor inquiry project that began in biology in the 1970s, and was adopted many years later in environmental sciences, earth sciences, and geography. Several studies followed the outdoor inquiry projects that were carried out usually in 11th grade (ages 16–17). In biology, Sadeh and Zion (2009) outlined a few examples of such field investigations. They compared guided inquiry with open inquiry and found that students who experienced open inquiry outperformed their counterparts who were engaged in guided inquiry in the development of dynamic inquiry skills. The project that they studied—the Biomind—was a development of an early outdoor inquiry unit—the biotope—that required students to be engaged in investigating a habitat through year-round data collection on biotic and abiotic variables in an outdoor environment. Students were requested to summarize their observations and measurements in a research report which was then orally assessed by an external expert (usually a teacher from a different school) as part (20 %) of their matriculation exam.

In environmental sciences—a field of study that was introduced into Israeli high schools only in the 1990s—the idea of outdoor inquiry was elaborated upon. Two inquiry projects make up 40 % of the student's final matriculation grade. One project, the Ecotop, is similar to the above-mentioned biology project. Pairs of students are required to identify and investigate an environmental problem, such as the influence of irrigation using recycled water on germs found in plant tissues or in the soil, or the impact of building noise barriers on noise levels in neighborhoods adjacent to highways (Tal and Argaman 2005). Students are required to submit a research report and are assessed by an external expert. The second project, the Environmental Workshop, is a whole class out-of-school investigation. The teacher has to choose three different environments (either natural or man-made) to which the students go out for 1 day per environment. These can include a sandy habitat, a Mediterranean forest, an urban environment, an industrial area, and so forth. In each environment they are requested to explore and collect data that would enable accurate description of the environmental variables. Some teachers use a more didactic approach to this project and present their own pre-prepared protocol for the activity, while others encourage a more action-based approach and allow students to become more active in identifying issues for investigation and involvement, and suggest means for data collection (Tal and Abramovitch 2012). The environmental workshop unit also requires students to be involved in environmental action. Again, this could be a very simple activity such as cleaning a dirty beach, or could become an experience in which students develop their own critical thinking, political action, and agency.

29.5 Teacher Challenges

As in our research in natural history and science museums, we found that teachers limit their students' learning experiences if they feel incapable of carrying out these outdoor research projects. A phenomenon that has developed and became quite common is the involvement of informal education institutions in the above-mentioned projects. The Society for the Protection of Nature and the Nature Parks Authority, for example, offer students to attend workshops and camps in which they get help in designing their project and in collecting the data. This could have been a good experience, of course, but the downside is that students are required to pay quite a lot to attend these activities, and another major limitation is that to be effective, these organizations offer "a package"—a definite list of projects that eventually look alike. This allowed distribution of research reports between students from different schools and years, which became a genuine ethical problem of plagiarism. It also undermines the goal of encouraging individual inquiry projects that stem from the students' interest.

To cope with this problem, and to enable teachers to become their students' inquiry advisors, we offered a PD that aimed at helping teachers to lead outdoor inquiry (Tal and Argaman 2005). A group of 15 environmental science teachers participated in the PD, whose framework was based on the "knowing in action" approach (Schön 1987), which involved the participation of teachers in practical inquiry work. The program was based on classroom-based learning, fieldwork, support given at school, and reflection meetings. During the first year of the program, the teachers met every other week at the university, and in the second year they were supported by us in the classrooms and met once a month for group discussions. The content knowledge aspect was addressed by experts, who taught a variety of environmental issues, and discussed with the teachers the country's current environmental problems. The teachers discussed how these issues relate to the environmental sciences curriculum and brought up ideas on how to integrate real issues into the more general curriculum. Pedagogical content knowledge was addressed in several ways. A course website was developed for the group, and the teachers were guided to use the web in order to communicate, search for information, share data, and present their ideas. Other activities included, for example, guided critical reading of scientific articles, and getting to know and use lab instruments and probes for measuring various environmental variables. Another part of the PD included field trips to various sites that allow students' investigations, and environmental education centers that provide guidance. At the end of the first year, the teachers were requested to start their own research project. In the second year, we supported the teachers in their schools, while they guided their students in their Ecotop inquiry projects.

In the study that followed this PD, we found that teachers who had more experience in mentoring their students in doing outdoor inquiry identified more skills required for this task than teachers with less experience. Furthermore, the more experienced teachers emphasized more pedagogical skills, while the inexperienced ones addressed mainly their inadequate content knowledge. The experienced teachers tended to provide more nondirective guidance while the inexperienced teachers were more authoritative and exhibited a directive pattern. The teachers addressed a number of difficulties they face in guiding these inquiry projects. Some were connected to the students and others to the teachers themselves. For example, students' difficulty in transferring knowledge, or with maneuvering between all the other exams they have in 11th and 12th grades that gives them little time to carry out a meaningful inquiry. Teachers' difficulties included, for example, lack of knowledge in statistics, lack of time, insufficient resources in school, and their sense of responsibility that prevents them letting their students fail.

In another project, we attempted to involve a group of teachers in an action research project in our institution's botanic garden (called "Ecological Garden"). With this small group of five teachers, we carried out a whole sequence of planning and enacting an outdoor activity. The teachers worked as a group that collaboratively designed learning activities in the outdoors. They gave feedback to each other, suggested modifications, brought up and discussed possible research questions, and then they each carried out their own mini research project that provided them with data on the questions they asked. Their questions addressed cognitive as well as affective aspects: To what extent did students identify different plant parts? How did the students perceive outdoor learning? Did the students connect ideas learned in the botanic garden with ones they learned in school? And, in what ways did the field trip affect students' feelings toward nature? (Tal and Morag 2009). A meaningful outcome of this action research was the participating teachers' self-reported confidence about carrying out field trips, their tendency to take their students out, and the experience they gained in the sequence of planning, executing and concluding field activities.

29.6 Exemplary Practice

Based on Orion's studies, we knew that good preparation in class, careful choice of the scientific concepts from the curriculum for exploration in the outdoors, and substantial summary in class, yield meaningful learning. However, the vast majority of field trips are not planned and enacted in this way. Teachers refrain from taking a leading role because of many constraints (i.e. Dillon et al. 2006), and use the guiding resources of informal institutions such as the Society for the Protection of Nature, or the Nature Parks Authority (Morag and Tal 2012). After our substantial investigation of field trips, we were able to pinpoint many challenges with respect to learning in natural environments. Teachers hardly provide sufficient preparation prior to the field trip. Goals are unclear and are not discussed between guides and teachers. The pedagogy is too often didactic, with guides transmitting information using maps, models, and drawings, but active learning is rare. The environment is used to some extent, but mainly in a generic way. Guides stop at specific places where they show a phenomenon such as a geological formation, a tree, or an animal den, and explain about it. Students' findings are not always addressed, and they are rarely encouraged to explore on their own.

