

Science Education in Hong Kong: Opportunities for Research and Development

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Changes in primary and secondary science education curriculum and the overall education policy in Hong Kong over the years have directed the way researchers conducted local science education research. Due to the large amount of academic publications related to science education in Hong Kong, research works reviewed in this article are identified from main local, Asia-pacific and international science-education related journals, and also by authors from the websites of all science-education related faculties or departments of local universities and teacher education institutes. This article aims to give an overview of what has been done to support science education at the primary and secondary level in Hong Kong in the past few decades and to provide researchers with a foundation on which future research studies can be built.

Key words: primary science, secondary science, science teacher education

Introduction

Science education is important in the sense that it not only provides the most important explanations we have of the material world, but also helps us to engage with many of the issues confronting contemporary society (Osborne & Dillon, 2008). In Hong Kong, science education is a core component of the school curriculum. As stated in the Science Education Key Learning Area Curriculum Guide (Curriculum Development Council, 2002b), science education in Hong Kong aims at providing learning experiences through which students acquire scientific literacy, developing the necessary scientific knowledge and understanding, process skills, values and attitudes for their personal development, to contribute towards a scientific and technological world. The following paragraphs endeavour to provide a summary of the science education research of the primary science education and secondary science education in Hong Kong in the past few decades.

Sources of Information

Changes in science education and the implementation of school-based support and development programs have directed the way in which educators of universities and teacher education institutes conduct research related to Hong Kong's unique educational context. Despite a large body of research work, there has been no comprehensive review administered to examine the work done. In the following paragraphs, though not exhaustive, an attempt has been made to organize some major research work on science education in Hong Kong so that readers may get a glimpse of what has been done to support science education in primary and secondary sectors, as well as teacher education.

In this article, issues about the research work on Hong Kong science education are considered. Research work refers to studies which included the step of gathering quantitative and/or qualitative data related to the topic or hypothesis. And the data is then analyzed systematically and scientifically for the purpose of providing interpretation or implication to Hong Kong education system. Hence, research papers related to General Studies (GS) in the primary curriculum, Integrated Science, Physics, Chemistry and Biology in the secondary curriculum, and science education in teacher education are collected, reviewed and discussed.

Due to the large amount of academic publications pertaining to Hong Kong science education, it is difficult to include all related information and articles. There were two main sources of information. First, the research works from the main local, Asia-Pacific and international journals related to education is identified. Second, authors of Hong Kong science education related to the faculties or departments of local universities or teacher education institutes were recognized for searching of their publications. Of the local journals, we focused on the *Journal of Basic Education*, the *Education Journal*, the *Hong Kong Educational Research Journal*, the *Journal of Quality School Education*, *Curriculum Forum*, the *School Science Review* and the *Journal of Science and Mathematics Education in Southeast Asia*. Several Asia-Pacific and international journals such as the *International Journal of Science Education*, and the *Canadian Journal of Mathematics*, *Science and Technology Education* are found to contain research papers contributed by local educators. Last but not least, the online journal, the *Asia-Pacific Forum on Science Learning and Teaching*, has provided a substantial input to this review.

Primary Science and General Studies Education

Most of the research studies on primary science education in Hong Kong were conducted after the implementation of GS. When the subject was first introduced, research mainly focused on issues related to its implementation. Later, the research focus shifted to study the effectiveness of the teaching and learning. Investigations concerning initial primary science teacher education and in-service teacher professional development also contributed a significant part to the body of research.

International Studies on Primary Science Education

The earliest recorded study of primary science education in Hong Kong occurred in the early 80s when Holbrook reported and analysed the data of a study of science education in Hong Kong schools undertaken as part of the international science study conducted by the International Association for the Evaluation of Educational Achievement (IEA).

In 1983–1984, Holbrook contributed to the Hong Kong Studies of the Second International Science Studies with Primary 4 students. The mean score of Hong Kong was lower than the international mean, and Hong Kong was ranked 14th amongst the 15 participating countries. In 1995, around 8,000 Primary 3 and 4 Hong Kong students took part in the Third International Mathematics and Science Studies (TIMSS) (Law, 1997). Hong Kong ranked 10th amongst the 26 participating countries and the mean average was very close to the international average.

So (2008) analyzed the TIMSS data from the 80s to 2003 and found that the international ranking of Hong Kong Primary 4 students had increased significantly in the past 20 years, which indicated and reflected the improvement of student science achievement and the effects of the reform of the science curriculum on teaching and learning. Hence, the components in the curriculum and teaching and learning leading to such progression has become an object of study for science educators.

Curriculum Studies

The results and reports of TIMSS presented an overall picture of achievement of Hong Kong primary students and provided information of implementing science education in primary schools. However, little was done in terms of the study of primary science until GS was first implemented in 1996.

Integrated Curriculum

A number of studies related to the integrated nature of the GS curriculum were conducted after the subject was implemented. Lee (1998) measured teachers' receptivity of the subject, and the responses were found to be negative. Difficulties faced by primary school teachers during the teaching of science-related topics in GS were identified. So, Cheng, and Tsang (1998) also found that the main obstacles faced by teachers included insufficient subject knowledge, inadequate resources, lack of experience, and difficulties in handling students' learning problems.

At the end of the second year of the curriculum implementation, So, Cheng, Leung, and Wong-Yu (1999) investigated teachers' views of the curriculum integration and their understanding of integrated subjects. After five years of implementation, Lo and Cheng (2001) evaluated the

perceptions and practices of GS teachers using a questionnaire. The findings provided useful information for curriculum development.

In response to the curriculum reform in Hong Kong, the GS curriculum was revised in 2002. The case study of a beginning teacher conducted by Cheng and Lo-Fu (2002) shed light on teachers' conceptions, the organisation and structure of the GS curriculum, concepts and skills in thematic teaching, as well as teaching strategies. In GS curriculum, schools are encouraged to adopt the inquiry approach in the learning and teaching of GS. So (2002a) then suggested a curriculum design based on the viewpoint of constructivist learning theory.

School-based Curriculum

Understanding that there is no "one-size fits all" curriculum, it was suggested that school-based curriculum helps to meet the learning needs of students (Curriculum Development Council, 2002a). Ng and Fung (2006) suggested including the concept and knowledge of DNA in the GS curriculum as they observed that primary students came across a lot of information related to biotechnology in daily lives. It was concluded that such infusion was successful and worth recommending to other schools. Another study concerning the rationale and strategies as well as the difficulties for implementation of a school-based GS curriculum was conducted by Wong-Yu (2008b). The interviews with school principals, panel heads and teachers revealed the main obstacles of the implementation.

Teaching and Learning in Classrooms

Since the first introduction of the GS curriculum in 1996, there has been development and research work on inquiry learning, project-based learning, lesson study, creativity, use of IT, and teacher thinking.

Inquiry Learning

It is also suggested by the GS curriculum guide (Curriculum Development Council, 2002c) that 20% of students' learning time should be flexibly arranged to cater for the interests and needs of the students. Running a thematic science day was a common way adopted to promote students' science learning using the 20% of the GS curriculum time.

Lee and Ng (2004) conducted a study aiming to gain a better understanding of students' existing cognitive understanding and reasoning ability in investigative task on heat conduction. They assured the effectiveness of science inquiry in promoting the cognitive understanding and reasoning of students. Cho (2005) shared the experience of designing and implementing science investigation activities. She described the process of planning and preparing the solar energy activities. Apart from classroom science inquiry, Cheng and Tsoi (2004) worked collaboratively with teachers to design a science day with the theme "electricity and living" for Primary 4 students. Besides, Y. Y. So, Cheng, and Tsoi (2007) introduced a science inquiry activity about "water rockets" with Primary 5 students on the science day. By evaluating the learning outcomes of the students, suggestions to improve the design and implementation of the above activities have been made.

Project Learning

Project learning, rooted in constructivist learning theory often implemented in combination with inquiry learning. Instead of relying solely on textbooks, project learning provides students with a dynamic and diversified learning experience by engaging them in a variety of learning activities. Cheng and Tsoi (2003a) provided a summary of experience gained from a science investigation activity. The paper described the considerations for designing, performing, and assessing science experiments, and the problems that teachers or students encountered in the process. .

Cheng (2006a) described the process of implementation as well as the considerations for designing and conducting project learning activities for Primary 6 students, which was one of the initiatives of the "Assessment for Student Science Learning" project. Cheng (2006b) summarised experience of another project learning activity for Primary 6 students. The process of designing and implementing the project learning activity was described along with considerations that were worth noting.

Since report writing is the most common method used by students to demonstrate their learning outcomes, So (2007) focused on how classroom teaching could help primary school students develop their inquiry and report writing skills through engagement in activities and student-teacher interactive discussion. It was suggested that teacher scaffolding is important for students' construction of knowledge and skills for project learning.

Creativity

Although creativity is one of the nine generic skills that are to be fostered in the school curriculum, constraints such as the lack of science laboratories and science apparatus in primary schools have impeded the teachers' and students' development of such skills. M. Y. V. Cheng (2001) therefore introduced a program for developing the creativity of primary science teachers in designing hands-on science activities using everyday materials.

Local school sponsoring bodies also realised the importance of such generic skills for both teachers and students. So (2003a) expressed her view on creative teaching design in GS in a curriculum guide for creative teaching to help teachers actualise creative thinking and teaching. Role play, game and relating learning to everyday experience were suggested to develop students' creativity and knowledge. In addition, M. Y. V. Cheng (2006) collected thirty-one articles contributed by educators, school principals and teachers on creativity in teaching. The experiences shared in the book enhanced the awareness and interest of educators in "creativity in teaching" and provided useful references.

Use of Information Technology in Learning

Rapid advancement in IT and the government's efforts in promoting the use of IT across the curriculum have stimulated research interest in how IT can be used in teaching and learning.

Attempts had been made by educators to develop multimedia resources to facilitate the teaching and learning of GS. So, Hung, and Kong (2001) developed a digital video database and analysed how it assisted teachers in using IT for teaching GS. Based on the teachers' responses, ways of improving the interface of the database and enriching the content of the videos were suggested.

So and Leung (2005) studied the effectiveness of using multimedia resources to support inquiry learning of various science topics in the GS curriculum. Students' pre- and post-lesson performances showed the use of multimedia resources had inspired students to answer questions by searching for information, and had increased their learning effectiveness.

The series of research with the design of computer-mediated learning resources for the inquiry approach started with the investigation of students' construction of knowledge of family trees (Kong & So, 2005, 2008). Puberty is a topic teachers found difficult and embarrassing to teach with

other resources and aids; the design of computer-mediated learning resources for inquiry-based learning of puberty (So & Kong, 2005) provided useful information to re-organize the huge amount of relevant Internet resources available.

The studies on students' understanding of the natural phenomenon of the Earth movement started with a use of the multimedia learning unit by a teacher in two classes of students, with different pedagogical approaches (So & Kong, 2007). A better achievement attained when teaching is carried out with a learner-oriented approach in which there was less teacher control over the use of multimedia components. Another in-depth study (So & Kong, 2008) on the interaction of students' academic background and support levels in a resource-based learning environment on Earth movement found that it provided little help for the learning of students of lower academic background, but greater help for those of higher academic background. Besides, Leung, Yu, and So (2007) discovered from their study that the use of multimedia resources together with teachers' scaffolding could help primary students acquire the observation and recording skills involved in the science inquiry process.

Other than multimedia teaching resources and units, the use of IT in GS can take many different forms. Cheng and Li (2002) implemented three innovative science teaching methods (data logger experiments, web technologies in a science project, and use of IT in science assessment) and found that these innovations benefited students' science learning. A conceptual framework which analyses the influence of IT on the teaching and learning of GS was also proposed. Yuen (2005) engaged primary students in an interschool asynchronous online threaded discourse through a computer mediated communications platform. The results showed that online discourse could broaden the basis for learning and teaching science. By involving primary students as research participants as Yuen (2005) did, Li, Law, and Lui (2006) discovered that the use of the cognitive perturbation strategy in conjunction with a dynamic computer-supported modelling environment could facilitate the conceptual change of students.

Notwithstanding the utilization of resources, teachers' beliefs and attitudes towards the use of IT in teaching are fundamental to the infusion of IT in classrooms. So (2002c) investigated teachers' feelings, intentions towards the use of IT, their perceptions of the usefulness of IT, and their ability to use IT in their teaching. The findings that teachers believed they were ill-prepared for the integration of IT into the classroom revealed the need to provide training for teachers.

Student Learning

Various research studies investigated strategies in the teaching and learning of science and GS; however, it is also important to know more about the development of students' investigative skills, metacognition, understanding and conceptions of science. Assessment of student learning has also been discussed.

Developing Science Inquiry and Investigation Skills

Science teacher educators of The Hong Kong Institute of Education (HKIEd) and government officials of the Curriculum Development Institute (CDI) have been working collaboratively to organise an annual event "Primary Science Project Exhibition" since 1998. Over the years, the work has provided valuable data for researchers to understand the process of science inquiry and the way in which science inquiry is carried out.

Besides, So (2000) administered questionnaires to collect the views of primary school teachers and students towards science inquiry activities. The findings revealed the difficulties encountered by teachers and students in the science inquiry process. To gain further understanding of how students are involved in the different stages of the science inquiry process, So (2003c) explored the cognitive process of the students involved in science investigations by studying the twenty-four outstanding written records. In a later study, So (2006) analysed the written reports, oral presentations and reflections from sixteen outstanding teams. A framework of an inquiry science model was constructed based on the findings.

So and Cheng (2002) made an attempt to understand the development of multiple intelligences among primary students through science projects by analysing oral presentations and written reports. In addition, So recognised the different needs of students, teachers and parents, she illustrated and presented the process of project learning in the form of a children's story (So, 2003b) and analysed the teaching effectiveness of project learning from the perspective of an educator (2003c).

Metacognition

Thomas and Au (2005) investigated the development of a learning environment instrument and reported the impact of altering the learning environment on the students' metacognition. The General Studies

Metacognitive Orientation Scale (GSMOS) was administered to primary students, and the results suggested that although there was no statistical difference between the pre- and post-intervention environment, positive shifts in metacognitive orientation and the effects of pedagogical changes on students' metacognition were revealed.

Integrating Science Learning and Chinese Language

Mak (1998) suggested a way of integrating the learning of GS to the learning of Chinese language. He shared his experiences in the design of two GS units by using mazes, riddles and other activities to improve student learning of content knowledge and Chinese writing skills, as well as to enhance students' motivation.

Cheng and Soon (2003, 2004) studied the relationship between Chinese characters and science learning with cooperating teachers who taught both Chinese language and GS. They found that the radicals (部首) of some living things influenced students' understanding of their classification, and that some radicals and terms (詞匯) could enhance students' understanding of the related science concepts. The related study conducted by Soon and Cheng (2008) interviewed primary students about twelve Chinese terms that could generate alternative conceptions. The results showed that the meanings of structural morphemes influenced the development of students' conceptions related to animal classification and might lead to misconceptions.

Student Understanding of Science Concepts

It is also important to understand children's beliefs about learning and how such beliefs relate to their understanding of the learning content. Chan and Sachs's (2001) study showed that the age of elementary students had an effect on their beliefs about constructivist learning, and subsequently had the effect on their epistemological beliefs on their science text understanding.

Lee and Kwok (2009) explored the conceptions of air resistance to Primary 6 students by using the egg-dropping race as an intervention. The findings showed that only a relatively small proportion of students achieved a greater understanding of the concept after the intervention. They suggested that the concept should be made more visible and be connected to their daily life experiences.

Assessing Student Learning

Assessment, as an integral part of the learning-teaching-assessment cycle (Curriculum Development Council, 2002c), is of vital importance to student learning. Cheng, So, and Cheung (2001a) reviewed the assessment practices that science teachers commonly adopt. Their findings revealed a need for professional development to enhance teachers' confidence in implementing formative or alternative assessment tasks.

Wong-Yu (2004) studied the difficulties in implementing formative assessment and pointed out the need to provide an on-going staff development to teachers. Suggestion of informing students the characteristics of formative assessment, their role in the process of learning, and teachers' feedback was recommended. In another study, Wong-Yu (2008a) surveyed primary students and their parents and identified neither the parents nor the students thought that school-based assessment would raise children's motivation.

The Schools Around the World (SAW) Project was an international project on teacher professional development initiated in 1999 by the Council for Basic Education (CBE) in the United States. Cheng (2002) as well as Cheng and So (2002) analyzed student work samples of the SAW project collected from Hong Kong and other parts of the world. The importance of developing interdisciplinary learning, lifelong learning skills and communication skills through alternative assessment was highlighted. With the rich collection of student work samples, Cheng (2005) discussed the design, implementation and evaluation of science inquiry activities and assessment tasks.

Teacher Education

Initial teacher education serves to prepare student-teachers with the competence, skills and attitudes to become professional teachers as well as to ensure student-teachers meet the requirements of qualified teachers. Teacher professional development refers to the on-going learning process to enhance in-service teachers' knowledge, skills, understanding and attributes.

Initial Teacher Education

So and Cheng (2001) contributed to the development of science teacher education by investigating how active learning enhances the scientific

literacy of student-teachers. Results provided evidence that active participation in science activities could promote the scientific literacy of the participants. The study also suggested that science inquiry could help student-teachers to better connect science learning to their daily lives.

In a study focusing on the usefulness of a website in supporting development of teaching competence during the various kinds of field experience activities (Cheng, So, & Yeung, 2005), it is found that the website was successful in supporting the learning of student-teachers. Moreover, these student-teachers appreciated the website helping them gain initial experience of teaching and providing them a platform to share feelings and exchange ideas. So, Hung, and Yip (2006, 2008) examined the use of a digital video database in building an online community for GS student-teachers. This study suggested that the digital video database had helped student-teachers learn about good teaching practices.