After similar findings from about 60 field trips we studied, we decided to use a different approach by looking at exemplary practices that stood out from this sample (Tal et al. 2014). We focused on five field trips that demonstrated good practices in at least a few aspects that we had studied earlier. One field trip was special because students were engaged in environmental action. As part of a field trip to Mt. Carmel to learn about the Mediterranean vegetation, they worked for 2 h —in a burnt forest. Through pruning and raking dead material, they were able to discuss conservation, biodiversity, the causes and the consequences of the fire, and they were very proud of their contribution to the environment. Another field trip stood out because of the teacher's high involvement. This teacher taught about prehistoric humans, and wanted to elaborate on the topic by visiting a prehistoric cave site. She had clear goals, and throughout the field trip, she acted as a mediator by drawing connections to what she taught in class. She also mediated between the guide and her students, and in a way, the two (teacher and guide), performed team teaching. Another example from this research was of a guide who really encouraged the students to enjoy nature, by giving them enough time to explore and wander around. She even led a high level conversation about nature conservation that resulted from discussing "good and bad behavior in a nature reserve". Excellent learning activities were observed in two other field trips, in which games were incorporated and students were active learners. Although the Field Trip in Natural Environments (FiNE) model we developed mapped a whole range of aspects that characterize a good field trip (Morag and Tal 2012), in our recent study we argued that even if a single component is carried out in an outstanding way, this could make a substantial impact on the entire field trip and lead to meaningful learning and an overall positive experience for the students (Tal et al. 2014).

29.7 Summary

I have shown in this chapter how nature education in Israel was first influenced and is still being influenced today by the country's history. Educating new generations that will be attached to the land was an ideal which was far beyond simply good teaching and learning. Knowing about the nature of the country and its historical and archeological sites became a value the entire education system adopted. Attempts to challenge this ideal were criticized. Even moving into more modern science education in the 1960s was criticized by older and respected educators for shifting students away from the simple and concrete experiences that the school garden allows, to teaching abstract science which is not relevant enough. However, the positive attitude toward outdoor education has evolved into the unique mandatory outdoor inquiry projects in several subject matters such as biology and Earth sciences. Students are required to identify a phenomenon or a problem they want to study—they need to collect data, analyze, present their findings, and draw conclusions. Although students electing to major in these subjects in high school are a minority, these students have the opportunity for meaningful learning in the outdoors. Recently, because of the teacher constraints that I indicated earlier, the high school biology curriculum has changed. The mandatory outdoor component has been reduced to only one field trip to a natural environment that the students need to document. On the other hand, more freedom has been given to students to choose whether to focus their inquiry project on a lab experiment or on a natural habitat.

Looking at the sequence of learning in the classroom and in nature, we find that nowadays, this sequence is not as clear as it was in the past when teachers were prepared to teach outdoors. Even in the elementary school, teachers use the outdoors much less than they did in the past. They do not feel they are capable enough to teach science in nature. However, teachers nowadays face new challenges compared to their older colleagues. The school system is much more testing-oriented and the old ideals of developing agriculture and farming communities are no longer relevant. Many more safety and security regulations make it very hard for teachers to take their students even to a nearby wood or field, and the country has become much more densely populated. While in the past it was very easy to find a nearby field—nowadays, most of the population lives in large urban areas, and to reach the closest open area needs transportation, which makes it more difficult to arrange, and more expensive.

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Chapter 30
Using Community Resources as Funds of Knowledge to Promote Science Learning in Thailand

Chanyah Dahsah and Chaninan Pruekpramool

Abstract The connection to a students' home community can have a positive and substantial impact on student learning. Especially, learning outside the classroom context makes science learning more relevant and accessible to the students. The knowledge or experiences that students bring to the classroom and use from their home or community are called, "Funds of Knowledge" and serve as powerful resources to promote students' meaningful learning. The National Education Act suggests schools to develop their school-based curriculum that provides the integration of the standards from the national curriculum with local knowledge, in addition of providing communities' learning resources to support lifelong learning or informal learning. The aim is not only to promote subject matter knowledge learning but also to enhance the sense of pride in their culture. However, most schools have difficulty integrating the funds of knowledge from the community into their school–based curriculum, and how to support people in the communities to use their resources as sources of learning. The question of how to connect funds of knowledge with content knowledge is often asked and needs clarification. Thus, this chapter will provide information on how funds of knowledge can be used in science learning by giving examples of related research studies done in Thailand as well as the results from our study that demonstrate how community funds of knowledge were used to promote science learning.

30.1 Introduction

Teaching and learning that is disconnected from the day-to-day life of the household and community prevents students from seeing how the knowledge and skills they learn in school are meaningful or useful in their daily life (Bouillion and Gomez 2001). Braund and Reiss (2004) suggest learning outside the classroom context, making science learning more relevant and accessible to students. Moll

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et al. (1992) developed an innovative classroom instruction technique that brings the knowledge and skills found in local households, called "funds of knowledge," to use as resources for teaching. Moje et al. (2004) state that the students come to school already drawing upon many different funds of knowledge, particularly from their families and communities. Many of those funds of knowledge directly connect to science learning. The learning activities that tap into the students' funds of knowledge motivate students to engage in a lesson much more effectively than a lesson that has little to do with their ethnic experiences (Fraser-Abder et al. 2010). Research studies pointed out that connection to the students' home and community can have positive and substantial impact on student learning, in both the cognitive and affective domains (i.e. Corlone and Johnson 2012; Gonzalez and Moll 2002; Szecsi and Spillman 2012; Upadhyay 2006). Rohandi and MD Zain (2011) also reported that incorporating students' funds of knowledge into science learning was effective in not only sustaining but also improving students' attitudes and increasing their interest in science. Students' interests are stimulated when they participate in family and community experiences that encapsulate the notion of funds of knowledge (Hedges et al. 2011).

In Thailand, we are rich in local wisdom, community knowledge and skills—especially, dealing with agriculture. Different parts of the country have unique knowledge and skills, including local wisdom and local resources. The National Education Act supports schools to develop a school-based curriculum that integrates local knowledge and skills with the basic educational core curriculum at the ratio of 30:70. That means 30 % of the content in the school's curriculum needs to be local knowledge or knowledge from the students' household or community. However, we found that integrating funds of knowledge into the National Curriculum has been a central issue in all schools. Teachers have difficulties in integrating funds of knowledge into the National Curriculum. In the curriculum of most schools, funds of knowledge were only partially integrated. In addition, the Act also strongly supports the communities to use their resources as learning resources for supporting lifelong learning for local members. Again, the communities' members also have difficulties in bringing community funds of knowledge into learning.

This chapter aims to provide information for teachers and educators on how funds of knowledge can be used to promote science learning based on the research done in Thailand both formal and in formal education. After reading this chapter, readers will be able to answer the following questions:

1. What is "funds of knowledge" and how are they important in science learning?
2. How does science education in Thailand promote the use of funds of knowledge?
3. How are funds of knowledge used in science learning?
4. How does community resource affect formal and informal science learning?

30.1.1 What Is "Funds of Knowledge"?

Moll et al. (1992) used the term, funds of knowledge, "to refer to the historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being" (p. 133). It is an individual's experiences that develop overtime within their family and community.

The concept of "funds of knowledge" is based on a simple premise that all learners have their own knowledge that accumulates and develops over time from their life experiences. According to social constructivist perspectives, relating what students bring to school or engaging students with knowledge that is already familiar to them makes learning more effective. Successfully bridging knowledge or experiences students gain from the home or community to what they are learning in school is what makes the learning so much more meaningful (Fraser-Abder et al. 2010). Gonzalez and Moll (2002) claim that funds of knowledge contain cultural and cognitive resources which are useful, powerful, and transferable for learning.

The funds of knowledge students bring with them to the classroom serve as powerful resources to promote meaningful learning (i.e. Corlone and Johnson 2012; Roth and Tobin 2007; Szecsi and Spillman 2012; Upadhyay 2006). Instruction utilizing funds of knowledge can break down the walls around the classroom by grounding students within their own cultural knowledge, and students become more engaged and motivated to learn through subject matter content that is based on their experiences (Gonzalez et al. 2005; Bell et al. 2009). Gilbert (2011) also claims that if students are taught with a curriculum that integrates culture in an academically relevant way, it will improve academic achievement while simultaneously preserving traditional cultural knowledge.

To use funds of knowledge in classroom learning, teachers and researchers need to work collaboratively to collect ethnographic information of knowledge and skills from students' home and community and use them to develop instructional units. As Gilbert (2011) suggested in this work, it is important that the curriculum developer contact community representatives and seek their guidance in order to work collaboratively in developing a culturally relevant curriculum. In this way, the content and methods of home and community knowledge (funds of knowledge) will inform the content and methods of school learning (Genzuk 1999).

30.2 Science Education in Thailand

Education in Thailand is administered by the government through three main agencies: the Ministry of Education, the Ministry of University Affairs and the Office of the National Education Commission. Since the 1999 National Education Act was established, these three agencies have been merged into one organization, the Ministry of Education. Thailand's education system is divided into three main categories, depending on the economic, community and cultural background of the learners. These categories are formal education, nonformal education, and informal education. Formal education involves, specifically, the school system, comprising basic and higher education. For nonformal education, we focus on services outside the school system. In the past, Thailand emphasized nonformal education, particularly for preschool children. Presently, this system is expanded for specific groups of citizens who have no opportunity to continue their studies in the formal educational system. Besides, Thailand also has informal education where learners can learn independently based on their readiness and interests (Office of the National Education Commission 2006). Regarding the learning differences of students, dealing with a variety of them is technically difficult to provide the classroom that suit to everyone. Especially in science subject, informal education such as learning in science museum, zoo, or community learning resources, is one of the most powerful ways to encourage and inspire students to learn science. This way of learning is also appropriate to the students with diverse talents (Hofstien and Rosenfield 1996; Bell et al. 2009). Moreover, the National Governors Association (2012) stated that informal science learning was allowed students to expand their knowledge from the classroom through hands-on learning environment. The informal learning can also be used to enhance science learning at all levels of students from K-12 until university level (Asghar 2012; Lloyd et al. 2012).

Science education in Thailand has been influenced by science curriculum reform in the United States. The pilot project for chemistry and physics teaching hosted by United Nations Educational Scientific and Cultural Organization (UNESCO) and United Nations Development Program (UNDP) had an important role in developing Thai science curriculum from 1964 to 1970. In 1965, the Thai government established the Institute for the Promotion of Teaching Science and Technology (IPST). IPST is the main organization that has been developing Thai science curriculum since 1970. IPST science curriculum is different from the previous ones in many respects. Specifically, in teaching, IPST science curriculum has changed drastically from lecturing to focusing on using experiments and increasingly encouraging students to think. In the 1980s, Thailand launched the new science curricula for students from primary to upper secondary school levels under the theme ‘A Science for All’. Furthermore, in 1999, the National Education Act established that students have the right to decide whether to study science and even mathematics (Office of the National Education Commission 2001; Klainin and Soydhurum 2004; Dahsah and Faikhamta 2008). Later on, the Basic Education Core Curriculum 2008 was launched and we have been using this curriculum to drive the educational system in Thailand since then.

However, Thai science education is still plagued by several problems. A large number of children, teens, and young adults do not like science because they think it is far away from and irrelevant to their everyday life (Office of the National Education Commission 2006; Pruekpramool et al. 2011). In fact, science is concerned with natural phenomena. This problem reveals that Thailand must engage in the process of reviewing, specifically, science education. The reviewing process must include all significant compositions, consisting of curriculum, teaching and learning strategies, and the evaluation procedures. Moreover, the source of learning science outside of school is essentially counted. This source of learning science has contributed significantly to the promotion of a positive attitude toward science learning (Bell et al. 2009; Lloyd et al. 2012). In addition, it will be utilized to enhance the meaningful outcomes of children's lifelong learning.

Learning science is not only about using advanced technology or innovative teaching strategies. For Thailand, science has blended straight forwardly into the lives of the Thai people, from the past to the present. Learning happens by using natural instructional materials, the local community, local wisdom, culture, and the traditions called "funds of knowledge". These kinds of learning resources contain massive amounts of scientific knowledge that we can use for our students (Munkatevit cited by Office of the National Education Commission 1999; Seang-Xuto 2009; Pruekpramool et al. 2013). Thai science curricula, from the past to the present, have gradually increased the relationship among science concepts, local wisdom, and community knowledge.