Teacher Thinking

Due to the advances in cognitive psychology and respective research techniques, research on teacher cognition has become more focused on teachers' unobservable thinking processes rather than on their observable behaviour. So (1997) uncovered teachers' thinking processes during lesson planning by using the Taxonomy of Observed Teacher Thinking developed by Tang and Watkins (1994).

In a study which examined teachers' thinking about teaching, So (2002b) found from the analysis of the lesson observations that pre-service teachers developed a more constructivist view of teaching and learning and moved to a student-centred approach. Another longitudinal study explored how teachers' thinking in four major aspects of conceptions, planning, teaching, and reflection was reported by So and Watkins (2005). Positive findings were that teachers became more constructivist in terms of their conceptions and practice of teaching, but they also tended to become more simplistic in planning and less coherent in thinking as they progressed.

Lesson Study

Originating in Japan, lesson study gives teachers the opportunity to examine the student learning and understanding process by observing and discussing actual classroom practice. So and Kwong (2003) reported on the findings from a lesson study conducted with Primary 6 students on the topic of

“solar eclipse”. It was found that the constructivist approach to teaching science was effective in enhancing children’s understanding. Lo-Fu and So (2004) examined the influence of lesson study on the professional development of teachers. The results of the students’ pre- and post-lesson tests indicated an improvement in student achievement, and the interviews with teachers showed that lesson study provided a great opportunity for teachers to experience personal, social and professional development.

The study of Lo, Chik, and Pang (2006) adopted the concept of “Learning Study”, which was developed with reference to the Theory of Variation and Lesson Study. The findings consented what teachers know and do to improve student learning were important, and the difference in the pattern of variation being created was a crucial factor in determining whether students were provided with the target learning experience.

Teacher Professional Development

So and Cheng (2000) evaluated the effectiveness of an in-service primary science teacher development workshop by using the data collected from surveys, journal writing and interviews. The findings suggested that the teacher development workshop supports the professional, personal and social development of teachers.

The project of SAW involved teacher educators and government officials from nine nations including Hong Kong. Cheng, So, and Cheung (2001b) reported how student work samples and technology can achieve the aim of stimulating professional discussions among local primary and secondary science teachers, as well as exchanges between the local and international science teaching communities. Cheng and Ching (2004a, 2004b) summarized the strategies adopted by the SAW project in order to facilitate teacher participation in the professional discussions using technology. The use of online courses, theme-based online discussion seminars, a system called SHARES (Shared Reflection System), and the SAW data-base in the facilitation of the professional development of science teachers were summarized by Cheng, Stoel, and Anderson (2004).

Secondary Science Education

Research studies of secondary science education focus on most of the areas in which researchers of primary science education are interested. Science-

Technology-Society, integrated science learning with creativity and IT, and the teaching and learning of specific topics in various disciplines of science are also important areas in the research of secondary science education. Also, there are studies focusing on assessment including the teacher assessment scheme, alternative assessment, and students' performance in science learning, and the influence of the learning environment and social issues on science learning and teaching.

International Studies on Secondary Science Education

Law (1996) discussed the findings of the TIMSS about students' science and mathematics achievement at junior secondary levels. Hong Kong ranked 16th among 41 countries, it was close to the international average but not better than other Asian Pacific countries and Western developed countries. Leung, Yung, and Tso (2002) analyzed the achievement of Hong Kong Secondary 2 students from TIMSS-R data collected in 1999. They found that Hong Kong students' science performance ranked 15th out of 38 countries, which was marginally above the international standard. Leung, Yung, and Tso (2005) further performed an analysis of student's science achievement in TIMSS-R. The objective was to identify the factors relating to curriculum provision, teacher characteristics and classroom conditions and climates.

Yung (2006b) edited a book contains the analysis result of TIMSS 2003 by different researchers as Yung (2006a), Wong (2006), M. W. Cheng (2006), Yung and Wong (2006) conducted similar studies related to the subject of biology and environmental science, physics, chemistry and nature of science respectively. Cheng, Yung, and Wong (2006) collaborated and focused on exploring gender differences in student's performance. In this book, it was revealed that Hong Kong students outperformed than the international average in every domain but improvement was specially needed for students' understanding on nature of science.

Curriculum and School-based Curriculum

In 1987, Tao (1987) conducted teacher questionnaire surveys to estimate the implementation of practical work in HKCEE physics. Popularity, types, time spent and obstacles faced in practical experiments were the main focus of his study. The following is a series of projects on measuring teachers' beliefs and concerns conducted by Cheung and his research colleagues.

Cheung and Ng (2000) measured teachers' beliefs about the curriculum design from different perspectives. The results showed that teachers' orientation was influenced by the teaching discipline, but the gap between cognitive process and humanistic orientation disappeared as teachers gained more experience. Additionally, Cheung (2002) based on a modified conducted research on the concerns of teachers about the education innovations. Six main stages of teachers' concerns about Teacher Assessment Scheme (TAS) were identified and the model was further used by Cheung and Wong (2002) to compare teacher beliefs about alternative curriculum designs. It was found that teachers' orientations were correlated and science teachers were less humanistic than English teachers. T. S. T. Wong (2001) worked with schools to plan, implement and evaluate a school-based science curriculum development model. He suggested that more exemplars, professional advices and administrative support were needed to help teachers become more competent in using group work. Chan and Kwok (2003) studied the teaching context of the topic "clean water", and identified three features in the teaching of the topic from lesson observations, including "relevance to learners' life", "problem-solving and thinking skills" and "science-technology-society".

Teaching and Learning in Classrooms

Science Inquiry

Research related to science inquiry conducted in the 2000s were mainly in three directions, namely the laboratory or practical arrangements for inquiry, the affective learning objectives, and the integration of inquiry with learning objectives.

The first group of studies began by Yip (2001), who designed an inquiry-based activity to illustrate how to use students' question to motivate and consolidate science learning. His further investigation was the implementation of inquiry-based learning in Hong Kong through examining laboratory manuals (Yip, 2005). Cheung (2008b) identified chemistry teachers' major concerns about inquiry-based laboratories including lack of class time, shortage of effective instructional materials and the need to teach large classes and hence designed a teaching strategy that adopting guided inquiry and student oral presentation as a key part of inquiry process.

The second group of studies was initiated by Yung and Tao (2004a). They studied the effects of cognitive and affective learning through lesson observations and interviews. They also evaluated affective learning from teachers' observations of their own lessons (Yung & Tao, 2004b).

The third group of studies endeavoured to link science inquiry with learning outcomes advocated in the recent education reform which included student autonomy in learning, developing understandings of the nature of science, and integrating science with interdisciplinary projects. Tao (2001) required students to work in groups and then evaluated the influences of social effort on the development of their problem solving skills and understanding. Cheng (2004), based on student work samples from different countries, described a variety of ways in which teachers designed or made use of open-ended journal entries for students to record biology experiment results, field observations and inquiry projects. Cheng and Tsoi (2005) introduced inquiry-based learning with exemplars at junior secondary level, concluding from evaluating students' homework that they would be better at handling inquiry if they had more autonomy. Cheng and Tsoi (2003b) also studied the inquiry-based learning about "acid rain" and concluded that the coordination among teaching, learning and assessment were needed for developing students' inquiry skill and logical thinking ability. Cheng (2006d) designed a series of teaching materials and guidelines based on the school-based assessment scheme to promote students' inquiry skills. Tao (2003) identified student understanding of the nature of science through learning with peer collaboration. Yung and Tao (2004c) then introduced scientific inquiry lesson to a Secondary 1 class and observed the learning outcome based on the theory of variation. They also provided a strategy of improving students' confidence on learning. Chan, Cheng, and Tsoi (2007) reported on a series of lessons designed to integrate the learning of the nature of science in the junior secondary science subject. The principles of the design, and the intentions and philosophy underpinning the various teaching activities were revealed. Cheng, Cheung, and Chung (2008) reviewed the experience of developing and implementing interdisciplinary project learning at the junior secondary level. The study illustrated how science could be integrated with other areas of learning.

Science-Technology-Society (STS)

The integration of science learning in the context of technology and society concerns was in line with contemporary science education research

directions (Education Commission, 2000) as well as the local education reform directions (Curriculum Development Council, 1999). The concern with STS teaching started with Or (1994); he found that many chemistry teachers, when teaching social-related content, had no idea which and when the suggested activities should be used. He suggested the curriculum developers to rank the effectiveness of the activities for each objective area to crystallise teachers' conceptions. Also, Lee (2006) introduced a scientific experiment on treating kidney failure to enhance students' problem solving skills in STS lessons. Lee identified students' misconceptions through the lesson observation and student attitude about the activity from the post-lesson questionnaire.

Creativity, Information Technology and the Teaching of Specific Topics in Science

Although creativity became a major objective in education in Mainland China and Taiwan, there was a lack of related teaching methods. M. Y. V. Cheng (2004) designed a series of creative activities which could be applied to physics lessons. Both teachers and students' opinions reflected these activities changed and enhanced students' ability, awareness and attitude of creativity in physics learning.

In the last decade, the Curriculum Development Council has devoted efforts to the development of IT for learning (Education and Manpower Bureau, 1998) to consolidate students' knowledge base and enrich their interest, as well as to make students lifelong learners. An organised research project introduced a data-logging activity to teach or implement physics experiments (Ng & Yeung, 2004). The activities implied that the guidelines, activities and public examination should be carefully structured.

There were also attempts to develop interventions and related evaluations for the teaching of secondary science topics. Lee (2004) designed a model with the use of pig's heart for illustrating heart and circulatory systems in mammalian animals. Cheng (2003b) described the considerations for designing, performing, and assessing science experiments, and the problems that teachers encountered in the process of science investigation and project learning with the topic "acid rain". Lau and Yip (2004) used the traditional and the constructivist approaches to teach the topic of genes in two classes. By studying students' answers in a test, their alternative concepts were identified and compared. Chan and Kwok (2005) introduced three experiments for teaching the concepts of Newton's first

law of motion. It was found that the learning outcome of teaching practices was supported by the teachers and the junior secondary students. Wong and Mak (2008) investigated the refractive indices of liquids with the use of laser pointer and the apparatus named lazy Susan. The guidelines of the experiment for high school teachers were provided. Lee (2007c) described four simple activities which were successful in engaging students' understanding on nature of science and were suitable for learners of different learning abilities. Lee (2007a) also raised another socio-scientific issue, smoking, for secondary school students. The lessons not only aimed at developing students' conceptual understanding and skill of scientific inquiry but also engaging their decision-making, attitudes and values.

Assessing Student Learning

Teacher Assessment Scheme

TAS aims to test students' science knowledge and practical abilities by means of a series of continuous laboratory experiments. This approach can determine student achievement which cannot be easily observed in an examination, but at the same time releases the pressure faced by students in formal examinations. Yung (2001b) reported that teachers' classroom decisions were affected by their notion of fairness when implementing TAS. He also claimed the need for teachers to learn the philosophy of the new assessment scheme. A more detailed report of his research findings was published in a 293-page book which related teacher professional development and teachers' knowledge and beliefs about science, purpose of TAS as well as their pedagogies (Yung, 2006c).

TAS changed the role of science teachers. Yung (2001a) found from interviews that science teachers analogized themselves as examiners, policemen and student companions in the classroom. These findings shed light on the future of teacher professional development. Another study by Cheung and Yip (2003) revealed teachers were concerned about the increase in the number of experiments, fearing that a lack of support from authority would lead to problems with teachers' and students' workload, resources and support, moderation mechanisms, student motivation and teacher collaboration. A similar study was carried out to determine AL biology teachers' concerns. The major concerns were the lack of resources and time, and student motivation (Yip & Cheung, 2005). Another aspect of research concerning TAS looked into the design,

implementation and teacher professional development. Cheung and his research team members studied the implementation of school-based assessment (SBA) in Hong Kong. These studies included determining the degree of implementation of SBA and teacher's concerns (Cheung, Hattie, Bucat, & Douglas, 1996) and the concerns of biology and chemistry teachers about SBA (Cheung & Yip, 2004). Yung (2002) made use of teachers' professional consciousness to determine their educational practices. Yip and Yung (1998) provided a guideline of constructing investigative practical works, which adapts to the current laboratory manuals. It was suggested that teachers should design the activities based on realistic contexts. Later, Yip and Yung (1999) thought most of the laboratory manuals in the practical work were dominated by instruction. They developed a program called "Promoting understanding and mastery of investigative skills" (PUMIS) with devised teaching strategies and evaluation of program.

Alternative Assessment

Alternative assessment advocates the implementation of alternative forms of science assessment tasks which are different from pencil and paper tests. C. L. Cheng and Tang (1997) suggested that practical assessment should be performed in Integrated Science in the junior secondary curriculum. Cheng (2003a) collected junior secondary teachers' views on alternative and formative assessment, which helped to explore their need for assistance, and provided suggestions for implementation.

The study of the practice of teachers related to alternative assessment started with the attempt of Cheng and Cheung (2001) to review science and biology assessment in science classes. They suggested the need for a change of assessment to alternative forms of assessment, and provided related recommendations to support teachers. They also studied the changes in teachers' practice as well as their beliefs about educational innovation after two years of implementation of the SBA (Cheng & Cheung, 2005). Implications for teacher professional development related to changing teachers' assessment practice were also drawn by Towndrow, Tan, Yung, and Cohen (2008), who compared the attitudes toward science practical assessment of teachers from Singapore and Hong Kong.

In terms of suggestions and support for science teachers in implementing alternative assessments, Cheng (2006c) defined practices for alternative assessment based on the constructivist view of learning. Cheung

(2006) suggested and evaluated a computer system called the Test Construction Support System (TCSS) for chemistry teachers which allowed them to implement formative assessment and assess students efficiently.

To sum up the various attempts to identify teacher practices and support for implementing alternative assessment, Cheng (2008) reported the movement towards SBA, findings of studies investigating teachers' perceptions of assessment, and project initiatives delivered to support the movement.

Student Performance in Science Learning

The research on student performance in science could be categorized into three main areas. The first area includes studies on student thinking, problem solving and communication abilities. Tao and Mak (1987) measured the qualitative reasoning abilities and strategies used in solving physics problems by Form 5 students as the curriculum moved from solving numerical problems to grasping relevant concepts. Cheng (1997) assessed students' communication skills in the CE level physics to show how students' communication marks in examinations could be awarded. Yip (2004b) also analyzed student performance in various types of questions which tested their abilities from different perspectives in the 2004 CE biology paper I. He discovered that communication skills and language proficiency were the major weaknesses of students.

The second group of studies identified students' understanding of particular science topics. Yip studied students' answers in HKCEE on various topics in biology including reproduction (Yip, 1998a), lactic acid fermentation (Yip, 2000) and transpiration (Yip, 2003), in order to understand students' comprehension of biological contexts. Mak and his research team members also analyzed three main technical and conceptual errors in the AL physics examination (Mak & Yip, 2002).

The third group of studies investigated the science learning of junior secondary students, encompassing research on scientific literacy, the nature of science, self-regulated learning (SRL) abilities, and students' attitudes to learning. Yip (2004a) determined junior secondary students' scientific literacy from the project of PISA2000 that Hong Kong students performed well on "using scientific knowledge" and "drawing conclusions" but were weak in "recognizing questions" in comparison with students from other countries. Tao (2002) focused on students' focal awareness when testing their understanding of the nature of science, with support from Marton's

theory of awareness. The study of Ho (2004) showed that Hong Kong students used SRL less frequently than students in other countries. It was suggested that the learning environment should be further studied. Research on science achievement or teacher's opinions is abundant; however studies about students' views are apparently inadequate. Cheung (2008a) used the attitude toward chemistry lesson scale (ATCLS) to determine student's attitudes and views concerning a chemistry lesson. He also used the same survey result to analyze the change of students' attitude due to the interaction of students' grade level and gender (Cheung, 2009a). Broad and longitudinal research studies were suggested for further development.

Learning Environment and Social Issues on Science Learning

Regarding learning environment, Lee, Li, Yeung, and Ling (1997) showed the main advantage of using visual aids in science teaching was that it effectively aroused students' interest and illustrated scientific facts, laws and theories. Besides, Mak and Wong (2006) designed a Laser-Assisted in Situ Keratomileusis (LASIK) experiment and evaluated its effectiveness by observing and interviewing students.

Thomas (2003) studied the validity of the Metacognitive Orientation Learning Environment Scale (MOLES-S) in science classroom learning. He further determined the validity of the scale by analyzing data from two individual populations, and applied the data sets to two different statistical models (Thomas, 2004). A comparison between the learning environment in classrooms with and without Confucian-heritage culture was conducted using MOLES-S.

Concerns have been prevailing about whether English is a suitable medium for science teaching and learning in Hong Kong. Loi (1986) determined the differences between student performance in the subjects of Natural Studies and Social Studies when students learnt with different languages. Tao (1994) studied students' comprehension of some English non-technical words used in science, whilst Yip, Tsang, and Cheung (2003) compared the science achievement of Hong Kong students studying science in Chinese and English. As for teachers, their awareness of the role of language was crucial for science learning in English (Hoare, 2003). Researchers have also studied different aspects of social effects on student's achievement. K. C. Cheung (1991) studied the relationship between the socio-educational status of students' homes, which reflected students'

science achievement was mainly based on parental occupation and education level. Chan (2001) randomly assigned students to four conditions with different forms of peer collaboration, and studied the effect of peer collaboration on engaging in productive discourses. Lam and Ho (2003) studied the information from the questionnaire in PISA2001 and discovered that communitarianism and social capital were positively related to student learning. Furthermore, Yeung, Liu, and Ng (2005) studied the characteristics of the social network of research collaboration in physics education, and found the less collaboration between researchers in physics education.