Under the educational reforms of the Constitution of the Kingdom of Thailand and the National Education Act B.E. 2542, IPST is responsible only for preparing the content and curricular standards. The concepts and learning standards, including the development of learning materials and activities, is operated and managed by local personnel themselves using local resources to meet the local community's demand. The expected curriculum has provided the guidelines in order to reach the goals of science education. The goals of science education, at this point, refer to modifying and adapting science concepts to suit the local community, and also adjusting teaching to facilitate learning as much as possible. Additionally, the curriculum needs to focus on the importance of the main content and methods or approaches to access knowledge (Dahsah and Faikhamta 2008; Office of the National Education Commission 2001; The Institute for the Promotion of Teaching Science and Technology 2005). The Basic Education Core Curriculum 2008 has focused more on the use of funds of knowledge in school science learning in Thailand (The Ministry of Education 2008). The 2008 curriculum provides only a framework and orientation for school. Thus, all schools have the right to manage their own curriculum depending on the Basic Education Core Curriculum 2008, the "school-based curriculum". In addition, a school can integrate their local wisdom and community's knowledge into their curriculum as well.

As previously mentioned, Thailand has a bounty of unique local wisdom and community knowledge, extending throughout all parts of the country. Students in every area go to school with their funds of knowledge. To promote students' interest in science or positive attitude toward science, science subjects need to integrate the funds of knowledge (Hedges et al. 2011; Yuenyong and Narjaikaew 2009). In the next part of this chapter, the related research and documents about using funds of knowledge in science learning in Thailand are reviewed. Readers will understand more clearly about the unique local wisdom in different areas of Thailand, and how those local knowledge and skills were integrated with science learning to promote learners' competencies in many aspects.

30.3 Research Studies in the Use of Funds of Knowledge in Science Learning

This section aims to clarify how funds of knowledge can be integrated into science disciplines, both inside and outside the classroom. Moreover, some of the unique local wisdom from different areas of the country will be introduced in this section. There are many research studies about using funds of knowledge in science learning conducted in Thailand. Most of the studies used funds of knowledge in terms of local community learning resources. In this chapter, we provide some examples that were conducted in different parts of the country in order to see not only their unique local wisdom and resources, but also a variety of local wisdom and resources that were integrated into science learning in both formal and informal education.

30.3.1 The Use of Funds of Knowledge in the Classroom

There are many research studies that have investigated integrating funds of knowledge into science classroom activities. Some use funds of knowledge to promote students' understanding of subject matter, and some use funds of knowledge such as materials and methods in laboratory learning. Here are some examples of the research studies in promoting classroom science learning utilizing funds of knowledge.

Saebug (2001) aimed to explore the local wisdom related to the topic of "colors for MatthayomSuksa 5 (Grade 11) nonscience students in Kalasin province, in the northeastern part of Thailand. The researcher reported that there were two types of local wisdom related to the topic "colors", natural dye and natural varnish color. The results on science learning achievement showed that the posttest scores were significantly higher than the pretest scores at 0.01 level. The students' attitudes toward incorporating scientific local wisdom into teaching were at the high level.

Jai-ngam (2002) developed science laboratories using the production of gasohol from local sugarcane plants. These were grouped into four main laboratories, consisting of (1) Alcohol fermentation from sugar cane, (2) Alcohol distillation, (3) Testing of the fundamental properties of alcohol and (4) Gasohol production. These laboratories were taught to MatthayomSuksa 5 (Grade 11) students in SuphanBuri province, in the central part of Thailand. The results indicated that these four laboratories had IC indices higher than 0.80 and had knowledge effectiveness as 79.16/82.79. The practical skills' effectiveness was at 84.54/86.70, indicating an excellent performance. In addition, 75 % of students reacted positively to the science integrated with the local knowledge laboratories.

Sangon (2003) used local pineapples in Prachuapkhirikhan province, in the western part of Thailand, to develop science activity packages. This study focused on assessing students' learning outcomes based on students' knowledge, science process skills and attitude towards the science activity packages. Scientific concepts used in this research study consisted of (1) general knowledge of pineapples,

(2) enzymes from pineapples and their usefulness, (3) agricultural product processing focusing on pineapples and (4) agricultural product processing focusing on pineapple cultivation for household consumption. The results indicated that students' knowledge and science process skills were higher than the medium level of the criteria. The posttest scores of students' knowledge and science process skills were significantly higher than the pretest scores. Lastly, students' attitudes toward science activity packages were at the good level of the criteria.

Un-on (2003) explored local wisdom and community resources for creating science learning lessons on the topic of transport and communication. This science learning lessons developed for MatthayomSuksa 3 (Grade 9) students in Buriram province, in the northeastern part of Thailand. The results revealed that there are 10 types of local wisdom and 11 types of community resources that could be used to create science learning lessons for this topic. For example, "Kwīen" (a cart) and "E-pong" boat are traditional vehicles for transporting rice and for traveling in local areas. "Khrokmong" (a rice mortar) is an old piece of equipment to pound the rice, used from long ago until the present. The results of the study also indicated that posttest scores in science learning achievement were significantly higher than the pretest ones at 0.01 level after learning with the science learning lessons.

Jansawang (2005) studied the development of a school-based elective science curriculum using *One Course One Cycle* strategy and applying local wisdom in creating science learning activities for lower secondary school students with the topic of "chemicals in everyday life". The results from this research study indicated that the posttest scores were significantly higher than the pretest ones at 0.05 level. Furthermore, the students who studied under this curriculum have science process skills at a higher level, as examined by experimental reports of the students. The students' attitudes toward learning science were also at a high level.

Nuangchalerm (2006) had designed the indigenous science curriculum based on the belief that balancing local knowledge and scientific knowledge can help students improve their learning. The local environment employed in this research study was "PahPoohTah", a small old woodland village, in a forested area in the northeastern part of Thailand. The scientific concepts related to this study are ecosystem, biological diversity and conservation—all for MatthyomSuksa 3 (grade 9). After the implementation of the curriculum, the results revealed that students' science learning achievement posttest scores were significantly higher than the pretest ones at 0.05 level. The students had more awareness of their local environment and environmental conservation behavior.

Punprasert (2008) developed a 5-day science teachers' training curriculum for 13 Grade 3 teachers. The curriculum's goal was to help teachers integrate local wisdom into science laboratory experiments. There were four designed laboratories incorporating local wisdom used in this research study, consisting of (1) Herbal juice, (2) Herbal rice steaming, (3) Making soap from waste oil and (4) Making a donut dessert. The results found that students who studied with these teachers were able to use science knowledge to explain local wisdom and positive attitude toward learning.

Pruekpramool (2011) developed an elective science course, emphasizing the science of sound concepts through traditional Thai musical instruments, local wisdom, and cultural heritage. This course was created specifically for upper secondary school nonscience students and implemented for 40 periods at a school in Bangkok, Thailand. The findings of this study revealed that, after the course, students' scientific creativity and understanding of the science of sound content posttest scores were higher than the pretest ones and increased significantly at the 0.05 level. Moreover, the students became more aware of their culture and traditional Thai musical instruments. However, the students' attitudes toward science before and after the course assessed by a rating scale evaluation form are not significantly different at the 0.05 level. However, the students were still satisfied with the course.

In summary, funds of knowledge have been used in science classrooms in several ways, for example, designing and developing science curriculum, science activity packages, and science laboratories. The results indicated that students gained more knowledge and skills, had positive attitudes toward science and were more aware of their local culture when funds of knowledge were used as resources of learning in science classrooms.

30.3.2 The Use of Funds of Knowledge Outside the Classroom

For out-of-classroom learning in Thailand, we have many local learning areas all over the country that suit learning science outside the classroom. There are more research studies in the use of funds of knowledge outside the classroom than inside the classroom. The most important was a project by the Rachabhat University research projects agency network. This network included all Rachabhat Universities (40 universities) in the four regions of Thailand, working collaboratively under the administration of the Office of the Higher Education Commission (2004). The four regions were divided into central, northeastern, northern, and southern parts of Thailand. The project consisted of 40 subprojects. In collaboration with experts, teachers, students, and the local community, each project team studied and created science lessons outside the classroom based on the scientific knowledge and local wisdom of each area.

The examples of subprojects have been reviewed based on regions. Firstly, in the northern part of Thailand, Chiang Rai Rachabhat University created science lessons on the topic of conservation and the utility of the Kok river to communities along the river. From Roummittr village to upstream of Chiang Rai, all were in Chiang Rai province. Another interesting project from the north of Thailand was developing science lessons about the "Mao Hom" fabric, the fabric dyed by the blue color from the plant called "Hom", conducted in Phare Province by Uttaradit Rachabhat University. Secondly, in the central part of Thailand, Kanchanaburi Rachabhat University designed a science lesson to study plant diversity in "Ban Houi Sapan Samakki" forest in Kanchanaburi Province. In the same way as Phetchaburi

Rajabhat University in Phetchaburi province, the researchers had created science lessons based on local knowledge of coconut palm sugar. Thirdly, in the southern part of Thailand, Suratthani Rajabhat University in Suratthani province developed science lessons using local knowledge of shrimp farms and the science concept of "quality of water." Lastly, in the northeastern part of Thailand, one research project by Loei Rajabhat University was involved with herbal plants in Loei province. Another project was related to Surindra Province's elephants by Surindra Rajabhat University (Rachabhat University research projects agency network 2004).

There are many subprojects in this big research project and other research studies that we did not mention here. However, all these studies are obvious proof that Thailand has a lot of local knowledge and wisdom related to the study of science. Moreover, students who live in those areas are familiar with this local wisdom, community knowledge, culture, and traditions, before they come into the science classroom. These funds of knowledge are part of a student's prior knowledge. Avery and Kassam (2011) state students acquire science skills and knowledge in the context of their daily life, and those somehow rural settings may offer greater opportunities for experiential learning of science because of the outdoor and rural nature of children's habitat.

Reviewing Thai literatures about funds of knowledge in science learning uncovered the fact that science can be integrated into the indigenous wisdom and local technology from each local community. Science curriculum, activity packages, lessons, and laboratories can be case studies for students or young local investigators to study both culture and science. These will complement the knowledge of the youth and help them see the value of both science and local wisdom. Students will get better understanding and skills in science, increase their own awareness and be proud of their own heritage. Moreover, they definitely will continue to preserve their local wisdom and maintain the sustainability of their community. The research studies confirmed that funds of knowledge are effective resources that promote effective and meaningful science learning.

In the last section of the chapter, we will clarify in detail how funds of knowledge are used to promote science learning in informal learning based on our research study. This research is about the integration of funds of knowledge from community resources with science content standards—this research project is called "Science Integrated Local Wisdom Learning Stations."

30.4 Science Integrated Local Wisdom Learning Stations

The "Science Integrated Local Wisdom Learning Stations" project was developed to provide resources for schools and communities to learn science that is grounded in their own cultural knowledge. The funds of knowledge in this study can be defined as the knowledge from students' household and community that students are familiar with and match the science content of the national standard. Learning in this research project does not happen inside the classroom; we used the community —learning resources called "Bodhi Learning Stations (BLS)" as a learning site.

BLS are developed for training the youth in the community to learn about daily household activities and community knowledge from local wise men and women who have expertise in community ways of knowing. This is a part of the tertiary education curriculum that provides alternative education programs for developing the youth of the community. This curriculum aims to train the young in making wise and alternative choices for better living within their own community. The principles of the curriculum are grounded in the ideas of Buddhist teachings and the philosophy of Sufficiency Economy (Sangsehanat 2010).

After visiting BLS in the year 2011, we found that the learning stations provide rich funds of knowledge about the household and community, and many of them were related to science. However, the information that was provided in BLS did not relate to any science concepts. Two research questions come immediately to our minds:

1. What science ideas or concepts that school students could learn from BLS?
2. Do the science learning activities that integrate funds of knowledge provided in BLS enhance students' understanding of science ideas and improve their attitude toward science learning?

To answer these two questions, researchers worked closely with community members, including the local wise men and women, undergraduate students (local youths), and school teachers. The methodology of this study involved five main steps.

30.4.1 Step I: Understanding Funds of Knowledge Provided in Bodhi Learning Stations

The researchers visited BLS to learn about the knowledge and practices that are provided in each learning station by local wise members and undergraduate students. Each learning station provides knowledge about how local people make use of the resources they have such as soil, plants, and animals, or how to build and use tools in everyday life, e.g., charcoal and clay houses. Then, we searched for more information to gain a better understanding about each learning station. After we reached a good understanding of each learning station, we brought the knowledge back to share and discuss with the local wise members to make sure that all knowledge we had was correct and complete.

30.4.1.1 Step II: Taping Funds of Knowledge with Science

We looked closely at science standards in the Basic Education Core Curriculum B. E. 2551 (Ministry of Education 2008) to see what science content can best match the funds of knowledge provided in Bodhi learning stations. Five learning stations were selected to serve as "Science Integrated Local Wisdom Learning Stations." The science concepts and funds of knowledge we utilized in each learning stations are shown in Table 30.1. This information is shared with the school teachers (primary and middle school level) and local wise members to check whether they could integrate it into the school curriculum.