Teacher Education

For research focusing on secondary teacher education, three main aspects were identified. The first aspect was related to teachers' science knowledge. Yip, Chung, and Mak (1998) determined physics teachers' knowledge and provided implications for improving tertiary education and teaching education. Yip (1999) investigated teachers' conceptions and misconceptions of control experiments in photosynthesis and germination. Yip (1998b) conducted a similar study to determine teachers' misconceptions of the circulatory system. Cheung (2009b, 2009c) focused on teachers' misconception on chemical equilibrium. The review and implications on teacher education as well as on the school curricula were suggested.

The second aspect was related to the use of IT in teacher education. Yung, Wong, and Cheng (2004) studied teachers' conception of good science teaching with the use of video data about exemplary science teaching. They had also investigated factors affecting student teachers' conception of science teaching. After two years, Wong, Yung, Cheng, Lam, and Hodson (2006) conducted a similar study and found that there was a conceptual change of good science teaching prior and after the formal instruction. Furthermore, Wong and Mak (2007) found that there was an awareness of alternative teaching methods as the novice teachers experienced different classroom situations.

The third aspect of secondary teacher education focused on development of student teachers or beginning teachers. Lee (2007b) shared his experience of performing a scientific experiment of "egg-in-the-bottle" for student teachers. The problem-solving, constructivist-approach activity greatly motivated the student teachers but some drawbacks were also

highlighted. Wong, Hodson, Kwan, and Yung (2008) provided insight into instructional materials which focused on the topic of SARS used in local pre-service and in-service teacher education programs. The research revealed the topic of SARS effectively promoted student-teachers' understandings on nature of science and scientific inquiry.

Future Direction in Hong Kong Science Education

The present review identified the areas of concerns of science educators and teachers. Neglected areas of studies in science education were discovered, for instance, discussions on students' science learning related to extra-curricular activities and project learning were only at the primary level. Besides, it was observed that some researchers used both quantitative and qualitative measurements in a study but most of them only used either one of them. Mostly, quantitative method was used in a large-scaled study concerning the general phenomenon or trend in Hong Kong schools, and data was collected mainly by means of questionnaire survey or student test. In this kind of research, researchers were more likely to focus on teachers' view or students' knowledge. Other research studying a small community or with a more specific aim would select qualitative method. The data came from a wide range of sources, such as interviews, journal writing, reflection reports, teaching materials, and student work sample. Moreover, though school-based curriculum is emphasized in local schools, action research and school-based research were not commonly found to involve teachers to integrate the theory and practice in their own classrooms.

Nevertheless, the research conducted in the past concerning science education in Hong Kong has provided researchers with a rich foundation upon which future research can be built. In respect of students' learning and acquisition of skills and abilities, future research in science education may need to focus more on the following aspects: students' prior knowledge, teacher instructional techniques and learning environments to support deep conceptual understanding, student learning processes, and students' reflection on their own learning. Whereas for teacher education, researchers may need to devote their efforts to research studies that make use of multidisciplinary and pluralistic methodologies, and take advantage of the new tools for the gathering and analysis of data (Borko, Whitcomb, & Byrnes, 2008).

References

- Borko, H., Whitcomb, J. A., & Byrnes, K. (2008). Genres of research in teacher education. In M. Cochran-Smith, S. Feiman-Nemser, D. J. McIntyre, & K. E. Demers (Eds.), *Handbook of research on teacher education: Enduring questions in changing contexts* (3rd ed., pp. 1017–1049). New York: Routledge.
- Chan, C. K. K. (2001). Peer collaboration and discourse patterns in processing incompatible information. *Instructional Science*, 29(6), 443–479.
- Chan, C. K. K., & Sachs, J. (2001). Beliefs about learning in children's understanding of science texts. *Contemporary Educational Psychology*, 26(2), 192–210.
- Chan, M. T., & Kwok, P. W. (2003). Facilitating active learning through a thematic science curriculum. *Asia-Pacific Forum on Science Learning and Teaching*, 4(2), Article 12.
- Chan, M. T., & Kwok, P. W. (2005). Challenging students' conceptions about the phenomena of inertia. *Asia-Pacific Forum on Science Learning and Teaching*, 6(1), Article 4.
- Chan, Y. L., Cheng, M. H. M., & Tsoi, H. L. (2007). Facilitating secondary students' understanding of the nature of science. In W. M. So & M. H. Cheng (Eds.), *Science education research in Chinese speaking societies* (pp. 58–71). Hong Kong: Seedland Publishing.
- Cheng, C. L. (1997). Assessing communication skills in the HKCE physics examination. *Hong Kong Science Teachers' Journal*, 20(1), 33–37.
- Cheng, C. L., & Tang, K. P. (1997). Practical assessment in science. *Hong Kong Science Teachers' Journal*, 20(1), 74–85.
- Cheng, M. H. M. (2002). Assessment of student work in science. *Asia-Pacific Forum on Science Learning and Teaching*, 3(2), Article 1.
- Cheng, M. H. M. (2003a). Junior secondary science teachers' understanding and practice of alternative assessment in Hong Kong: Implications for teacher development. *Canadian Journal of Science, Mathematics and Technology Education*, 6(3), 227–243.
- Cheng, M. H. M. (2003b). A secondary two science investigation project — The effects of acid rain on plant growth. *Asia-Pacific Forum on Science Learning and Teaching*, 4(1), Article 6.
- Cheng, M. H. M. (2004). Motivating the learning of biology through daily journal. *Biology Teaching in Middle Schools*, 131, 7–13.
- Cheng, M. H. M. (2005). *The design and assessment of science learning tasks*. Taipei: Wu Nan Culture Enterprise.
- Cheng, M. H. M. (2006a). Designing project learning activity: Creating a new organism. *Asia-Pacific Forum on Science Learning and Teaching*, 7(2), Article 6.
- Cheng, M. H. M. (2006b). *Project learning: Design and implementation*. Hong Kong: Chinese Technical Press.

- Cheng, M. H. M. (2006c). Constructing science assessment based on a constructivist view of learning of learning — Hong Kong secondary teachers' beliefs and practice. *International Journal of Learning*, 12(8), 11–21.
- Cheng, M. H. M. (2006d). Junior secondary science investigation activities: Students' needs and design strategy. *Journal of Basic Education*, 15(1), 77–94.
- Cheng, M. H. M. (2008). The assessment reform in science in Hong Kong: Policy, teacher beliefs and practice. In R. K. Coll & N. Taylor (Eds.), *Education in context: An international examination of the influence of context on science curricula development and implementation* (pp. 333–342). Rotterdam, The Netherlands: Sense publications.
- Cheng, M. H. M., Cheung, L. M., & Chung, S. C. (2008). The design and implementation of interdisciplinary projects at junior secondary levels. In M. H. Cheng & T. Y. Lo (Eds.), *Integrated learning in secondary schools: Theories and practice* (pp. 183–210). Singapore: Manhattan Press.
- Cheng, M. H. M., & Cheung, W. M. F. (2001). Science and biology assessment in relation to the recently proposed educational reform in Hong Kong. *Journal of Biological Education*, 35(4), 170–177.
- Cheng, M. H. M., & Cheung, W. M. F. (2005). Science and biology assessment in Hong Kong — Progress and developments. *Journal of Biological Education*, 40(1), 11–17.
- Cheng, M. H. M., & Ching, Y. K. (2004a). Schools around the world project: Using information technology to facilitate science teaching. *China Educational Technology*, 2, 77–80.
- Cheng, M. H. M., & Ching, Y. K. (2004b). Schools around the world project (SAW): Facilitation of professional development of science teachers through the use of information technology. *The Journal of Quality School Education*, 3, 59–67.
- Cheng, M. H. M., & Li, K. M. (2002). The use of information technology in science teaching: Implications on student learning. *Asia-Pacific Forum on Science Learning and Teaching*, 3(1), Article 2.
- Cheng, M. H. M., & So, W. M. W. (2002). The assessment of interdisciplinary tasks — Implications from the constructivist view of learning. *Asia-Pacific Forum on Science Learning and Teaching*, 2(2), Article 1.
- Cheng, M. H. M., So, W. M. W., & Cheung, W. M. F. (2001a). The assessment of science learning in schools in Hong Kong: The status quo and future directions. *Asia-Pacific Forum on Science Learning and Teaching*, 1(2), Article 2.
- Cheng, M. H. M., So, W. M. W., & Cheung, W. M. F. (2001b). The schools around the world project: An attempt to enhance the quality of science teaching. *Asia-Pacific Forum on Science Learning and Teaching*, 1(2), Article 3.
- Cheng, M. H. M., So, W. M. W., & Yeung, Y. Y. (2005). An effective web-based approach to support the initial training of science teachers. *Journal of the International Society for teacher education*, 9(1), 13–22.
- Cheng, M. H. M., & Soon, A. L. (2003). A study of the structure of Chinese characters and science learning. *Asia-Pacific Forum on Science Learning and Teaching*, 4(2), Article 4.