30.4.2 Step III: Developing Learning Materials and Activities

The materials we developed for each learning station consisted of a video presentation, station boards, instructional plans (for instructors), learning handouts (a reading and a worksheet), and a guidebook. The activities included card games, role

Table 30.1 Funds of Knowledge and Science Concepts in Science Integrated Local Wisdom Learning Station

Learning station	Funds of knowledge	Science concept
Adobe clay house	Making adobe bricks Building adobe brick house	Heat transfer (conduction, convection) Properties of materials (elasticity, hardness)
Charcoal	Making charcoal Collecting wood vinegar (coproducts)	Pyrolysis Combustion (complete and incomplete) Heat flow Distillation Phase change
Bio-extraction	Bio-extraction (plants and meats) Application of bio-extraction in everyday life	Microorganism Extraction Hormone pH
Alternative energy	Pumping water by wind turbine and bicycle	Piston Kinetic and potential energy Energy conservation
Community forest	Local plants and fish Communities and environment	Biodiversity (plants and fishes) Water qualities (pH, turbidity, temperature) Human and environment

plays, simple experiments, model construction, questions, and answers. To complete all the activities provided in each learning station, the participants need to spend about 20–30 min.

30.4.3 Step IV: Reviewing and Revising Learning Activities and Materials

All learning materials were reviewed by three experts who are presently teaching science or science education at the university level. The review is not only to check the content validity but also to give valuable comments about how the activities may develop student understanding and increase positive attitudes, both in science, and community knowledge. All experts' comments were used to revise the learning instructions and materials to make them more complete and more effective.

30.4.4 Step V: Try Out

The materials were tried out with two groups of local students. One group was 13 primary school students. The school is about 0.5 km from BLS. The other group was 9 undergraduate students. These undergraduate students will study in an undergraduate program at BLS next coming year. The students were evaluated on their understanding of science concepts by a conceptual test with 30 multiple choice items (six items for each learning station), and their attitude toward science learning in each learning stationby a rating scale questionnaire. The test was administered before and after engaging in the activities using Pretest—Posttest Design. The questionnaire was administered after completion of the activities. The results of the pilot study indicated that both groups of students gained a better understanding of science concepts related to local knowledge (see Table 30.2). They were very appreciative of the interesting activities that were provided in each learning station (see Table 30.3).

There are some points of concern regarding the integration of funds of knowledge in a science learning environment. First, the developers (researchers or teachers) who are creating these integrated lessons need to have an in-depth understanding of both funds of knowledge and science concepts in order to create

Table 30.2 The Pretest–posttest mean scores

Participant	Means (total score = 30)		Effect size
	Pretest	Posttest	
Primary school students (N = 13)	15.94 (SD = 1.26)	18.82 (SD = 1.01)	2.3
Undergraduate students (N = 9)	16.89 (SD = 1.69)	23.00 (SD = 2.83)	3.6

Table 30.3 The attitude toward science learning in each learning station

Station	Undergraduate Students ($N = 9$)		Primary school students ($N = 13$)	
	Opinion (SD)	Interpretation	Opinion (SD)	Interpretation
Adobe clay house	4.54 (0.52)	Very appreciate	3.88 (0.70)	Appreciate
Charcoal and wood vinegar	4.46 (0.52)	Appreciate	4.59 (0.71)	Very appreciate
Bio-extraction	4.62 (0.51)	Very appreciate	4.94 (0.24)	Very appreciate
Alternative energy	4.38 (0.51)	Appreciate	5.00 (0.00)	Very appreciate
Community forest	4.38 (0.65)	Appreciate	4.94 (0.24)	Very appreciate

effective materials and activities that promote meaningful learning. Second, to understand the funds of knowledge, developers need to get into the context and work collaboratively with local personnel. Third, there are many science concepts that can be linked to funds of knowledge, but the selected science concepts need to be appropriate for the level of students' cognitive development. Complicated and difficult concepts might lead to negative attitudes toward science. Thus, for outside classroom learning, the developers might need to develop learning materials and activities for different levels of students.

30.5 Conclusions

The research studies and projects as mentioned in this chapter indicated that the funds of knowledge could be used to promote science learning both inside and outside classrooms. When funds of knowledge are utilized in the classroom, students are more likely to be actively engaged in science learning activities when they see the science they learned is related to their everyday life. For learning outside the classroom context or informal science learning, it helps students to see clearly the relationship between science in the schools and their everyday life experiences. In addition, the students are more engaged in the learning activities when they had a chance to learn outside the science classroom. A study by Hedges et al. (2011) also indicated that students were more interested in learning when they intently participated in family and community experiences that encapsulated the notion of funds of knowledge. Learning in places outside of school also offers explicit opportunities to connect the students' home and community with the larger global environment (Avery and Kassam 2011). The use of funds of knowledge not only promotes better understanding and positive attitudes towards science, but also improves students' attitudes toward learning and science in general (i.e. Gilbert, 2005; Rohandi and MD Zain 2011). In addition, tapping into funds of knowledge helps students to better understand their community, appreciate its value, and work to sustain their community knowledge and resources (Gilbert 2011).

As Gilbert (2005) stated "knowledge children bring to the classroom is just as important as what is being taught in the classroom (p. 30)." Thus, developing science curriculum that includes culturally related knowledge can build on effective science learning. However, to integrate funds of knowledge with the science curriculum, educators, and teachers need to research students' funds of knowledge by collaboratively learning from their household and community (Gilbert 2011; Gonzalez et al. 2005), and then blend these funds of knowledge with the science curriculum or content. The cultural knowledge can be obtained from various sources such as community leaders, parents, and cultural experts (local wise members) (Gilbert 2005). In order to achieve in blending in funds of knowledge from community learning resources into science learning, the appropriate continued professional development programs for science teachers and communities are necessary (Asghar 2012; Lloyd et al. 2012).

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Chapter 31
Commentary: Transforming Science Education in Cultural-Historical Context and the Role of Teacher Professional Development

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Abstract In this reflection, I discuss how each of the chapters in this section challenges the reader to grapple more deeply with the historical context in which teaching and professional development take place, and use the emerging narrative to challenge some of the fundamental assumptions we hold about what teachers might learn and do in order to be "good teachers." I discuss three themes in particular: a) Cultural context and local wisdom is a central aspect of teaching and learning to teach; b) Supporting teachers as intellectuals transform teaching and learning in profound and meaningful ways for students; and c) Views of good teaching and learning involve breaking down critical binaries with and in place.

I begin this commentary by sharing a quote from a letter written by a young man, Quentin. Now a 9th grader, Quentin wrote this letter to his fifth grade teacher 6 months into the school year. This was the same teacher he had had all school year long, for all subjects. He wrote the letter because, in his words, he wanted his teacher to "know something" about him.

> Hi Mr. B., this is your student [Quentin] the first one in the 2nd row. I'm going to tell you about things that we should to in Science. I'm in Green Club and Green Club helps me get my grade for science to like a B or a A…
> I do things out of school and out of Green Club that involve science. I went to door to door and ask adults if they use CFL lights. The majority of the adults did NOT use CFL lights, I will try to decrease the amount of people who use incandescent lights. I did it on Wain Wright Ave. and I did it because people's bills are up because they use just Incandescent lights…

Quentin's letter reminds us just how much many youth feel marginal and even invisible in science class—"This is your student Quentin, the first one in the second row." At the same time, he also points to the creative ways in which he works hard to leverage his place and his cultural knowledge and practice to move scientific ideas

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and community concerns across the boundaries that are often set up between the two. As Quentin later states about his letter, "Doing science that matters [is important.] I mean it matters to everyone, not just me or not just school." He also says, "It's not so much for energy that I get attention at school, but for being I'm funny. I'm recognized for that. For being a smart aleck. But I think that should be good."

What can we learn from Quentin's? And how does this relate to a set of chapters about teachers and teacher development? There are two core lessons in Quentin's letter, which I believe are directly tied to these chapters. The first lesson is that Quentin positions himself as a capable science consumer and producer—a make-a-difference science expert. This positioning speaks both to how his cultural repertoires of practice matter in his own development as well as to how his local context shapes how he frames scientific problems. These practices, Quentin believes, should be recognized by teachers as legitimate assets for his learning in science. Second, his story pushes on the binaries that often make science so inaccessible for youth—binaries that also shape what it means to be and to become a good teacher: formal/informal, teacher/researcher, insider/outsider, science/nonscience. These two core areas of teacher learning—and their importance in professional development—undergird the chapters in this section.

When I first read this set of chapters, I wondered how did they fit together? Two were explicitly about teacher professional development and two were explicitly about the role of out-of-school learning in formal schooling. Yet, as I began to reflect on the chapter set it became clear that cutting across them was a focus on how cultural-historical context matters in how we understand science teacher learning for empowering teaching and how it might be supported in professional development. It became clear that the very issues that shape my own deep engagement in youth learning and development across settings and time—such as is evident in Quentin's letter—also speak loudly across these four chapters. Each one of these chapters challenges the reader to grapple more deeply with the historical context in which the work described takes place, and uses the emerging narrative to challenge some of the fundamental assumptions we hold about what teachers might learn and do in professional development in order to be "good teachers."

Below I discuss, in an integrated fashion, three themes that emerge from this point of view, and which hold possibility for undergirding teacher professional development in transformative ways:

(1) Cultural context and local wisdom is a central aspect of teaching and learning to teach;
(2) Supporting teachers as intellectuals transforms teaching and learning in profound and meaningful ways for students; and
(3) Views of good teaching and learning involve breaking down critical binaries with and in place. Reflecting on this tension point is important for teacher learning and professional development.

Cultural Context and Local Wisdom. Teacher learning and professional development that engages teachers in making sense of the cultural contexts in which their work takes place, and how such contexts shape their work, is important. The four chapters in this section all point toward the importance of the broader cultural contexts in which science teaching takes place, and how these contexts shape the questions and concerns of teachers in these systems. In each of these manuscripts we learn something about the values, goals, purposes, and histories of science education in three different national contexts: Israel, Thailand, and Japan.

How culture matters is critical in both the national level and local discourses on teachers and teaching science. From a learning standpoint, a particularly compelling narrative is shared by Tal in her description of how out-of-doors education—generally in the form of fieldtrips to the natural environment—have become a central aspect of science education in Israel. In documenting the history of out-of-school learning in Israel, Tal reminds us that out-of-door fieldtrips to natural environments have a dual purpose in Israeli education. They are meant to support young people in engaging with the natural environment—developing care for the local ecology, complex thinking about phenomena, and science skills, such as observation. At the same time they are meant to support a sense of unity with the developing nation-state; one that values a strong relationship to the land—"a transition from European urban life to living in harmony with nature and becoming attached to the land" (p. 3)—and one that embraced a set of values that reflected a national-Zionist thought. She writes, "The history of out-of-school learning in Israel is as long as the history of the Hebrew school. Unlike field trips in other countries, they have a strong national value, in addition to other more common international aims. In Israel, the field trip became a central means to creating a new nation" (p. 1).

In the chapter by Dahsah and Pruekpramool we see a similar narrative in the sense that "local wisdom" from living with the land provides deep insight and connection to science. The argument here is that these funds of knowledge—or the knowledge that individuals have because of the cultural experiences in the world—contribute greatly to being and becoming scientifically literate. While this differs from the nation-state argument made by Tal, there is a similarly written about connectedness between the individual and the land that fundamentally shape how individuals may come to be and to learn in science. Here, the authors report on seven forms of funds of knowledge that connect the individual-as-embedded in Thai culture/land with science:

> 1) local wisdom about food such as tools, food preservation and agriculture, 2) local wisdom about dwellings such as houses, temples, and others constructions, 3) local wisdom about clothing such as fabric dyeing and weaving, 4) local wisdom about medical therapy such as herbs and massage, 5) local wisdom about transportation such as carts and boats, 6) local wisdom about careers such as pottery, wickerwork and basketwork, and 7) local wisdom about recreation such as musical instruments, toys and plays. (p. 6).

At the same time, Dahsah and Pruekpramool describe the tensions inherent in science education in Thailand as a result of the merging western educational ideals and traditional Thai culture. As the authors tell us, in Thai culture, "Learning happens by using natural instructional materials, the local community, local wisdom, culture and the traditions called "funds of knowledge." These kinds of learning resources contain massive amounts of scientific knowledge that we can use for our students" (p. 5). However, despite funds of knowledge as possible resources for science learning, many Thai students express dislike for science. "They think it is far away from and irrelevant to their everyday life" because of how it is often taught (p. 4). As a result, the authors write about efforts to integrate knowledge systems in school science curricula. This tension is not unlike the one pointed about Tal who describes the vast decrease in out-of-doors learning in Israeli education, as national education efforts and practices move towards a testing-orientation in a post-agrarian society.