- Cheng, M. H. M., & Soon, A. L. (2004). Chinese radicals/words and the construction of science concepts. *Asia-Pacific Forum on Science Learning and Teaching*, 5(3), Article 2.
- Cheng, M. H. M., Stoel, C. F., & Anderson, E. (2004). Online professional development of teachers through the schools around the world (SAW) program. In C. Vrasidas & G. V. Glass (Eds.), *Online professional development for teachers* (pp. 177–198). Greenwich, CT: Information Age Publishing.
- Cheng, M. H. M., & Tsoi H. L. (2003a). A primary six science investigation project — “Force and simple mechanics”. *Asia-Pacific Forum on Science Learning and Teaching*, 4(2), Article 9.
- Cheng, M. H. M., & Tsoi, H. L. (2003b). A secondary two science investigation project — The effects of acid rain on plant growth. *Asia-Pacific Forum on Science Learning and Teaching*, 4(1), Article 6.
- Cheng, M. H. M., & Tsoi, H. L. (2004). The exemplar of science day activity on “electricity and living” (Primary 4). *Asia-Pacific Forum on Science Learning and Teaching*, 5(2), Article 3.
- Cheng, M. H. M., & Tsoi, H. L. (2005). Designing and implementing scientific investigation activities at junior secondary level. *Asia-Pacific Forum on Science Learning and Teaching*, 6(1), Article 5.
- Cheng, M. W. (2006). Learning from students’ performance in chemistry and environmental science-related questions. In B. H. W. Yung (Ed.), *Learning from TIMSS: Implications for teaching and learning science at the junior secondary level* (pp. 51–74). Hong Kong: Education and Manpower Bureau.
- Cheng, M. W., Yung, B. H. W., & Wong, S. L. (2006). Gender differences in student performance. In B. H. W. Yung (Ed.), *Learning from TIMSS: Implications for teaching and learning science at the junior secondary level* (pp. 95–115). Hong Kong: Education and Manpower Bureau.
- Cheng, M. Y. V. (2001). Enhancing creativity of elementary science teachers — A preliminary study. *Asia-Pacific Forum on Science Learning and Teaching*, 2(2), Article 4.
- Cheng, M. Y. V. (2004). Developing physics learning activities for fostering student creativity in Hong Kong context. *Asia-Pacific Forum on Science Learning and Teaching*, 5(2), Article 1.
- Cheng, M. Y. V. (2006). *Development of creativity in teaching*. Hong Kong: Ming Pao Publications.
- Cheng, N. Y., & Lo-Fu, Y. W. (2002). Interdisciplinary curriculum: A case study of General Studies teaching. In Y. T. Cheng, K. T. Tsui, K. W. Chow, & M. M. C. Mok (Eds.), *Subject teaching and teacher education in the new century: Research and innovation* (pp. 317–348). Hong Kong: The Hong Kong Institute of Education.
- Cheung, D. (2002). Refining a stage model for studying teacher concerns about educational innovations. *Australian Journal of Education*, 46(3), 305–322.
- Cheung, D. (2006). TCSS: A new computer system for developing formative assessments. *School Science Review*, 88(322), 61–70.

- Cheung, D. (2008a). Developing a scale to measure students' attitudes toward chemistry lessons. *International Journal of Science Education*, 31(6), 2185–2203.
- Cheung, D. (2008b). Facilitating chemistry teachers to implement inquiry-based laboratory work. *International Journal of Science and Mathematics Education*, 6(1), 107–130.
- Cheung, D. (2009a). Students' attitudes toward chemistry lessons: The interaction effect between grade level and gender. *Research in Science Education*, 39(1), 75–91.
- Cheung, D. (2009b). The adverse effects of Le Chatelier's principle on teacher understanding of chemical equilibrium. *Journal of Chemical Education*, 86(4), 514–518.
- Cheung, D. (2009c). Using think-aloud protocols to investigate secondary school chemistry teachers' misconceptions about chemical equilibrium. *Chemistry Education Research and Practice*, 10(2), 97–108.
- Cheung, D., Hattie, J., Bucat, R., & Douglas, G. (1996). Measuring the degree of implementation of school-based assessment schemes for practical science. *Research in Science Education*, 26(4), 375–389.
- Cheung, D., & Ng, P. H. (2000). Science teachers' beliefs about curriculum design. *Research in Science Education*, 30(4), 357–375.
- Cheung, D., & Wong, H. W. (2002). Measuring teacher beliefs about alternative curriculum designs. *The Curriculum Journal*, 13(2), 225–248.
- Cheung, D., & Yip, D. Y. (2003). School-based assessment of chemistry practical work: Exploring some directions for improvement. *Education Journal*, 31(1), 133–152.
- Cheung, D., & Yip, D. Y. (2004). How science teachers' concerns about school-based assessment of practical work vary with time: The Hong Kong experience. *Research in Science & Technological Education*, 22(2), 153–169.
- Cheung, K. C. (1991). Socio-educational status and science achievement — A quantitative view on social stratification in Hong Kong. *Education Journal*, 19(1), 57–68.
- Cho, K. F. (2005). Solar energy investigation activities for primary pupils — Experience sharing from a teacher of a solar energy school in Hong Kong. *Asia-Pacific Forum on Science Learning and Teaching*, 6(1), Article 7.
- Curriculum Development Council. (1999). *A holistic review of the Hong Kong school curriculum proposed reforms*. Hong Kong: Government Printer.
- Curriculum Development Council. (2002a). *Basic education curriculum guide — Building on strengths (Primary 1 to Secondary 3)*. Hong Kong: Government Printer.
- Curriculum Development Council. (2002b). *General Studies for primary schools curriculum guide (Primary 1 to Primary 6)*. Hong Kong: Government Printer.
- Curriculum Development Council. (2002c). *Key learning area curriculum guide (Primary 1 to Secondary 3): Science education*. Hong Kong: Government Printer.

- Education and Manpower Bureau. (1998). *Information technology for learning in a new era five-year strategy 1998/99 to 2002/03*. Hong Kong: Government Printer.
- Education Commission. (2000). *Learning for life, learning through life: Reform proposals for the education system in Hong Kong*. Hong Kong: Government Printer.
- Ho, S. C. E. (2004). Self-regulated learning and academic achievement of Hong Kong secondary school students. *Education Journal*, 32(2), 87–107.
- Hoare, P. (2003). *Effective teaching of science through English in Hong Kong secondary schools*. Hong Kong: The University of Hong Kong.
- Kong, S. C., & So, W. M. W. (2005). The design of computer-mediated learning resources for the inquiry approach to building knowledge of family trees. *Global Chinese Journal on Computers in Education*, 2(2), 44–58.
- Kong, S. C., & So, W. M. W. (2008). A study of building a resource-based learning environment with inquiry learning approach: Knowledge of family tree. *Computers and Education*, 50(1), 37–60.
- Lam, Y. P. T., & Ho, S. C. E. (2003). Reconstruction of communitarianism and creating of social capital: Analysis of the HK-PISA trial study. *Educational Research Journal*, 18(1), 73–95. [in Chinese]
- Lau, K. C., & Yip, D. Y. (2004). Alternative conceptions on genetic diagrams — What are they and how could they be eliminated. *Hong Kong Science Teachers' Journal*, 22(1), 44–53.
- Law, N. (1996). *Science and mathematics achievements at the junior secondary level in Hong Kong*. Hong Kong: TIMSS Hong Kong Study centre, The University of Hong Kong.
- Law, N. (1997). *Science and mathematics achievements at the mid-primary level in Hong Kong*. Hong Kong: TIMSS Hong Kong Study centre, The University of Hong Kong.
- Lee, C. K. J. (1998). Primary school teachers' receptivity to curriculum changes in Hong Kong: A comparison between target-oriented curriculum and General Studies. *Curriculum Forum*, 7(2), 71–83.
- Lee, Y. C. (2004). There is more to the dissection of a pig's heart. *Journal of Biological Education*, 38(4), 172–177.
- Lee, Y. C. (2006). Kidney failure and dialysis: A problem-solving approach in teaching science, technology and society. *School Science Review*, 87(320), 119–125.
- Lee, Y. C. (2007a). Developing decision-making skills for socio-scientific issues. *Journal of Biological Education*, 41(4), 170–177.
- Lee, Y. C. (2007b). From a museum demonstration to problem solving: Promoting the construction of conceptions. *Physics Education*, 42(4), 170–177.
- Lee, Y. C. (2007c). Teaching the nature of science through practical problem solving in daily life contexts. *School Science Review*, 88(324), 97–105.
- Lee, Y. C., & Kwok, P. W. (2009). Can an egg-dropping race enhance students' conceptual understanding of air resistance? *Physics Education*, 44(2), 151–158.