From a teaching standpoint, Isozaki describes the history of professionalism in teaching in Japan, and how it formed over time through a range of cultural practices, including study groups in normal schools, attending, presenting, and publishing through professional organizations, and lesson study. In this chapter, we see how practices associated teaching—and with becoming teachers within professional communities—provide a unifying lens for the profession, situating teachers as engaged practitioners, and with expectations for performances that extend beyond the classroom. It is important to note that these practices have long traditions within the teaching profession in Japan, and shape national discourse around what it means to become a teacher.

Echoes of this kind of defining coherence at a national level regarding what it means to develop as a teacher, can be seen in Mamlok-Naaman, Katchevich, and Hofstein descriptions of teacher professional development and leadership. In their chapter, they explain how national centers work in tandem with the Ministry of Education in order to provide a professional vision of "quality teaching of inquiry science." In order to enact reforms focused on quality teaching, the Ministry set up national and regional centers for professional development, which specialized in teacher leadership, and also what I might call teacher agency. The goal across these centers has been to be responsive to the education mandates while attending to the "multicultural state" (p. 27). Across these centers, teachers are offered opportunities to engage in leadership workshops, action research, evidence-based professional development, and opportunities to develop curriculum. What strikes me here, however, is not the differences in approaches across the centers, but rather the fundamental investment in teachers as intellectuals and cultural brokers. Across these initiatives teachers are viewed as "producers rather than just consumers" of educational mandates (p. 26).

In all four of these chapters we see a direct challenge to the binaries that mark novice/expert and producer/consumer as teachers are positioned as owners of curricular initiatives and leaders, whether it is in out-of-door education or teacher action research. This stands in contract to some educational policy frames (at least in the US) where teachers' actions need to be "controlled" for with teacher proof materials, such as scripted curriculum and page-a-day tactics.

Teachers as Intellectuals. A second important theme is that supporting teachers as intellectuals within professional development opportunities transforms teaching and learning in profound and meaningful ways for both teachers *and* students. Each one of these chapters positions teachers as "life long learners" (Mamlok–Naaman, Katchevich, and Hofstein, p. 4). While the focal point of teacher learning differs somewhat across the chapters, each narrative positions teachers as the fulcrum. They are not passive recipients of knowledge to be passed down to them from the experts. Rather, through their own action research, critical reflections, or working collaboratively to design activities, teachers are positioned as capable, creative, intelligent professionals who produce critical craft knowledge.

I would like to return to Isozaki's chapter for a moment to further develop this point. It stands out to me that the teachers written about in his chapter are positioned, at all times, as teachers and as researchers, and that this positioning is an historical practice. Teachers, in voluntary educational research organizations have conducted wide-ranging practical research studies, focused on children's learning and teaching materials that support that learning. What is interesting is that this information is really intended for a Japanese schooling audience—disseminated only in Japanese and only among teachers. As this author states, "We must not ignore science teachers' traditionally accumulated wisdom and expertise based on their enthusiasm and reflective practices as professional cultures in our own country" (p. 18). As noted earlier, we see a similar theme in Mamlok–Naaman's chapter as Israeli teachers are always acting as leaders in how they work with curricular materials, action research, and so on.

I want to turn my attention, however, for a moment, back to Tal's chapter, for this chapter presents an interesting challenge for teachers as intellectuals. Tal and her colleagues found that students' learning opportunities were limited when they felt incapable of leading fieldtrips and the associated inquiry projects. When informal education institutions stepped into help with the problem, it led to other larger problems such as extra costs for students and a more tightly packaged curriculum. Tal and her colleagues, therefore, designed both a professional development model and action research experiences, to better support teachers in becoming their students' inquiry advisors. What resulted what a more comprehensive view of the scientific skills required for this task on the part of students and more pedagogical skill on the part of teachers, along with greater confidence among teachers in planning, executing and concluding field activities. The point here is that embracing teachers in solving the out-of-door education program together, by supporting them in action research, a more robust approach to fieldtrips was made possible.

Good Science Teaching. Lastly, I want to comment on how embedded across these chapters is an argument for what good teaching and learning is within national contexts. However, cutting across these papers is a view of good teaching that values youth and teachers as whole people, with intellectual and cultural lives that are much broader than classroom structures make visible. Like Quentin's letter, shared in the opening section of this commentary suggests, where science is taken up, how and for what purposes ought to be a part of how we view science teaching and learning in classrooms. How such threads may become foundational to teacher professional development is important and, yet, as these chapters point out, challenging.

In the study on professional teacher communities in Japan, we can see that good science teaching is grounded in a deep understanding of students. It is expected that Japanese secondary science teachers hold many roles, in addition to classroom teacher, such as club leader and counselor, giving them far greater opportunities to understand their students better. As Isozaki writes, “Therefore, science teachers in secondary school can understand students’ characteristics as a whole, not only through their performance in science lessons but also through other school activities such as pastoral care and tutoring classroom students” (p. 13).

These broader understandings of students are also strongly echoed in Dahsah and Pruekpramool chapter examining the importance of funds of knowledge. Here the emphasis focuses on the student and the teacher. From a student’s point of view, “funds of knowledge not only promote better understanding and positive attitudes towards science, but also improve students’ attitudes toward learning and science in general” (p. 14). From a teacher’s point of view, a highly effective and empowering way to better understand students’ funds of knowledge is through learning with youth in places outside of school, where local wisdom can be experienced in action.

Tal also hones in on the value of out-of-door education as a way to expand not only opportunities for teachers to interact with their students differently, but to fundamentally expand the focus of environmental science education. As Tal suggests, “Educating new generations that will be attached to the land was an ideal which was far beyond simply good teaching and learning. Knowing about the nature of the country and its historical and archeological sites became a value the entire education system adopted” (p. 10).

Across these manuscripts, good science teaching and learning directly challenges the binaries which limit and frame science education in school contexts, such as insider/outsider or formal/informal, and the role that deeply understanding cultural-historical context plays in these efforts.

In closing, if we return to Quentin’s story, we see how a young 5th grade student articulates the desire to be respected by his teachers for what he knows and can do. He worries that his teacher does not know him well enough to remember his name and he implores his teacher to consider teaching “fcience” or science that is fun, science that matters.

Across the chapters in this section, we can see similar threads with historical roots in three different national contexts. Teaching science, and becoming a teacher in science, is grounded in local wisdom and a sense of place. We can learn from the efforts outlined in these four chapters about how to better support teachers through supporting their learning and in professional development in reclaiming their agency to learn within context and to incorporate the local wisdoms of professional teaching communities as well as the communities of their students in their craft.

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