- Lee, Y. C., Li, K. M., Yeung, Y. Y., & Ling, S. H. (1997). Use of visual aids in teaching science: Practices and attitudes of Hong Kong secondary science teachers. *Journal of Science and Mathematics Education in Southeast Asia*, 20(2), 21–36.
- Lee, Y. C., & Ng, P. H. (2004). Hong Kong primary pupils' cognitive understanding and reasoning in conducting science investigation: A pilot study on the topic of "keeping warm". *Asia-Pacific Forum on Science Learning and Teaching*, 5(3), Article 8.
- Leung, F. K. S., Yung, B. H. W., & Tso, A. S. F. (2002). *Secondary analysis of TIMSS-R data for Hong Kong: A report for Hong Kong in the Third International Mathematics and Science Study-Repeat (TIMSS-R)*. Hong Kong: The University of Hong Kong.
- Leung, F. K. S., Yung, B. H. W., & Tso, A. S. F. (2005). Digging below the surface: Secondary analysis of TIMSS data for Hong Kong and its implications for educational reform. *Canadian Journal of Mathematics, Science and Technology Education*, 5(3), 329–360.
- Leung, W. C., Yu, C. M., & So, W. M. W. (2007). Facilitating multimedia resources: Observation and record skills in inquiry learning. In W. M. So & M. H. Cheng (Eds.), *Science education research in Chinese speaking societies* (pp. 138–145). Hong Kong: Seedland Publishing.
- Li, S. C., Law, N. W. Y., & Lui, K. F. A. (2006). Cognitive perturbation through dynamic modelling: A pedagogical approach to conceptual change in science. *Journal of Computer Assisted Learning*, 22(6), 405–422.
- Lo, M. L., Chik, P. M. P., & Pang, M. F. (2006). Patterns of variation in teaching the colour of light to Primary 3 students. *Instructional Science*, 34(1), 1–19.
- Lo, T. Y., & Cheng, N. Y. (2001). A study of the Hong Kong primary General Studies as an integrated curriculum: Theory and practice. *New Horizons in Education*, 44, 52–63.
- Lo-Fu, Y. W., & So, W. M. W. (2004). Lesson studies at primary science classrooms: "Water in the air", "solar eclipse", "flow of electricity". *Asia-Pacific Forum on Science Learning and Teaching*, 5(3), Article 3.
- Loi, T. S. (1986). Effect of the medium of instruction on the academic achievement of Form 1 students. *Educational Research Journal*, 1, 11–15.
- Mak, S. Y. (1998). Integrated assignments for General Studies and language learning. *Journal of Basic Education*, 7(2), 95–106.
- Mak, S. Y., & Wong, S. L. (2006). Modelling LASIK in a school laboratory — Away from "cookbook" experiments. *School Science Review*, 85(312), 57–61.
- Mak, S. Y., & Yip, D. Y. (2002). How to construct written practical items in physics examinations. *Education Journal*, 30(1), 15–29.
- Ng, P. H., & Yeung, Y. Y. (2004). Implications of data-logging on A. L. physics experiments — A preliminary study. In Y. Y. Yeung (Ed.), *Innovative ideas in science teaching: Theories and exemplars* (pp. 127–135). Hong Kong: The Hong Kong Institute of Education.

- Ng, P. Y., & Fung, S. W. (2006). Experience sharing in infusing the concept and knowledge of DNA into primary formal curriculum. *Asia-Pacific Forum on Science Learning and Teaching*, 7(1), Article 7.
- Or, C. K. (1994). Selecting teaching strategies for the 93 certificate chemistry syllabus. *Hong Kong Science Teachers' Journal*, 19(1), 35–40.
- Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. London: The Nuffield Foundation.
- So, W. M. W. (1997). A study of teacher cognition in planning elementary science lessons. *Research in Science Education*, 27(1), 71–86.
- So, W. M. W. (2000). Examples of inquiry activities in primary science. *Asia-Pacific Forum on Science Learning and Teaching*, 1(2), special section II.
- So, W. M. W. (2002a). Science learning at the primary level: Constructivist learning and integration of learning experiences in curriculum development. *Journal of Basic Education*, 11(2), 35–53.
- So, W. M. W. (2002b). Constructivist teaching in primary science. *Asia-Pacific Forum on Science Learning and Teaching*, 3(1), Article 1.
- So, W. M. W. (2002c). Teachers' attitude on the use of information technology in primary science education. In Y. C. Cheng, K. T. Tsui, K. W. Chow, & M. M. C. Mok (Eds.), *Subject teaching and teacher education in the new century* (pp. 123–140). Hong Kong: The Hong Kong Institute of Education.
- So, W. M. W. (2003a). Design of teaching with creative thinking in the General Studies. In M. F. Hui (Ed.), *Teaching suite of creative thinking* (pp. 19–20). Hong Kong: The Association of Heads of Primary Schools, The Hong Kong Council of the Church of Christ of China.
- So, W. M. W. (2003b). *Project learning: Theories and practice*. Hong Kong: Educational Publishing House.
- So, W. M. W. (2003c). Learning science through investigations: An experience with Hong Kong primary school children. *International Journal of Science and Mathematics Education*, 1(1), 175–200.
- So, W. M. W. (2006). Inquiry into primary pupils' science projects: Implication for design of inquiry learning. *Asia-Pacific Forum on Science Learning and Teaching*, 7(1), Article 3.
- So, W. M. W. (2007). Constructivist teaching design: Supporting pupils' learning of project report writing skills. *Journal of Basic Education*, 15(3), 121–140.
- So, W. M. W. (2008). Primary science learning of Hong Kong through the lens of TIMSS. *Asia-Pacific Forum on Science Learning and Teaching*, 9(1), Article 16.
- So, W. M. W., & Cheng, M. H. M. (2000). A study on the professional development of primary school teachers in teaching science. *Journal of science and mathematics Education in Southeast Asia*, 13(2), 1–20.
- So, W. M. W., & Cheng, M. H. M. (2001). Developing scientific literacy for student teachers through active learning. *Asia-Pacific Forum on Science Learning and Teaching*, 2(2), Article 3.

- So, W. M. W., & Cheng, M. H. M. (2002). To facilitate the development of multiple intelligences among primary school pupils through science project. In Y. Y. Yeung (Ed.), *Innovative ideas in science teaching: Theories and exemplars* (pp. 82–93). Hong Kong: The Hong Kong Institute of Education.
- So, W. M. W., Cheng, M. H. M., Leung, C. Y., & Wong-Yu, L. W. (1999). The teaching of General Studies as an “integrated” subject in Hong Kong primary schools. *Journal of Basic Education*, 8(2), 13–28.
- So, W. M. W., Cheng, M. H. M., & Tsang, C. L. (1998). Problems of teaching science-related topics in Hong Kong primary schools. *Journal of Basic Education*, 7(2), 43–57. [in Chinese]
- So, W. M. W., Hung, H. K., & Kong, S. C. (2001). Information technology in learning and teaching: Digital video clip resources bank. *New Horizons in Education*, 43, 71–77.
- So, W. M. W., Hung, V. H., & Yip, Y. (2006). Digital video database: Supporting student teachers’ learning about teaching during teaching practice. In R. Mizoguchi, P. Dilenbourg, & Z. Zhu (Eds.), *Learning by effective utilization of technologies: Facilitating intercultural understanding* (pp. 389–396). Amsterdam: IOS Press.
- So, W. M. W., Hung, V. H., & Yip, W. Y. (2008). The digital video database: A virtual learning community for teacher education. *Australasian Journal of Educational Technology*, 24(1), 73–90.
- So, W. M. W., & Kong, S. C. (2005). The design of computer-mediated learning resources for inquiry-based learning of puberty. *Journal of Basic Education*, 14(1), 149–161.
- So, W. M. W., & Kong, S. C. (2007). Approaches of inquiry learning with multimedia resources in primary classrooms. *Journal of Computers in Mathematics and Science Teaching*, 26(4), 229–354.
- So, W. M. W., & Kong, S. C. (2008). Interaction of student’s academic background and support levels in a resource-based learning environment on Earth’s movement. *Interactive Learning Environments*, 16, 1–23.
- So, W. M. W., & Kwong, Y. F. (2003, December). Research on teaching of “solar eclipse” in primary classroom. *Asia-Pacific Forum on Science Learning and Teaching*, 4(2), Article 1.
- So, W. M. W., & Leung, W. C. (2005). *Start from inquiry learning: Fun with multimedia classroom*. Hong Kong: HKedCity.
- So, W. M. W., & Watkins, D. (2005). From beginning teacher education to professional teaching: A study of the thinking of Hong Kong primary science teachers. *Teaching and Teacher Education*, 21(5), 525–542.
- So, Y. Y., Cheng, M. H. M., & Tsoi, H. L. (2007). Design and reflection on science inquiry activity in primary schools. In W. M. So & M. H. Cheng (Eds.), *Science education research in Chinese speaking societies* (pp. 84–98). Hong Kong: Seedland Publishing.

- Soon, A. L., & Cheng, M. H. M. (2008). The influences of Chinese morphemes on the understanding of scientific concepts. *Journal of Educational Studies*, 4(1), 25–31.
- Tang, T. K. W., & Watkins, D. (1994). Towards a taxonomy of teacher thinking. *Educational Research Journal*, 9(1), 38–43.
- Tao, L. P. K. (1987). Practical work in physics at the CE level in Hong Kong schools. *Hong Kong Science Teachers' Journal*, 15(1), 26–39.
- Tao, L. P. K. (1994). Comprehension of non-technical words in science: The case of students using a foreign language as the medium of instruction. *Research in Science Education*, 24(1), 322–330.
- Tao, L. P. K. (2001). Developing understanding through confronting varying views: The case of solving qualitative physics problems. *International Journal of Science Education*, 23(12), 1201–1218.
- Tao, L. P. K. (2002). A study of students' focal awareness when studying science stories designed for fostering understanding of the nature of science. *Research in Science Education*, 32(1), 97–120.
- Tao, L. P. K. (2003). Eliciting and developing junior secondary students' understanding of the nature of science through a peer collaboration instruction in science stories. *International Journal of Science Education*, 25(2), 147–171.
- Tao, L. P. K., & Mak, S. Y. (1987). Pupil's qualitative reasoning ability in solving physics problems. *Educational Research Journal*, 2, 78–85.
- Thomas, G. P. (2003). Conceptualisation, development and validation of an instrument for evaluating the metacognitive orientation of science classroom learning environments: The Metacognitive Orientation Learning Environment Scale — Science (MOLES-S). *Learning Environments Research*, 6(3), 175–197.
- Thomas, G. P. (2004). Dimensionality and construct validity of an instrument designed to measure the metacognitive orientation of science classroom learning environments. *Journal of Applied Measurement*, 5(4), 367–385.
- Thomas, G. P., & Au, K. M. D. (2005). Changing the learning environment to enhance students' metacognition in Hong Kong primary school classrooms. *Learning Environments Research*, 8, 221–243.
- Towndrow, P. A., Tan, A.-L., Yung, B. H. W., & Cohen, L. (2008). Science teachers' professional development and changes in science practical assessment practices: What are the issues? *Research in Science Education*. Retrieved September 30, 2009, from <http://www.springerlink.com/content/y97335xj8l653354/fulltext.pdf?page=1>
- Wong, S. L. (2006). Learning from students' performance in physics and environmental science-related questions. In B. H. W. Yung (Ed.), *Learning from TIMSS: Implications for teaching and learning science at the junior secondary level* (pp. 29–49). Hong Kong: Education and Manpower Bureau.
- Wong, S. L., Hodson, D., Kwan, J., & Yung, B. H. W. (2008). Turning crisis into opportunity: Enhancing student teachers' understanding of the nature of science

- and scientific inquiry through a case study of the scientific research in Severe Acute Respiratory Syndrome. *International Journal of Science Education*, 30(11), 1417–1439.
- Wong, S. L., & Mak, S. Y. (2007). Tracking pre-service teachers' changing conception of good science teaching. *Research in Science Education*, 37(3), 239–259.
- Wong, S. L., & Mak, S. Y. (2008). Investigative studies of refractive indices of liquids by the use of a laser pointer and a lazy Susan. *Physics Education*, 43(2), 198–202.
- Wong, S. L., Yung, B. H. W., Cheng, M. W., Lam, K. L., & Hodson, D. (2006). Setting the stage for developing pre-service teachers' conceptions of good science teaching: The role of classroom videos. *International Journal of Science Education*, 28(1), 1–24.
- Wong, T. S. T. (2001, December). Group work in science learning — International scenarios and implications for teaching and learning in Hong Kong. *Asia-Pacific Forum on Science Learning and Teaching*, 2(2), Article 9.
- Wong-Yu, L. W. (2004). Formative assessment in General Studies classrooms. *Hong Kong Teachers' Centre Journal*, 3, 141–154.
- Wong-Yu, L. W. (2008a). Implementing learning assessment to the lesson of the General Studies. In S. C. Po & W. M. So (Eds.), *Integrated learning in primary schools: Theories and practice* (pp. 243–260). Singapore: Marshall Cavendish Education.
- Wong-Yu, L. W. (2008b). Implementing school-based curriculum to the General Studies. In S. C. Po & W. M. So (Eds.), *Integrated learning in primary schools: Theories and practice* (pp. 55–72). Singapore: Marshall Cavendish Education.
- Yeung, Y. Y., Liu, T. C. Y., & Ng, P. H. (2005). A social network analysis of research collaboration in physics education. *American Journal of Physics*, 73(2), 145–151.
- Yip, D. Y. (1998a). Children's misconceptions on reproduction and implications for teaching. *Journal of Biological Education*, 33(1), 21–26.
- Yip, D. Y. (1998b). Teachers' misconception of the circulatory system. *Journal of Biological Education*, 32(3), 207–215.
- Yip, D. Y. (1999). Assessing the concept of controlled experiments in science teachers. *Journal of Biological Education*, 33(4), 204–208.
- Yip, D. Y. (2000). Promoting a better understanding of lactic acid fermentation. *Journal of Biological Education*, 35(1), 37–40.
- Yip, D. Y. (2001). Which came first, the chicken or its egg? — An inquiry-based activity. *School Science Review*, 82(300), 109–114.
- Yip, D. Y. (2003). Developing a better understanding of the relationship between transpiration and water uptake in plants. *Journal of Science Education and Technology*, 12(1), 13–19.
- Yip, D. Y. (2004a). Scientific literacy of Hong Kong students in PISA 2000: An analysis of performance on the released items. *Education Journal*, 31(2) & 32(1), 141–159.

- Yip, D. Y. (2004b). Student performance in the CE biology examination — Implications for teaching and learning. *Hong Kong Science Teachers' Journal*, 22(1), 55–62.
- Yip, D. Y. (2005). Analysis of laboratory manuals for an investigative approach. *Teaching Science*, 51(3), 34–38.
- Yip, D. Y., & Cheung, D. (2005). Teachers' concerns on school-based assessment of practical work. *Journal of Biological Education*, 39(4), 156–162.
- Yip, D. Y., Chung, C. M., & Mak, S. Y. (1998). The subject matter knowledge in physics related topics of Hong Kong junior secondary science teachers. *Journal of Science Education and Technology*, 7(4), 319–328.
- Yip, D. Y., Tsang, W. K., & Cheung, S. P. (2003). Evaluation of the effects of medium of instruction on the science learning of Hong Kong secondary students: Performance on the science achievement test. *Bilingual Research Journal*, 27(2), 295–331.
- Yip, D. Y., & Yung, B. H. W. (1998). Providing meaningful contexts for scientific investigations. *Australian Science Teachers' Journal*, 44(1), 35–42.
- Yip, D. Y., & Yung, B. H. W. (1999). Promoting understanding and mastery of investigative skills. *Curriculum Forum*, 8(2), 44–59.
- Yuen, H. K. (2005). Learning science through online threaded discourse. In D. Hung & M. S. Khine (Eds.), *Engaged learning with emerging technologies* (pp. 127–147). Dordrecht, The Netherlands: Springer.
- Yung, B. H. W. (2001a). Examiners, policeman and students' companion: Teachers' perceptions of their role in an assessment reform. *Educational Review*, 53(3), 251–260.
- Yung, B. H. W. (2001b). Three views of fairness in a school-based assessment scheme of practical work. *International Journal of Science Education*, 23(10), 985–1005.
- Yung, B. H. W. (2002). Same assessment, different practice: Professional consciousness as a determinant of teachers' practice in a school-based assessment scheme. *Assessment in Education*, 9(1), 101–121.
- Yung, B. H. W. (2006a). Learning from students' performance in biology and environmental science-related questions. In B. H. W. Yung (Ed.), *Learning from TIMSS: Implications for teaching and learning science at the junior secondary level* (pp. 7–28). Hong Kong: Education and Manpower Bureau.
- Yung, B. H. W. (2006b). *Learning from TIMSS: Implications for teaching and learning science at the junior secondary level*. Hong Kong: Education and Manpower Bureau.
- Yung, B. H. W. (2006c). *Assessment reform in science: Fairness and fear*. Dordrecht, The Netherlands: Springer.
- Yung, B. H. W., & Tao, L. P. K. (2004a). Advancing pupils within the motivational zone of proximal development: A case study in science teaching. *Research in Science Education*, 34(4), 403–426.
- Yung, B. H. W., & Tao, L. P. K. (2004b). Experiencing scientific investigation and building up confidence. In W. W. Ki, S. K. Tse, & S. K. Shum (Eds.), *Theory of*

- variation and space of learning* (pp. 103–124). Hong Kong: Hong Kong University Press.
- Yung, B. H. W., & Tao, L. P. K. (2004c). Prioritising the affective: An analysis of classroom discourse of a junior secondary science lesson. *Teaching Science*, 50(4), 6–13.
- Yung, B. H. W., & Wong, S. L. (2006). Learning from students' performance in questions related to nature of science. In B. H. W. Yung (Ed.), *Learning from TIMSS: Implications for teaching and learning science at the junior secondary level* (pp. 95–94). Hong Kong: Education and Manpower Bureau.
- Yung, B. H. W., Wong, S. L., & Cheng, M. W. (2004, December). A curriculum innovation on student teachers' developing conceptions of good science teaching. *Asia-Pacific Forum on Science Learning and Teaching*, 4(2), Article 11.